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REPUBLIC OF SOUTH AFRICA

DWA REPORT NO: P WMA 12/T60/00/3811

Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme (WP 10317)




Assessment of Augmentation from Groundwater

NOVEMBER 2013

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Report Title:	***Assessment of Augmentation from Groundwater***
Author:	***J.A. Myburgh***
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* *BKS (Pty) Ltd was acquired by AECOM Technology Corporation on 1 November 2012*

LIST OF STUDY REPORTS

This report forms part of the series of reports, prepared for the ***Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme****. All reports for the Study are listed below.*

Report Name	DWA Report Number
Water Resources Assessment	P WMA 12/T60/00/3711
Assessment of Augmentation from Groundwater	*P WMA 12/T60/00/3811*
Intermediate Reserve Determination	P WMA 12/T60/00/3911
Legal, Institutional and Financial Arrangements	P WMA 12/T60/00/4011
Domestic Water Requirements	P WMA 12/T60/00/4111
Irrigation Potential Assessment	P WMA 12/T60/00/4211
Water Distribution Infrastructure	P WMA 12/T60/00/4311
Materials and Geotechnical Investigations	P WMA 12/T60/00/4411
Zalu Dam Feasibility Design	P WMA 12/T60/00/4511
Regional Economics	P WMA 12/T60/00/4611
Environmental Screening	P WMA 12/T60/00/4711
Record of Implementation Decisions	P WMA 12/T60/00/4811
Main Study Report	P WMA 12/T60/00/4911

This report is to be referred to in bibliographies as:

Department of Water Affairs, 2011. FEASIBILITY STUDY FOR AUGMENTATION OF THE LUSIKISIKI REGIONAL WATER SUPPLY SCHEME: ASSESSMENT OF AUGMENTATION FROM GROUNDWATER, P WMA 12/T60/00/3811

Prepared by:

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In association with:

Executive summary

INTRODUCTION

- *AGES (Pty) Ltd was appointed by BKS to evaluate the groundwater resources within the Lusikisiki study area and to identify the best possible sources to perform sustainable groundwater augmentation from. Groundwater sources are to be used in areas of considerable distance from the planned Zalu Dam and where topography is unfavourable for pipeline infrastructure. Where high yielding groundwater sources exist, they should also be linked into the planned bulk water reticulation network.*

- *The initial terms of reference supplied by DWA was briefly requesting the geohydrological focus to be placed on finding the optimum augmentation volume that is available from groundwater to assist in the final sizing of the proposed Zalu Dam. It was noted that previous feasibility study outcomes should be incorporated by including production boreholes already drilled and by addressing rural areas outside the reach of the existing bulk water infrastructure in terms of groundwater potential through a phased approach. It was stated that finding the final balance between groundwater and surface water use will require the evaluation of different cost scenarios.*

- *A phased approach for the geohydrological component of the feasibility study was followed through the six tasks indicated below.*

  1. *Inception*
  2. *Hydrogeological desktop study*
  3. *Detailed groundwater flow balances and numerical modelling*
  4. *Groundwater-community interdependency survey*
  5. *Optimisation of groundwater abstraction network*
  6. *Hydro-census and spring characterisation*

- *The study area is located in the Port St Johns and Ngquza Hill Local Municipalities of the Eastern Cape Province, stretching from the Msikaba River in the north-east to the Umzimvubu River in the south-west and extending approximately 15 km north-west of the town of Lusikisiki inland (**Figure i**).*

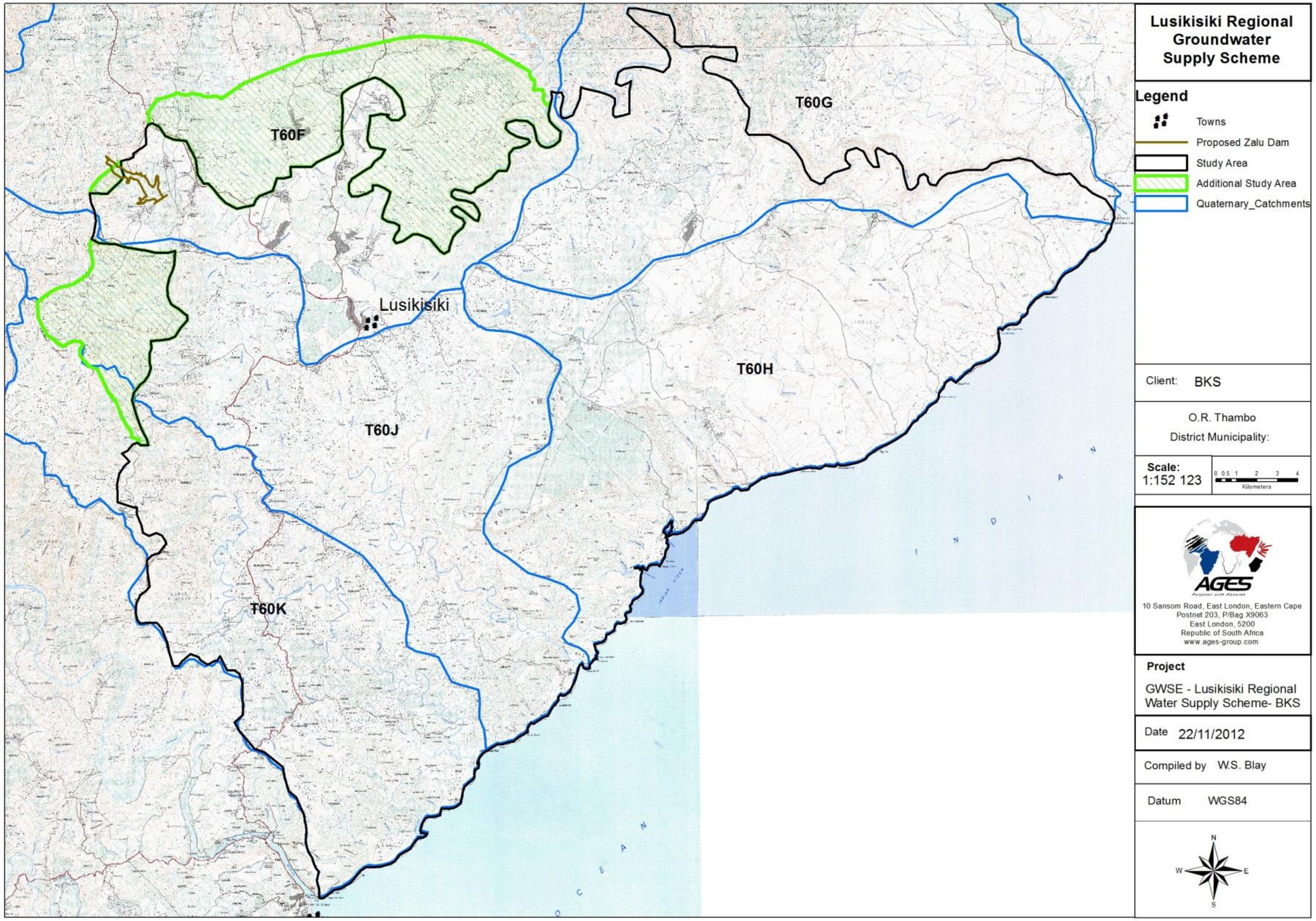

Figure i: Location of the study area

Table i: Summary of the SRK report (P WMA 12/000/00/1507)

<table>
<tr><th colspan="2">Report</th><td colspan="5">LUSIKISIKI GROUNDWATER FEASIBILITY STUDY PHASE 2</td></tr>
<tr><th colspan="2"></th><td colspan="5">INVESTIGATING THE POTENTIAL TO SUPPLIMENT THE LUSIKISIKI RURAL WATER SUPPLY SCHEME(LRWSS)</td></tr>
<tr><th colspan="2">DWA report number</th><td colspan="5">P WMA 12/000/00/1507</td></tr>
<tr><th colspan="2">Author</th><td colspan="5">SRK Consulting (South Africa) (Pty) Ltd</td></tr>
<tr><th colspan="2">Date</th><td colspan="5">May-09</td></tr>
<tr><th colspan="2">Relevance to Reserve study</th><td colspan="5">Hydrocensus, Drilling and Aquifer testing</td></tr>
<tr><th colspan="7">Comments:</th></tr>
<tr><th>Groundwater potential</th><th>Yields of existing boreholes through hydrocensus & NGDB where available</th><th>Springs</th><th>Borehole drilling</th><th>Lineaments</th><th>Fracturing / weathering</th><th>Geological contacts</th></tr>
<tr><td>Natal Group Sandstone 0-10 ℓ/s</td><td>Dry or no data approximately 27 boreholes</td><td>No spring flows were taken,EC values are below 70 mS/m</td><td>A total of 30 boreholes were drilled, 12 in the NGS, 10 in the Dwyka and 8 in the Ecca</td><td>East West – Significant strikes in Dwyka, none in NGS</td><td>In Dwyka – strikes associated with EW lineament</td><td>Between Ecca / Dwyka – no significant strikes</td></tr>
<tr><td>Dwyka 0-5 ℓ/s</td><td>Yield between 0.13 and 1.89 ℓ/s 7 boreholes</td><td>Spring flow is seasonal</td><td>Significant water strikes in NGS >5 ℓ/s for thin dyke contacts, for thick dykes the yield was 5 ℓ/s with shallow strikes</td><td>South East – No strikes in NGS</td><td>In thick Dolerite sheets – Not targeted</td><td>Between Dwyka / NGS – significant strikes with little fracturing</td></tr>
<tr><td rowspan="5">Ecca low</td><td rowspan="5">Yield between 1.90 and 4.55 ℓ/s only one borehole close to Lusikisiki</td><td>No proper protection of the springs</td><td rowspan="2">Low yields in Dwyka and Ecca formations where they are intersected by dolerite dykes.</td><td rowspan="5">East north east – No strikes in NGS</td><td rowspan="5">Associated with Dykes – High yields up to 85 l/s in NGS with fracturing within 2-20 m of dykes.</td><td rowspan="3">Significant strikes considered to be more than 1.5 ℓ/s</td></tr>
<tr><td rowspan="3">A total of 90 villages were hydrocensused</td></tr>
<tr><td rowspan="3">Inside dolerite dykes 2-3 ℓ/s in the NGS with < 1 ℓ/s for dykes in Dwyka</td></tr>
<tr><td rowspan="2">Lineaments drilled near Mkambati were dry</td></tr>
<tr><td>NGDB borehole and spring positions are inconsistent with respect to other more updated databases</td></tr>
</table>

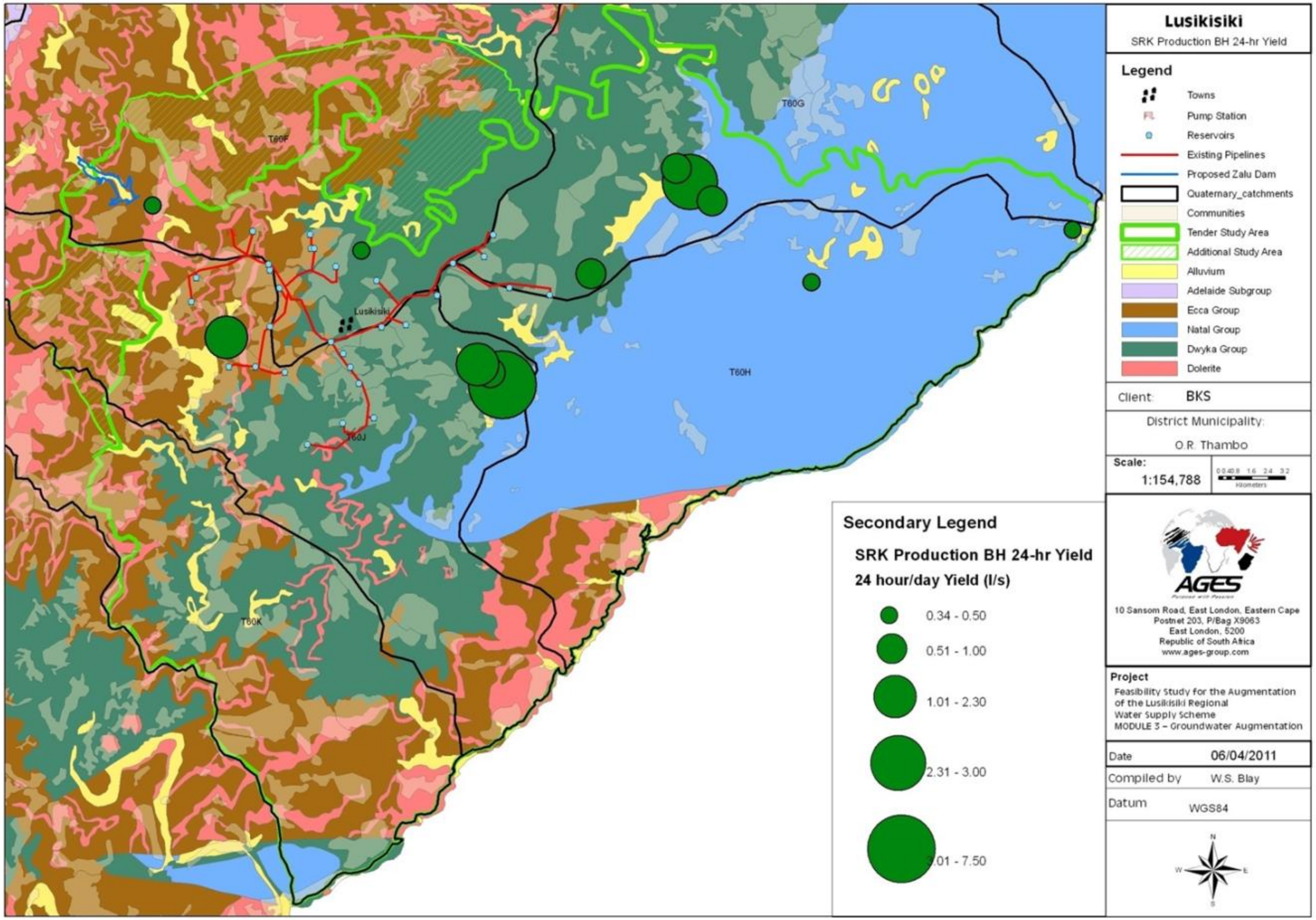

Figure ii: Lusikisiki RWSS study area geology and previous SRK feasibility study boreholes with yields

HYDROGEOLOGICAL DESKTOP STUDY

- *A detailed review of the Eastern Pondoland Basin Study (EPBS) groundwater report and SRK feasibility study report (2009) was performed. The desktop study was carried out in different phases and continued review of existing information and reports ensured incorporation of existing information in all components of the study as is evident from this report.* ***Table i*** *summarises findings from the SRK study.*

- *The study area is predominantly underlain by sedimentary rocks of the Karoo Supergroup sequence of rocks in the inland and southwest coast with hypabassal dolerite intrusions in the form of sills (sub-horizontal and horizontal structures) and dykes (sub-vertical to vertical linear structures). The brittle Natal Group sandstone (NGS) which Woodford (1999) further narrowed down to the Msikaba Formation (also sandstone), dominates the south-eastern and eastern quadrant of the study area (see* ***Figure ii****). This formation has a number of faults and is highly incised creating dramatic landscapes. Groundwater potential of the geology is summarised in* ***Table i*** *above.*

RESULTS

EXISTING GEOSITE INFORMATION & AGES HYDROCENSUS

- *Geosites per database are indicated in* ***Figure iii*** *below. Currently the two main databases (NGA & GRIP) indicate a geosite concentration in the western and northern parts of the project area. There is limited data available for the south eastern portions of the project area as indicated in* ***Figure iii****.* ***Table ii*** *summarises all the geosites within the study area identified through the hydro-census conducted by SRK as well as geosites from the GRIP and NGDB databases and newly drilled boreholes from the SRK Feasibility Study.*

Table ii: Geosites in study area

Description	Total
Total boreholes known in study area	**235**
Boreholes reflected on NGDB database	152
Additional boreholes sourced from GRIP survey	17
Boreholes identified during SRK hydrocensus	36
New boreholes drilled during SRK study	30
Total springs in study area	**119**
Springs reflected on NGDB database	49
Additional springs sourced from GRIP survey	22
Springs identified during SRK hydrocensus	48

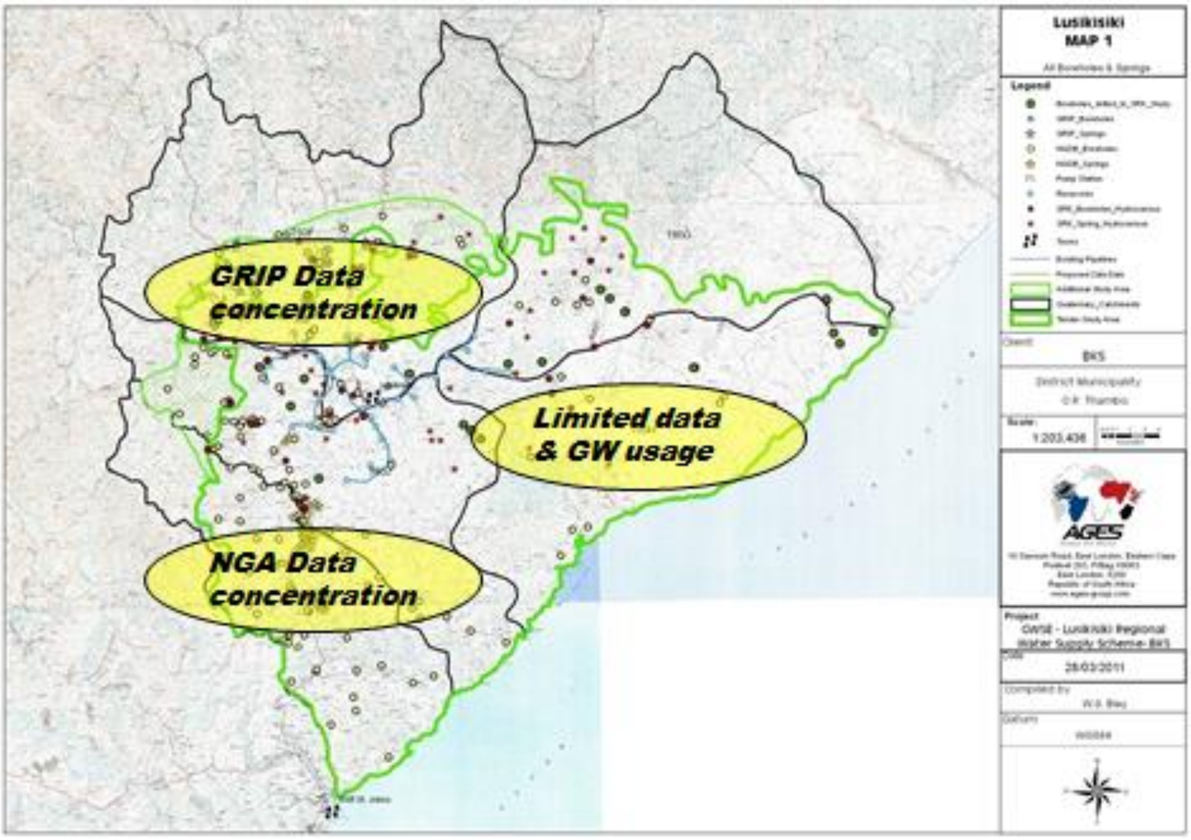

Figure iii: GRIP and NGDB/NGA data availability

- *AGES (Pty) Ltd was appointed on the DWA Term Tender W0202WTE to carry out a hydrocensus at 62 communities that were not covered during the previous feasibility studies in order to determine the number of existing springs and boreholes. It further aimed to characterise springs and seeps towards optimisation of the groundwater yield model and numerical model as reported in* ***Appendices A*** and ***B***. *The spring survey was also focused in areas that are preferred groundwater supply areas, due to their distance from the planned Zalu Dam and unfavourable topography.*

- *A total of 4 boreholes and 89 springs and seeps were identified during the survey.*

- *The majority of springs (34%) are located in the Dwyka Group followed by 33% in the Ecca Group. Pollution sources do occur in close proximity to springs and seeps although 72% of springs are expected to have a low chance of being polluted. In the project area there is a general absence (89%) in the protection/fencing of springs. This can result in the source being polluted or damaged by animals to an extent where it can no longer be equipped for production purposes.*

- *Springs are more abundant in the Lower Karoo GRU/GMU in comparison to the Msikaba GRU/GMU which has more high yielding springs than low yielding springs (see* ***Figure iv***).

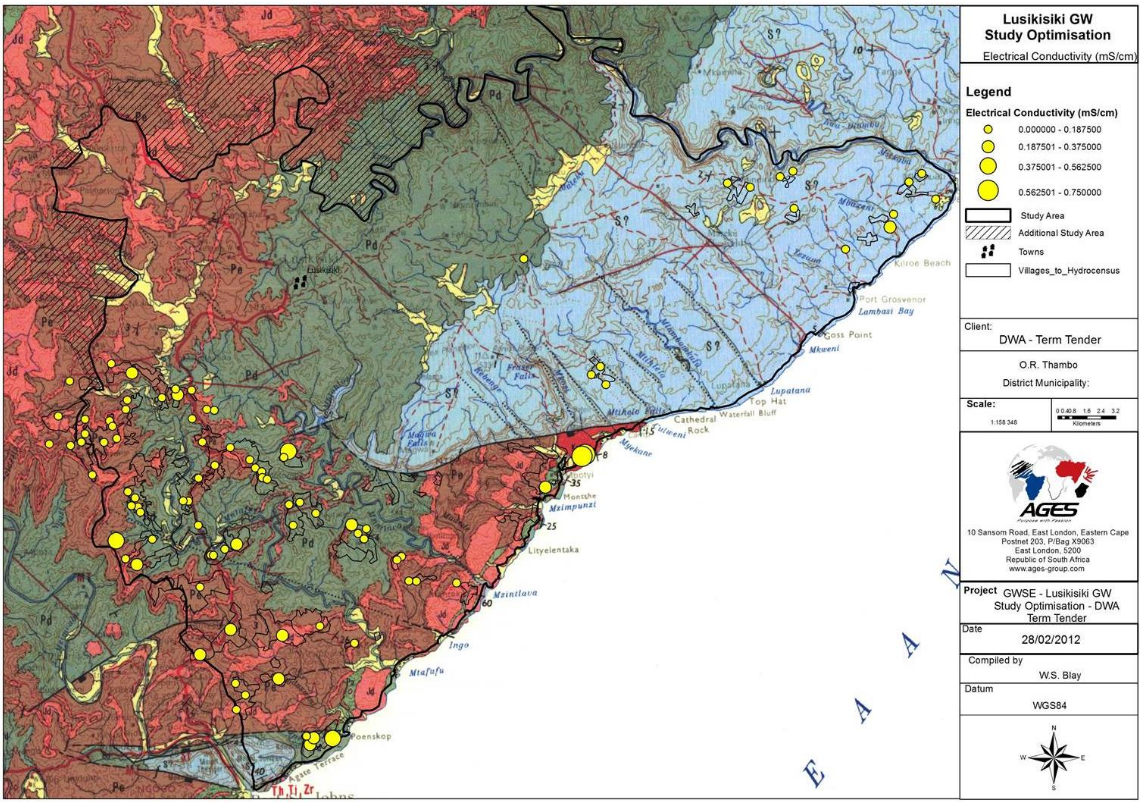

Figure iv: **Electrical conductivities measured at springs during AGES hydrocensus**

GROUNDWATER VOLUMES IN THE STUDY AREA AND RESERVE DETERMINATION

- *The Groundwater Yield Model for the Reserve (GYMR) was simulated to assess potential groundwater flow balances on an annual basis. Recommendations on management options based on the outcome of the assessments are made, for the DWA RDM Office's decision making purposes. The resulting groundwater volumes that were calculated are shown in* ***Table iii****. The scenarios that were simulated were the following:*

    1. Present day GYMR, 95% assurance of supply, GA's included - groundwater inflow from estimated recharge and rainfall at 95% assurance level; GYMR accounting for drought cycles, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).

    2. Present day GYMR, 95% assurance of supply, GA's excluded - groundwater inflow from estimated recharge and rainfall at 95% assurance level; GYMR accounting for drought cycles, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).

    3. Present day GYMR, MAP rainfall, GA's excluded - groundwater inflow from estimated recharge and mean annual precipitation (MAP) calculated from WR2005, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).

4. Future 2020 GYMR scenario, 95% assurance of supply, GA's excluded - groundwater inflow from estimated recharge and rainfall at 95% assurance level; 2020 groundwater use and population figure estimates used predominantly from EPBS (2001); GYMR accounting for drought cycles, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).

Table iii: GYMR analytical water balance results

GYMR Scenario 1: Present day, 95% assured rainfall, GA's Included

Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (million m^3/a)	Total inflow (million m^3/a)	Total outflow before losses (million m^3/a)	Evapo-transpiration flow loss (million m^3/a)	Net Baseflow (million m^3/a)	GYMR Index % (Total outflow/ Total inflow)
T60E	198	885	709	6.03%	8.47	8.47	-3.40	-2.39	2.67	40%
T60F	463	940	753	6.63%	23.13	23.13	-7.20	-5.23	10.69	31%
T60G	359	1116	895	8.29%	26.65	26.65	-7.46	-6.35	12.84	28%
T60H	322	1277	1024	9.90%	32.59	32.62	-10.58	-5.37	16.67	32%
T60J	293	1101	882	8.23%	21.31	21.31	-5.32	-4.72	11.27	25%
T60K	242	1075	862	7.50%	15.64	15.64	-4.32	-4.93	6.39	28%
Total study area	1151	1114	893	8.25%	84.77	84.81	-24.32	-20.49	40.00	29%

GYMR Scenario 2: Present day, 95% assured rainfall, GA's Excluded

Catchment	Surface Area (km2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm3/a)	Total inflow (Mm3/a)	Total outflow before losses Mm3/a	Evapo-transpiration flow loss (Mm3/a)	Net Baseflow (Mm3/a)	GYMR Index % (Total outflow/ Total inflow)
T60E	198	885	709	6.03%	8.47	8.47	-2.51	-2.39	3.56	30%
T60F	463	940	753	6.63%	23.13	23.13	-5.12	-5.23	12.78	22%
T60G	359	1116	895	8.29%	26.65	26.65	-2.06	-6.35	18.23	8%
T60H	322	1277	1024	9.90%	32.59	32.62	-5.76	-5.37	21.49	18%
T60J	293	1101	882	8.23%	21.31	21.31	-3.12	-4.72	13.47	15%
T60K	242	1075	862	7.50%	15.64	15.64	-3.23	-4.93	7.48	21%
Total study area	1151	1114	893	8.25%	84.77	84.81	-13.55	-20.49	50.77	16%

GYMR Scenario 3: Present day, MAP rainfall, GA's Excluded

Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)
T60E	198	885	709	6.03%	10.56	10.56	-2.51	-2.39	5.66	24%
T60F	463	940	753	6.63%	28.85	28.85	-5.12	-5.23	18.50	18%
T60G	359	1116	895	8.29%	33.24	33.24	-2.06	-6.35	24.83	6%
T60H	322	1277	1024	9.90%	40.65	40.69	-5.76	-5.37	29.56	14%
T60J	293	1101	882	8.23%	26.59	26.59	-3.12	-4.72	18.75	12%
T60K	242	1075	862	7.50%	19.51	19.51	-3.23	-4.93	11.36	17%
Total study area	1151	1114	893	8.25%	105.76	105.80	-13.55	-20.49	71.76	13%

GYMR Scenario 4: Future 2020, 95% assured rainfall, GA's Excluded

Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)
T60E	198	885	709	6.03%	8.47	8.47	-3.25	-2.39	2.82	38%
T60F	463	940	753	6.63%	23.13	23.13	-5.96	-5.23	11.94	26%
T60G	359	1116	895	8.29%	26.65	26.65	-2.21	-6.35	18.09	8%
T60H	322	1277	1024	9.90%	32.59	32.62	-7.88	-5.37	19.37	24%
T60J	293	1101	882	8.23%	21.31	21.31	-3.24	-4.72	13.35	15%
T60K	242	1075	862	7.50%	15.64	15.64	-3.36	-4.93	7.35	22%
Total study area	1151	1114	893	8.25%	84.77	84.81	-16.16	-20.49	48.17	19%

NUMERICAL GROUNDWATER FLOW MODELLING & SUSTAINABILITY

- *A numerical groundwater flow model was constructed for simulation of abstraction from high yielding boreholes in the study area and to determine the effect future abstraction would have on regional groundwater levels (determine the sustainability of planned abstraction). Three scenarios were simulated:*

    1. Scenario 1: Steady state present day water balance and flow conditions. This scenario was used to calibrate the flow model.
    2. Scenario 2: Transient state to evaluate and simulate impacts of proposed water supply from existing boreholes drilled by SRK.
    3. Scenario 3: Transient state to evaluate and simulate impacts of proposed water supply from both Scenario 2 boreholes and conceptual boreholes (included a sensitivity analysis on recharge values i.e. recharge set as % of MAP and of lower 95th percentile).

- *Results from the numerical model are as follows:*

    - *From the three scenarios and sensitivity analysis it is evident that enough water is available for abstraction from the SRK boreholes to supply water to the Lusikisiki water project.*
    - *During dry periods or droughts the available water will be significantly less and can affect baseflow and spring flow if abstraction is continued at the same rate as during normal periods of rainfall.*
    - *The volume through recharge available in the model is less than that in the GYMR scenario.*
    - *Scenario 2 shows the abstraction of groundwater from the SRK boreholes at the recommended sustainable rates. These rates are proven to be sustainable in the modelled environment over a period of 25 years with storage and recharge balancing the extra loss through abstraction.*
    - *Scenario 3A and 3B shows the sensitivity of the groundwater system to a change in recharge.*
    - *An average drop of 7.2 m is observed in all observation borehole water levels when a one in twenty year drought is simulated.*
    - *Drawdown in the SRK and Conceptual boreholes pumped during Scenario 3 increases with an average of 5 m.*
    - *Throughout all modelling scenarios the EWR was not taken into account. When the EWR has been finally determined, another modelling scenario can be performed to determine whether groundwater levels are drawn down below River channels as well as determine the amount of baseflow available to the EWR.*

- *The available groundwater volumes simulated by the numerical model are below available groundwater volumes indicated by the GYMR scenarios.*
- *With abstraction from SRK boreholes and conceptual boreholes a total daily volume of 3 081 m^3/d is needed.*
- *If the lower 95% assurance level is used to simulate a drought the available groundwater from the GYMR is 232 356 m^3/d, calculating 57% of this volume equates to 132 443 m^3/d available in the modelled catchment.*

GROUNDWATER-COMMUNITY INTERDEPENDENCE SURVEY

- *The objectives of this study were to identify community dependencies and attitudes towards groundwater; assess regional groundwater use and infrastructure statistically; and determine water source preference based on perceptions. These factors aim to support the geohydrological study. In order to investigate these objectives, a desktop study was initiated and the questionnaire sheets of 360 participants in the Lusikisiki project area were analysed using statistical methods of analysis. In the survey analysis, three salient themes were identified namely: local groundwater knowledge, attitude towards groundwater, and source preference based on perceptions. The desktop study sourced and plotted regional groundwater use and infrastructure statistics.*

- *In summary it can be concluded that in all regions covered during the survey, there is a preference towards groundwater and spring water as drinking water source. This is most probably due to the fact that communities have been relying on groundwater as a source through springs historically and possibly due to the existing surface water scheme not always meeting the full demand of the communities it has been serving. The highest preference to use surface water has been noted at the Zalu Dam site. For statistics of the questionnaire survey, please refer to the community interdependency survey section of the report as well as the full report in* ***Appendix F****.*

- *One of the main recommendations of the interdependence survey is that the groundwater compatibility assessment team must be given the opportunity to present findings to ensure that the engineering team incorporate social trends that might influence the final design approach and layout.*

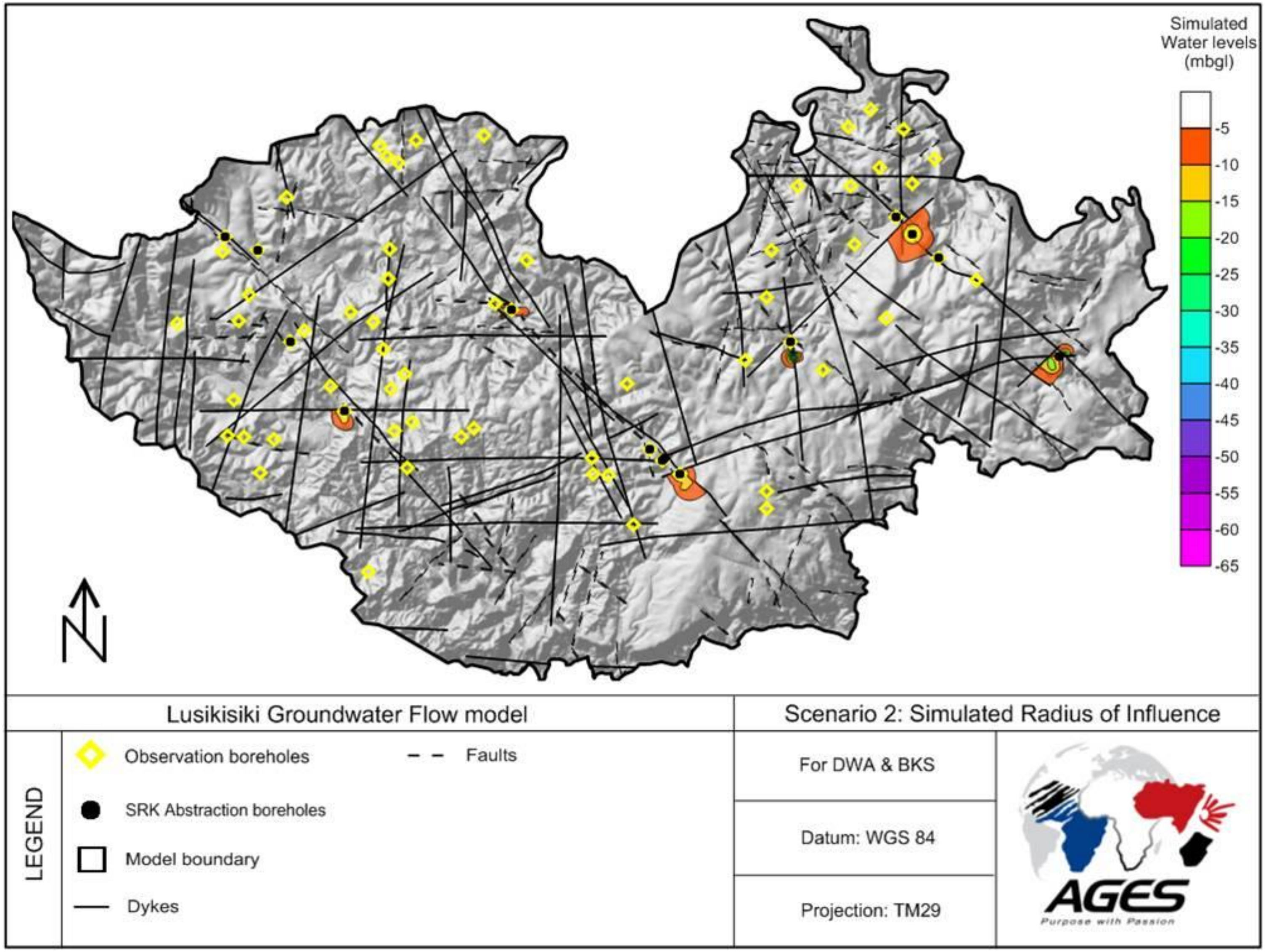

Figure v: Lusikisiki Groundwater Flow Model – Scenario 2: Simulated radius of influence

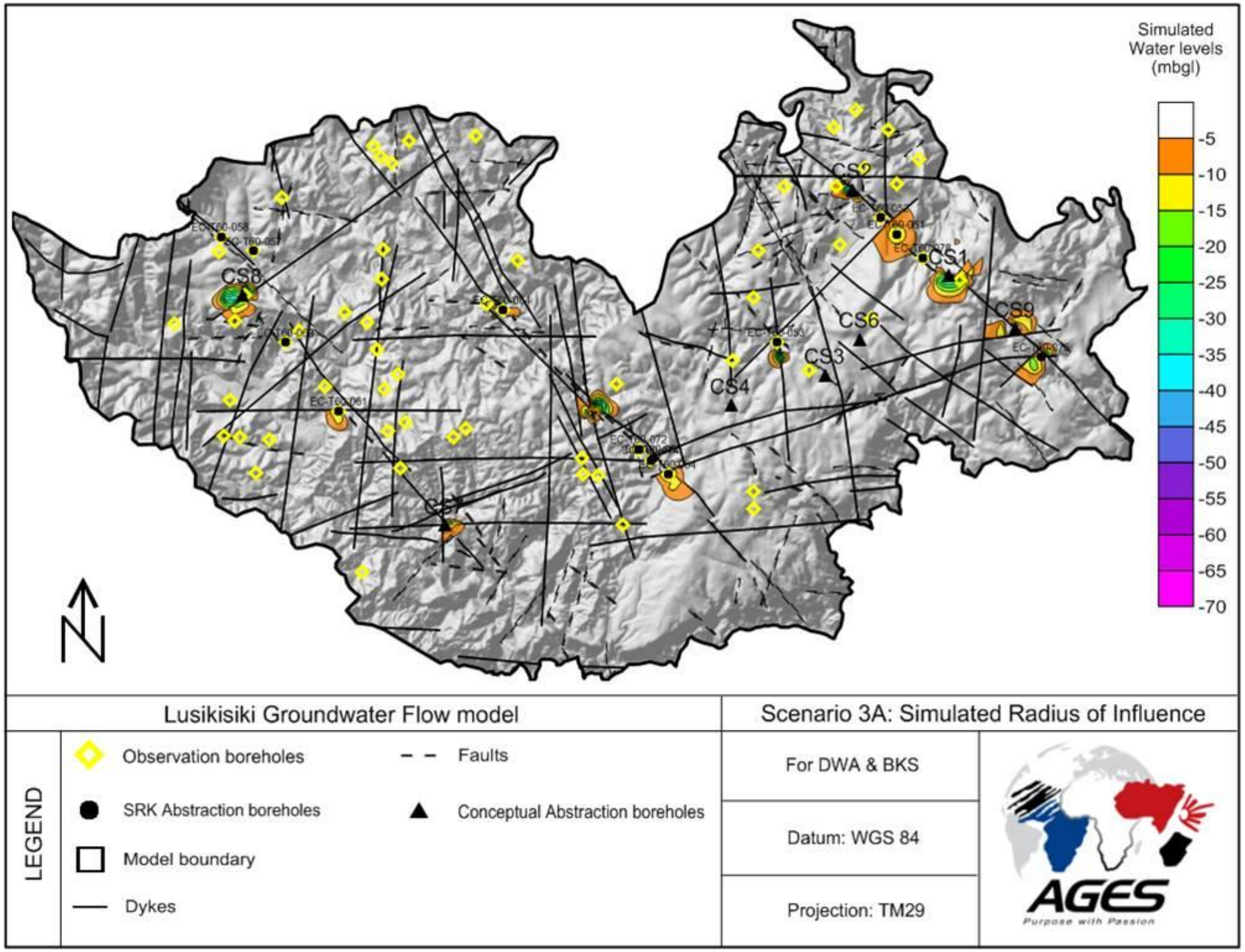

Figure vi: Lusikisiki Groundwater Flow Model – Scenario 3A: Simulated radius of influence

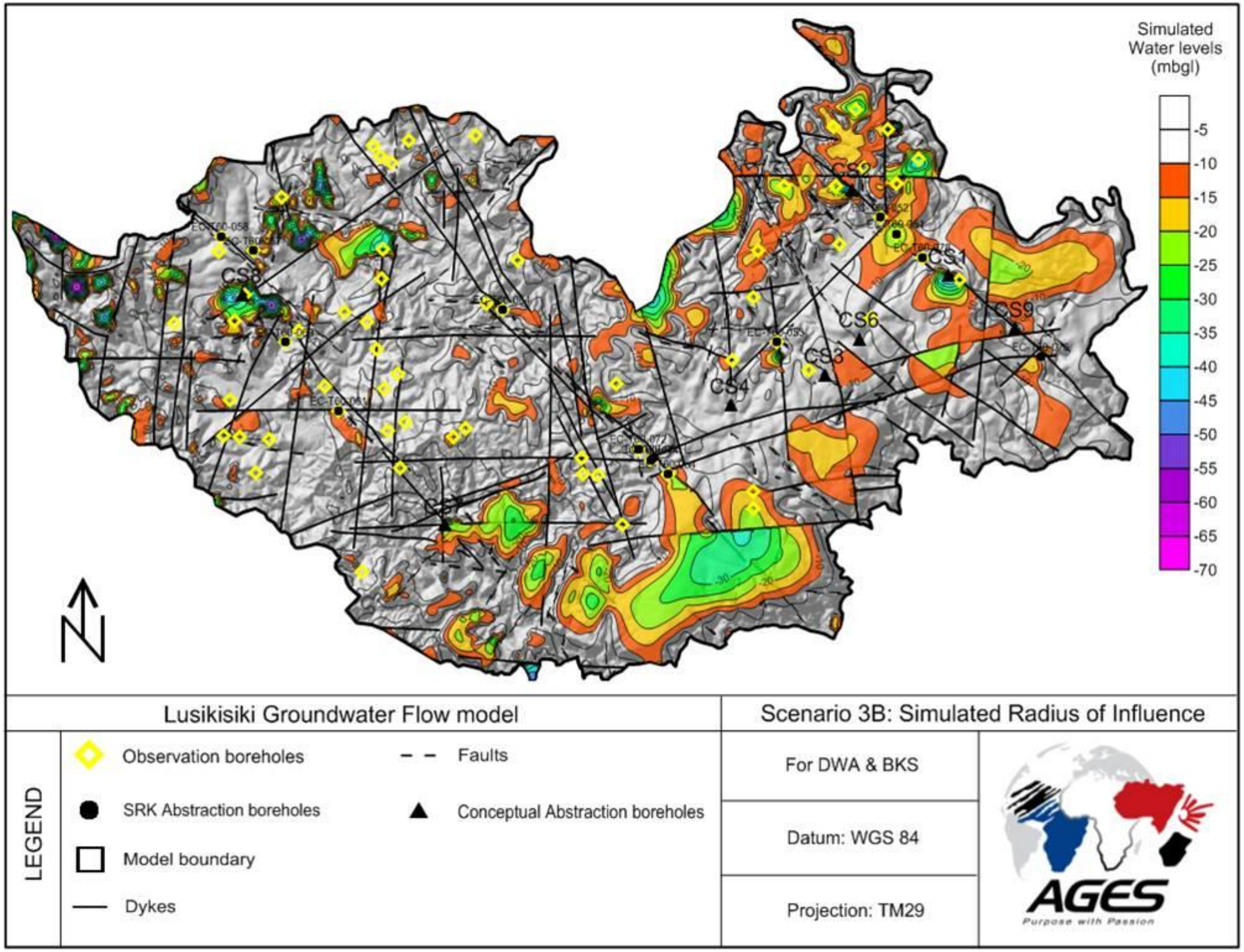

Figure vii: Lusikisiki Groundwater Flow Model – Scenario 3B: Simulated radius of influence

GROUNDWATER AWARENESS CREATION

- *The purpose of the water awareness initiative was to increase project sustainability through creating awareness around ground- and surface water and stimulate sensitivity within participants concerning the importance of conserving water.*

- *The water awareness initiatives were conducted in four wards (wards 20, 21, 22, and 23), which had previously been identified as having:*
  - *a) The least groundwater knowledge, and*
  - *b) High negative perceptions and attitudes towards the use of groundwater as a water source, in a social survey conducted during phase 1 of the project (for more information, see AGES social report with reference no 2011/03/14/SCL).*

- *As part of the awareness initiative:*
  - *a) Two awareness workshops were conducted with relevant and prominent community members,*
  - *b) Three local schools were targeted (Mxhume High School; Maqulu Junior Secondary School; and Miqikela Senior Secondary School), and*
  - *c) The local radio station, Nkonjane Community Radio, gave AGES a slot to broadcast knowledge on ground- and surface water.*

OPTIMISATION OF THE GROUNDWATER ABSTRACTION NETWORK

- *The purpose of this component of the study is to report yields and positions of future production boreholes within the regional well-field and numerically modelled area (RWA). This comprised conceptual boreholes as well as existing boreholes already drilled by SRK during feasibility studies. Final amended recommendations for abstraction rates of SRK boreholes are given since the model has indicated that some of these boreholes are too close to each other and will have to be utilised at reduced rates to minimise the influence between neighbouring boreholes.*

- *Based on groundwater quality, more specifically elevated iron concentrations, it will be important for groundwater from the regional well field to be blended with surface water as far as possible. The engineering team also need to look at optimum pipeline routes and lengths to decide which feasibility study and conceptual boreholes will be used in the end. Surface water quality need to be evaluated against groundwater quality to determine if suitable blending ratios can be achieved while still meeting the water demand. Treatment options must be found for the possible oxidation and precipitation of high-iron content water.*

- *Abstraction at all 14 feasibility study boreholes that occur in the RWA, as well as 9 conceptual boreholes were simulated. Based on one simulation where it became apparent that groundwater level drawdowns at production boreholes may affect springs and wetlands if pumped under lower 95% assured recharge conditions, amendments were made to abstraction rates of feasibility boreholes as well as conceptual boreholes.*

- *The final recommendation is for only 9 feasibility study boreholes to be equipped and for an additional 8 conceptual boreholes to be drilled and equipped to finally abstract 2 553 m^3/day from the Regional Well-field Area. This is therefore the total volume of groundwater that is available for augmentation to the surface water supply scheme (RWSS) from the RWA and relates to 28% of the projected 2020 water demand of the Planning study area as reported in the Domestic Water Requirement Report.*

- *Numerous communities fall outside of the RWA. These communities need to be served by stand-alone schemes. These schemes will either serve single communities or small clusters of communities depending on local groundwater conditions. Water sources will involve springs as well as new boreholes that need to be developed. Detail regarding the clustering of these stand-alone communities as well as cost summaries to develop groundwater sources for all these clusters and communities are given in **Appendix E**.*

- *Several zones of higher groundwater potential were delineated outside the RWA, as indicated in **Figure vii**. These zones were used to cluster individual communities together where possible to minimise the number of stand-alone schemes. Six such clusters could be identified.*

- ***Figure vii** should be used as a planning tool to determine the optimum layout of pumping and pipeline infrastructure required to utilise the 9 feasibility study and 8 conceptual boreholes. It should be aimed for that supply from these 17 boreholes is fed into the bulk surface water scheme to allow effective blending to decrease elevated iron concentrations that are noted in some boreholes.*

- *Integration with the surface water infrastructure planning team will determine the final layout of well fields versus stand-alone schemes to find the optimum balance that will result in the most cost effective approach in terms of capital expenditure as well as long term operation and maintenance costs.*

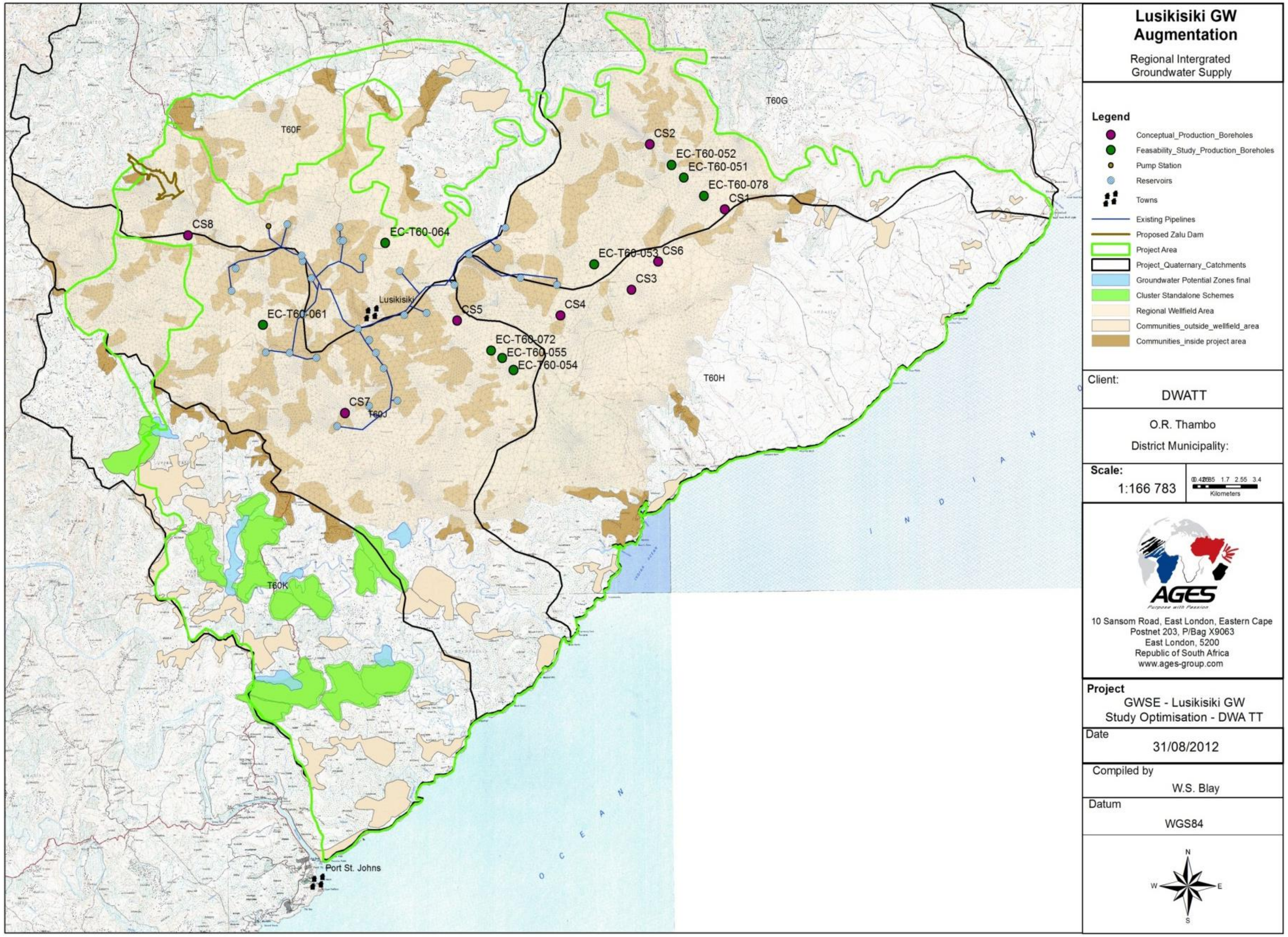

Figure viii: Regional integrated groundwater supply

CONCLUSIONS & RECOMMENDATIONS

- *The analytical Groundwater Yield Model for the Reserve (GYMR) balance found that in all four scenarios there is more than adequate groundwater recharge to meet planned water supply volumes, even in the 2020 scenario. One must however remember that it is not possible to construct a spatially distributed borehole network to abstract every last drop of the volumes reported in the GYMR scenarios, due to terrain inaccessibility for example.*

- *A numerical groundwater flow model was constructed to simulate the sustainability of abstraction from existing SRK feasibility study boreholes as well as new conceptual boreholes targeting high yielding groundwater zones.*

- *From the three scenarios numerically modelled and the sensitivity analysis it is evident that enough groundwater is available for abstraction from the SRK boreholes and conceptual boreholes to supply water to the Lusikisiki RWSS.*

- *Groundwater level monitoring near or in the proposed RWSS abstraction boreholes is recommended to measure the effect of abstraction in SRK and possible new abstraction boreholes, and to adjust yields if necessary, for instance during dry periods.*

- *To this investigation's knowledge, no continuous (time series) groundwater level monitoring is being conducted in the study area. It is recommended that groundwater level monitoring be conducted at strategically located sites. This could tie in with the groundwater monitoring proposed near or in the RWSS abstraction boreholes.*

- *One of the recommendations from the groundwater-community interdependence survey is that the groundwater-community assessment team must be given the opportunity to present findings to ensure that the engineering team incorporate social trends that might influence the final design approach and layout.*

- *Optimisation of the groundwater abstraction network was performed to report on yields and positions of future production boreholes within the regional well-field and numerically modelled area (RWA). This comprised conceptual boreholes as well as existing boreholes already drilled by SRK during feasibility studies. Final amended recommendations for abstraction rates of SRK boreholes are given since the model has indicated that some of these boreholes are too close to each other and will have to be utilised at reduced rates to minimise the influence between neighbouring boreholes.*

- *The final recommendation is for only 9 Feasibility Study boreholes to be equipped and for an additional 8 conceptual boreholes to be drilled and equipped to finally abstract 2 553 m^3/day from the Regional Well-field Area (RWA). This is therefore the total volume of groundwater that is available for augmentation to the surface water supply scheme from the RWA and relates to 28% of the projected 2020 water demand of the Planning study area as reported in the Domestic Water Requirement Report.*

- *Numerous communities fall outside of the RWA. These communities need to be served by stand-alone schemes (**Figure viii**). These schemes will either serve single communities or small clusters of communities depending on local groundwater conditions. Water sources will involve springs as well as new boreholes that need to be developed. Detail regarding the clustering of these stand-alone communities as well as cost summaries to develop groundwater sources for these clusters and communities are given in **Appendix E**.*

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List of abbreviations

BHN	borehole number
BPEO	best practicable environmental option
DSL	dead storage level
DTM	digital topographic model
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EARTH	Extended model for Aquifer Recharge and soil moisture Transport through the unsaturated Hardrock
EC	electrical conductivity
EIA	Environmental Impact Assessment
EMPR	Environmental Management Programme Report
EWR	Ecological Water Requirements
GA	Groundwater assessment
GIS	Geographical Information System
GMC	Groundwater Management Constraints
GRAII	Groundwater Resources Assessment Phase II
GRDM	Groundwater Resource Directed Model
GRIP	Groundwater Resource Information Project
GRU	Groundwater Resource Units
GUA	Groundwater Unit of Analysis
GUC	Groundwater Use Component
GYM	Groundwater Yield Model
GYMR	Groundwater Yield Model for the Reserve
IMF	instream maintenance flow
ISD	Institutional and Social Development
JSS	Junior Secondary School
LRWSS	Lusikisiki Regional Water Supply Scheme
MAMSL	meter above mean sea level
MAE	mean annual evaporation
MAP	mean annual precipitation
MAR	mean annual runoff
MBGL	meter below ground level (i.e. depth)
NEMA	National Environmental Management Act
NGDB	National Groundwater Database
NGS	Natal Group Sandstone

NGI	National Geo-spatial Information
NWA	National Water Act
PSC	Project Steering Committee
RDM	Resource Directed Measures
RWA	regional wellfield area
TDS	total dissolved solids
TWQR	target water quality range
WMA	water management area
WRYM	Water Resources Yield Model

List of units

A	annum
ha	hectare
hrs	hours
km	kilometer
km^2	square kilometre
ℓ	liter
ℓ/c/d	liter per capita per day
m	meter
m/s	meter per second
m^3/s	cubic meter per second
masl	meters above sea level
million m^3	million cubic meters
million m^3/a	million cubic meters per annum
Mℓ/d	megaliter per day
mm	millimetre
MW	megawatt
Ø	diameter in millimetres
S	seconds

1 INTRODUCTION

The Department of Water Affairs (DWA) appointed **BKS (Pty) Ltd** in association with four sub-consultants (**Africa Geo-Environmental Services, KARIWA Project Engineers & Associates, Scherman Colloty & Associates and Urban-Econ**) with effect from 1 September 2010 to undertake the **Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme**.

On 1 November 2012, BKS (Pty) Ltd was acquired by **AECOM Technology Corporation**. The new entity is a fully-fledged going concern with the same company registration number as that for BKS. As a result of the change in name and ownership of the company during the study period, all the final study reports will be published under the AECOM name.

1.1 BACKGROUND TO THE PROJECT

In the 1970s Consultants O'Connell Manthé and Partners and Hill Kaplan Scott recommended that a regional water supply scheme based on a dam on the Xura River and a main bulk supply reservoir close to Lusikisiki (located within the then defined "administration area" of the Zalu Dam) would provide potable water supply for the entire region between Lusikisiki and the coast, extending from the Mzimvubu River in the south west to the Msikaba River in the north east. Some areas up to 15 km inland of Lusikisiki would also be supplied. A **White Paper** describing the scheme was tabled by the Transkei Government in 1979. It was envisaged that the scheme would be constructed in phases. Details of the proposed phasing of the scheme are provided in (Hill Kaplan Scott, 1986).

After the reincorporation of the Transkei Homeland *into* the Republic of South Africa (RSA) in 1994, the DWA took over responsibility for further development of the scheme. The Directorate: National Water Resource Planning commissioned the *Eastern Pondoland Basin Study* (EPBS) in 1999 to further investigate the water supply situation in the area, with a specific focus on further development in the area originally earmarked for the Lusikisiki Regional Water Supply Scheme (LRWSS). This detailed investigation was undertaken for surface and groundwater sources, which re-affirmed that the Zalu Dam was the preferred source of surface water and recommended further investigation of groundwater sources to augment water supply to the entire area or to sub-areas.

In 2007, SRK Consulting undertook the *Lusikisiki Groundwater Feasibility Study* to investigate groundwater potential and compare the new data with data produced by earlier studies. This study reported that there is a relatively strong possibility of finding high yielding boreholes, and that a combination of surface water (Zalu Dam) and groundwater would be the most feasible solution for the LRWSS.

1.2 STUDY AREA

The study area comprises the entire region between Lusikisiki (up to about 15 km inland) and the coast, extending from the Mzimvubu River in the south-west to the Msikaba River in the north-east. This area includes the Zalu Dam site (and its catchment) in the Xura River and the selected conveyance routes between the dam and the extended supply area. It also includes the boreholes to be selected for augmentation and the routes of the pipelines to augment the water supply to the users.

During the Inception Phase the study area was extended in the vicinity of the Zalu Dam and to the north of Lusikisiki, as agreed with the DWA and as indicated on **Figure 1.1**. In the south-western part of the study area the main focus will be on water supply from groundwater, due to the distance from the surface water source, Zalu Dam, as well as unfavourable topography.

1.3 OBJECTIVE, SCOPE AND ORGANISATION OF THE STUDY

The objective of this study was to complete a comprehensive engineering investigation at feasibility level for the proposed LRWSS, including the proposed Zalu Dam in the Xura River, and to define the most attractive composition and size of the water supply components, taking augmentation from groundwater resources into account.

This feasibility study provided for the assessment of all aspects that impact on the viability of utilising a combination of surface water (via the Zalu Dam on the Xura River) and groundwater (via boreholes) for the expansion of the existing water supply scheme to provide all water users in the study area with an appropriate level and assurance of water supply. The study is therefore required to:

- Identify all of the technical issues likely to affect implementation, and to define and evaluate all of the actions required to address these issues;
- Provide an estimate of cost with sufficient accuracy and reliability to ensure that management decisions can be made with confidence;
- Investigate irrigation viability; and
- Provide sufficient information to enable design and implementation to proceed without further investigation.

The required activities for this project have been grouped into 14 modules, as shown in **Table 1.1**.

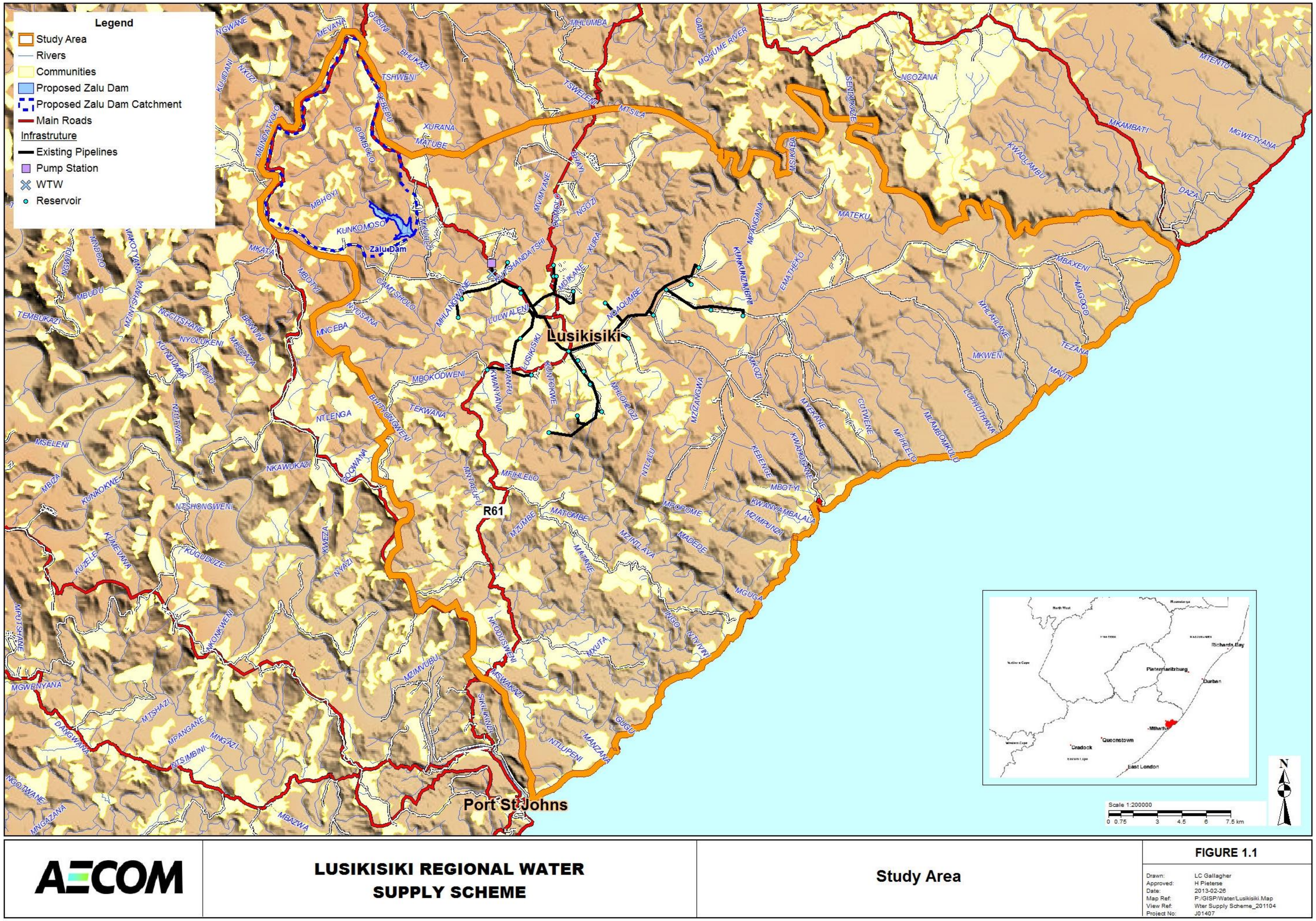

Figure 1.1: Study area

Table 1.1: Study structure

Modules	Deliverable
1. PROJECT MANAGEMENT 1.1 Study initiation and inception 1.2 Project management and administration	**Inception Report**
2. WATER RESOURCES	**Water Resources Report**
2.1 Hydrology	♦ Hydrology chapter
2.2 Yield analysis	♦ Yield Analysis chapter
2.3 Reservoir sedimentation	♦ Sedimentation chapter
3. GROUNDWATER AUGMENTATION	**Assessment of Augmentation from Groundwater Report**
4. RESERVE - ECOLOGICAL WATER REQUIREMENTS	**Reserve Determination Report** ♦ Reserve Template
5. WATER REQUIREMENTS	
5.1 Domestic water requirements	**Domestic Water Requirements Report**
5.2 Agriculture / Irrigation potential	**Irrigation Development Report**
6. WATER SERVICE INFRASTRUCTURE	**Water Distribution Infrastructure Report**
6.1 Distribution infrastructure	♦ Chapter in Water Distribution Infrastructure Report
6.2 Water quality	♦ Chapter in Water Distribution Infrastructure Report
7. PROPOSED ZALU DAM	
7.1 Site investigations	**Materials & Geotechnical Investigations Report**
7.2 Dam technical details	**Dam Preliminary Design Report, including design criteria, dam type selection, dam sizing**
8. COST ESTIMATE AND COMPARISON	**Cost Estimate and Economic Analysis report**
9. REGIONAL ECONOMICS	**Regional Economics Report**
10. ENVIRONMENTAL SCREENING	**Environmental Screening Report** ♦ Scope of work for EIA
11. PUBLIC PARTICIPATION	♦ Included in Environmental Screening Report
12. LEGAL, INSTITUTIONAL AND FINANCIAL ARRANGEMENTS	♦ Legal, institutional and financing arrangements chapter in Main Study Report
13. RECORD OF IMPLEMENTATION OF DECISIONS	**Record of Implementation Decisions**
14. MAIN REPORT AND REVIEWS	**Main Study Report**

1.4 SCOPE OF THIS REPORT

This document reports on the quantity and quality of groundwater resources within the Lusikisiki study area as well as the feasibility and sustainability of existing and conceptual abstraction boreholes to augment the RWSS. Community perceptions and compatibility surveys and workshops regarding water sources have also been performed and reported on. Recommendations are made on the final volume of groundwater to be supplied to the RWSS, abstraction rates of proposed RWSS boreholes as well as groundwater standalone schemes in the far western and south-western part of the study area, utilising springs and boreholes.

This **Groundwater Augmentation Report** is the deliverable for **Module 3: Groundwater Augmentation** of the *Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme*.

2 METHODOLOGY

2.1 INCEPTION PHASE

During the inception phase, available information and reports were reviewed, with special emphasis on the *Lusikisiki Groundwater Feasibility Study* that was conducted and reported by SRK in 2006 and 2009, as well groundwater aspects of the Eastern Pondoland Basin Study, which was reported on in 2001 by UWP Engineers.

Information that is readily available from other regional groundwater studies was sourced and reviewed, including the recent and partially completed Groundwater Resource Information Project (GRIP), which is being carried out under the instruction and guidance of the DWA. Meetings and workshops were held with appropriate people on the project team to quantify the domestic water demands and existing infrastructure in relation to the groundwater potential as well as to define the institutional and social development (ISD) structure for the study.

The hydrogeological terms of reference and identification of additional tasks for execution under the study were developed during this phase and agreement was reached with the Client on the final hydrogeological scope of work, which was then finally defined in the inception report.

2.2 HYDROGEOLOGICAL DESKTOP STUDY

The desktop study was carried out in different phases. The first phase being the continued review of existing information, and reports, as identified in the inception stage and the incorporation of the Eastern Cape GRIP project data for the compilation of borehole and groundwater use statistics.

Known groundwater resources (aquifers), as defined in the SRK studies, is indicated on a GIS system with the updated borehole distribution data. Aquifers were evaluated and ranked based on potential to supply domestic water. The availability of groundwater and surface water were viewed in combination to determine areas where water is in short supply and where conjunctive use would be possible with special reference to the Zalu Dam. This required a collaborative and integrated approach in which the different task leaders were responsible for the water demand determination, the water resource assessment and the bulk distribution infrastructure. The GIS system was used to rank areas in terms of shortage of domestic water supply and to focus the further development work required. An initial indication has already been given in the previous studies where potential is low and high, this was critically reviewed to provide an improved assessment.

Evaluation of groundwater quality and mapping of low quality groundwater areas is provided for, and interpretation thereof is included in the assessment of groundwater available for domestic water supply. Where possible, proposals for groundwater quality improvement were developed that includes a definition of groundwater treatment solutions and blending scenarios. Preliminary analytical groundwater flow balances were done on the quaternary and local catchments to determine the first order of groundwater availability as an assurance check for the initial feasibility-level recommendations. Preliminary cost curves for groundwater augmentation to surface water supply were compiled and include capital and operational cost modelling within the budget framework's time-cost allocation.

This first-level estimation of groundwater availability (quantity, quality and locality) serves as input to the tasks attending to the demands for water from the proposed Zalu Dam and the bulk infrastructure distribution.

2.3 Groundwater Flow Balances and Numerical Modelling

This task involved a more detailed assessment on the availability of groundwater to determine the sustainability of supply for a higher appropriate level of confidence for a feasibility-level study. The groundwater flow balances, and numerical modelling, in selected areas were assessed to determine the sustainable yield of the resource for groundwater reserve definition purposes. This improved information was provided to the other task leaders for the continued improved assessment of water source development, distribution and augmentation. A working group was formed between the groundwater, hydrology, reserve and irrigation modules to define scenarios and overlaps / interactions with other modules.

The following actions were undertaken to achieve the stated objectives in this phase of the study:

- Obtained and evaluated existing groundwater data. This included an evaluation of borehole locations, borehole depths, water levels, hydrogeological units and water quality.
- Evaluated rainfall and groundwater recharge with spatial and temporal variations. The rainfall was analysed in terms of statistical significance of droughts and the potential effects they can have on the sustainability of the groundwater resource.
- Collated and evaluated spatial land-use data, geology, surface water features and environmental components. The integration of surface water features such as dams, rivers and wetlands were done.
- Developed a regional conceptual groundwater flow model and determined the interactions between surface water and groundwater with other environmental

components. Detailed conceptual models were developed for selected local aquifers, or groundwater resource, units of interest.

- Developed analytical groundwater yield models (GYMR method) on quaternary catchment scale for all the quaternary catchments that cover the project area. The analytical models yielded flow volumes that are in line with the groundwater component of the reserve.
- A numerical model was developed for selected aquifers, or groundwater resource units, of interest.
- A comparison of groundwater results of the GYMR approach was made with the numerical model and other methods such as the GRAII outputs.

2.4 Groundwater – Community Interdependency Survey and Awareness Creation

An assessment of community dependencies and attitudes towards groundwater as a domestic water source, considering the development of the Zalu Dam and possible groundwater augmentation, was essential. It was thus proposed that this component of the study will include:

- An assessment of community dependencies and attitudes towards groundwater;
- An assessment of regional groundwater use and infrastructure statistics;
- Attitude analyses: groundwater versus surface water;
- Groundwater awareness creation workshops in target areas to cultivate community competencies concerning issues related to groundwater and
- Survey inputs to be given for the final Groundwater Report.

2.5 Optimisation of Groundwater Abstraction Network

Based on discussions during the Inception Phase, and project launch meeting, as well as taking note of the inputs defined as part of the desktop study phase of the hydrogeological study, a limited time input was defined for the optimisation of the groundwater abstraction network, based on the outcomes of the desktop, groundwater modelling and community study phases.

Inputs for the final Groundwater Report were given with updated information within the framework as defined for the desktop phase.

The availability of groundwater and surface water was reviewed in combination to determine areas where water is in short supply and where conjunctive use would be possible, with special reference to the Zalu Dam. This required a collaborative and integrated approach with the Task Leaders responsible for the water demand determination, the water resource assessment and the bulk distribution infrastructure.

2.6 HYDROCENSUS AND SPRING CHARACTERISATION

With reference to the framework and criteria of the DWA Term Tender W0202WTE, on which AGES has been appointed, the following methodology was defined, based on the requirement to fill data-gaps towards optimising the groundwater reserve study:

- Complete the hydrocensus at the remaining 62 communities in the study area that were not covered in the earlier phases of the study carried out by SRK Consulting.
- Selective water sampling at identified boreholes and springs.
- Characterise springs and seeps in different hydrogeological terrains and groundwater management units.
- Process and integrate hydrocensus data for incorporation into the GYMR and groundwater model.
- Integrate updated groundwater use statistics from hydrocensus for finalization of groundwater-surface water use balance.
- Define final augmentation and optimum groundwater infrastructure requirements on capital and operational expense level.

3 RESULTS

This chapter summarises the outcomes of the different phases of the groundwater investigation with detailed results contained in the appendices at the end of the report.

3.1 INCEPTION REPORT

The final Inception Report was rendered by the main consultant (BKS) with inputs from AGES based on meetings and discussions during the inception phase around issues detailed in Chapter 2 of this report. Comments were received from DWA on 20 November 2012 and addressed by AGES. The final Inception Report was re-submitted by BKS and will not form part of this report to prevent duplication.

3.2 HYDROGEOLOGICAL DESKTOP STUDY

A detailed review was carried out on the *Eastern Pondoland Basin Study* Report and *SRK Feasibility Study* reports. The report by SRK also incorporated the Pondoland Study outcomes thus the SRK report was used as primary source of information of previous studies completed. The SRK findings are summarized in Error! Reference source not ound.. The main Geohydrological investigations was completed by SRK

3.2.1 Hydrocensus results

During the hydrocensus conducted by SRK a total of 90 villages, as indicated in **Figure 3.1**, were visited including those that fall within the areas identified for the feasibility drilling program.

According to the SRK *Lusikisiki Groundwater Feasibility Study Report* (Report number P WMA 12/000/00/1507) the groundwater development potential for the study area is the highest in the western portions of the project area underlain by dolerite dykes, faults and lineaments intersecting the Natal Group Sandstones followed by the Dwyka and Ecca formations in descending groundwater development potential.

a) Study area Geology

According to the geological map 3128 (Umtata) the project area is underlain by the Ecca Group, the Dwyka formation of the Karoo Supergroup sequence of rocks and the Natal Group Sandstones (**Figure 3.3**).

Table 3.1: Summary of the SRK report (P WMA 12/000/00/1507)

<table>
<tr><th colspan="2">Report</th><td colspan="5">LUSIKISIKI GROUNDWATER FEASIBILITY STUDY PHASE 2</td></tr>
<tr><th colspan="2"></th><td colspan="5">INVESTIGATING THE POTENTIAL TO SUPPLIMENT THE LUSIKISIKI RURAL WATER SUPPLY SCHEME(LRWSS)</td></tr>
<tr><th colspan="2">DWA report number</th><td colspan="5">P WMA 12/000/00/1507</td></tr>
<tr><th colspan="2">Author</th><td colspan="5">SRK Consulting (South Africa) (Pty) Ltd</td></tr>
<tr><th colspan="2">Date</th><td colspan="5">May-09</td></tr>
<tr><th colspan="2">Relevance to Reserve study</th><td colspan="5">Hydrocensus, drilling and aquifer testing</td></tr>
<tr><th colspan="7">Comments:</th></tr>
<tr><th>Groundwater potential</th><th>Yields of existing boreholes through hydrocensus & NGDB where available</th><th>Springs</th><th>Borehole Drilling</th><th>Lineaments</th><th>Fracturing / weathering</th><th>Geological contacts</th></tr>
<tr><td>Natal Group Sandstone 0-10 ℓ/s</td><td>Dry or no data approximately 27 boreholes</td><td>No spring flows were taken,EC values are below 70 mS/m</td><td>A total of 30 boreholes were drilled, 12 in the NGS, 10 in the Dwyka and 8 in the Ecca</td><td>East West – Significant strikes in Dwyka, none in NGS</td><td>In Dwyka – strikes associated with EW lineament</td><td>Between Ecca / Dwyka – no significant strikes</td></tr>
<tr><td>Dwyka 0-5 ℓ/s</td><td>Yield between 0.13 and 1.89 ℓ/s 7 boreholes</td><td>Spring flow is seasonal</td><td>Significant water strikes in NGS >5 ℓ/s for thin dyke contacts, for thick dykes the yield was 5 ℓ/s with shallow strikes</td><td>South East – No strikes in NGS</td><td>In thick Dolerite sheets – Not targeted</td><td>Between Dwyka / NGS – significant strikes with little fracturing</td></tr>
<tr><td rowspan="5">Ecca low</td><td rowspan="5">Yield between 1.90 and 4.55 ℓ/s only one borehole close to Lusikisiki</td><td>No proper protection of the springs</td><td rowspan="2">Low yields in Dwyka and Ecca formations where they are intersected by dolerite dykes.</td><td rowspan="5">East north east – No strikes in NGS</td><td rowspan="5">Associated with Dykes – High yields up to 85 l/s in NGS with fracturing within 2-20 m of dykes.</td><td rowspan="3">Significant strikes considered to be more than 1.5 ℓ/s</td></tr>
<tr><td rowspan="3">A total of 90 villages were hydrocensused</td></tr>
<tr><td rowspan="3">Inside dolerite dykes 2-3 ℓ/s in the NGS with < 1 ℓ/s for dykes in Dwyka</td></tr>
<tr><td rowspan="2">Lineaments drilled near Mkambati were dry</td></tr>
<tr><td>NGDB borehole and spring positions are inconsistent with respect to other more updated databases</td></tr>
</table>

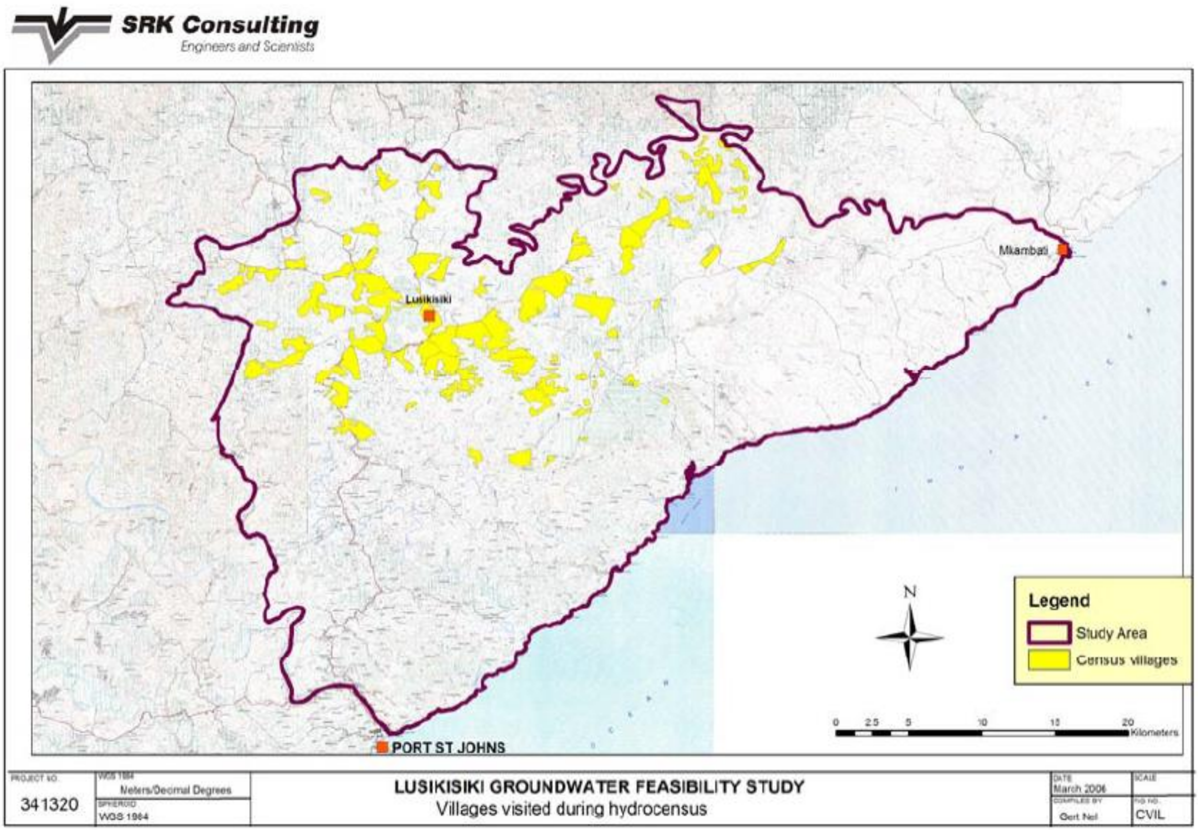

Figure 3.1: Villages hydrocensused by SRK (SRK May 2009)

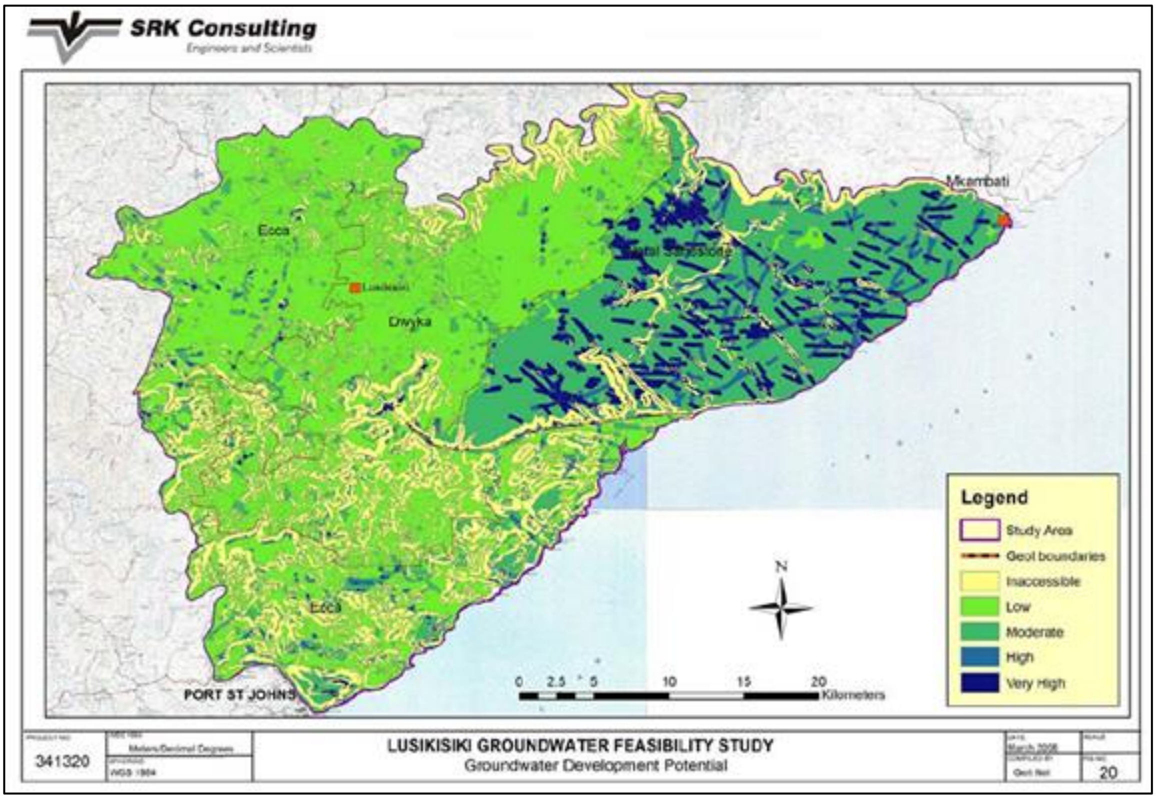

Figure 3.2: SRK Groundwater development potential in the study area (SRK May 2009)

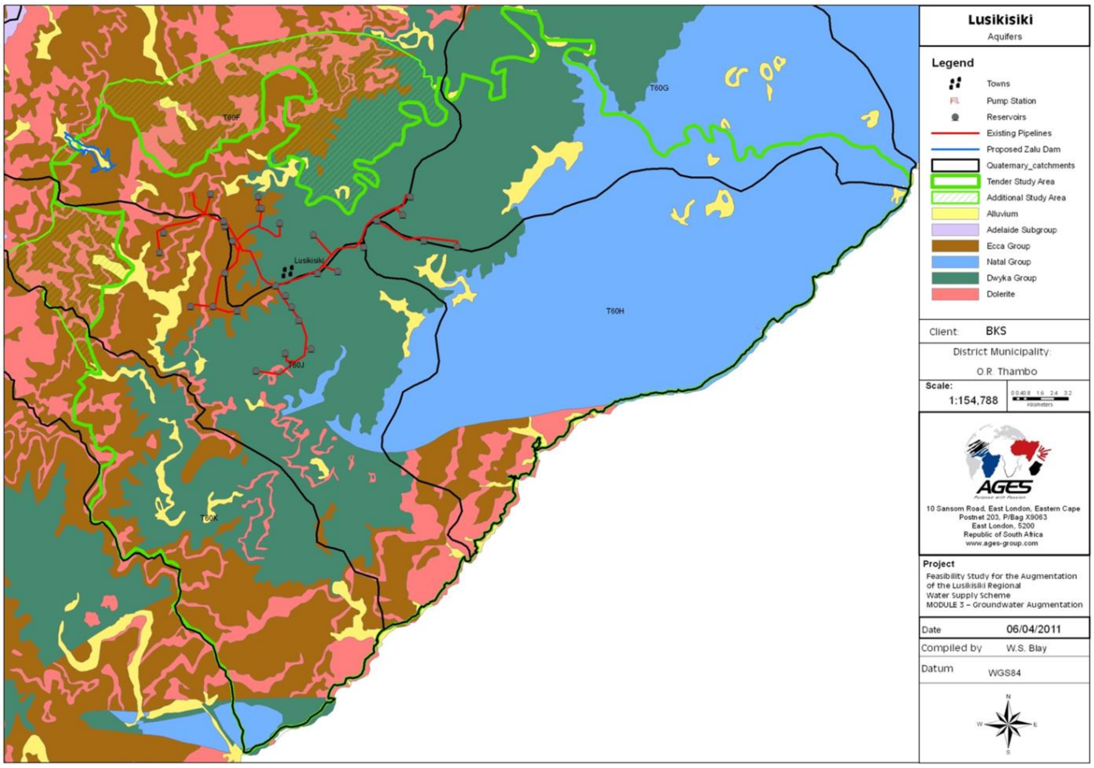

Figure 3.3: Geological formations over the study area

Ecca group:

The Ecca Group consists of dark grey shale, mudstone and sandstone. The average dip angle of the formation is 3 degrees north-west with dolerite intrusions striking in the same direction over the entire project area. Parts of the project area are covered by dolerite sills with dolerite dykes intersecting the sills.

Dwyka formation:

The dwyka formation consists of tillite an associative glacial deposit. The general strike of dolerite dykes, faults and lineaments through the formation is north-west.

Natal group sandstones:

The light grey quartzitic sandstone occurs in the eastern parts of the project area has a dip of 2 degrees to the west. Dolerite dykes and lineaments have a strike consistent with the other formations mentioned in a north-west direction. The geosite concentrations per database are indicated in **Figure 3.4**. Currently the two main databases (NGA & GRIP) indicate a geosite concentration in the western and northern section of the project area. There is limited data available for the south eastern portions of the project area as indicated in **Figure 3.4**. **Table 3.2** summarises all the geosites within the study area identified through the hydrocensus conducted by SRK as well as geosites from the GRIP and NGDB databases and newly drilled boreholes from the *SRK Feasibility Study*.

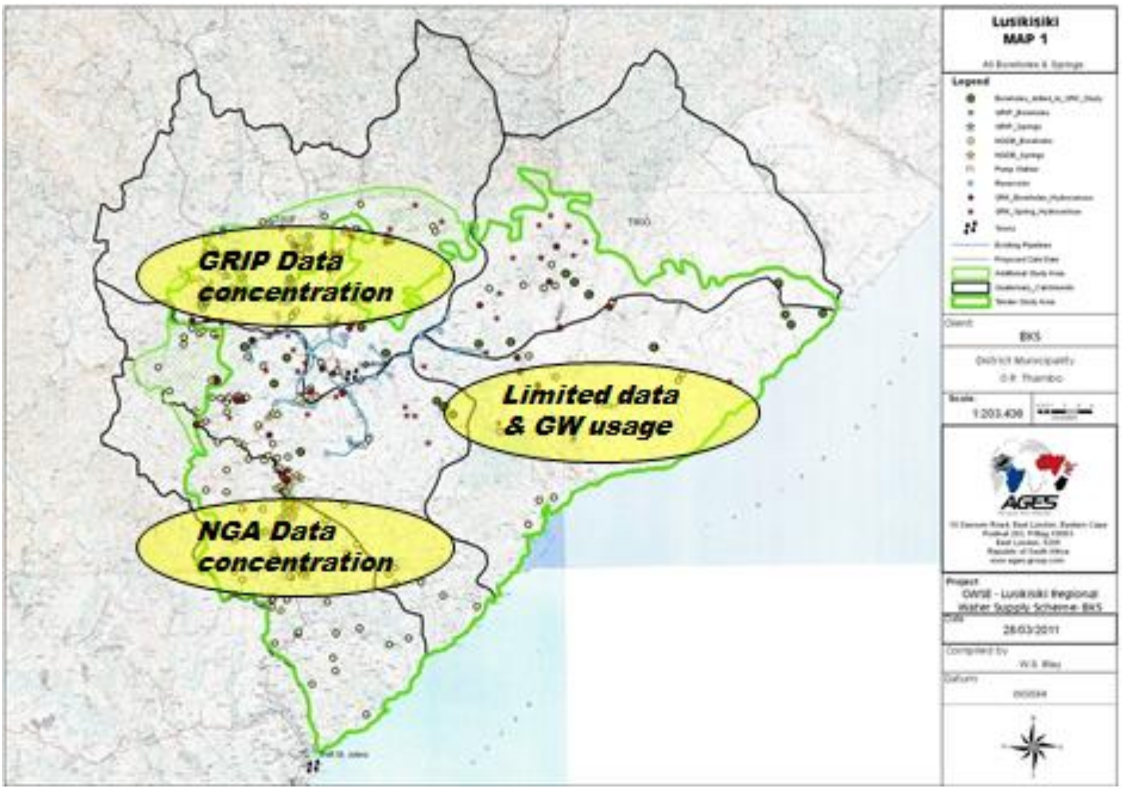

Figure 3.4: Geosite concentration over the project area

Table 3.2: Geosites in study area

Description (Geosites in Study Area)	Total
Total nr of Boreholes in known in study area	**235**
Boreholes reflected on NGDB database	*152*
Additional boreholes sourced from GRIP survey	*17*
Boreholes identified during SRK Hydrocensus	*36*
New boreholes drilled during SRK study	*30*
Total nr of Springs in study area	**119**
Springs reflected on NGDB database	*49*
Additional springs sourced from GRIP survey	*22*
Springs identified during SRK Hydrocensus	*48*

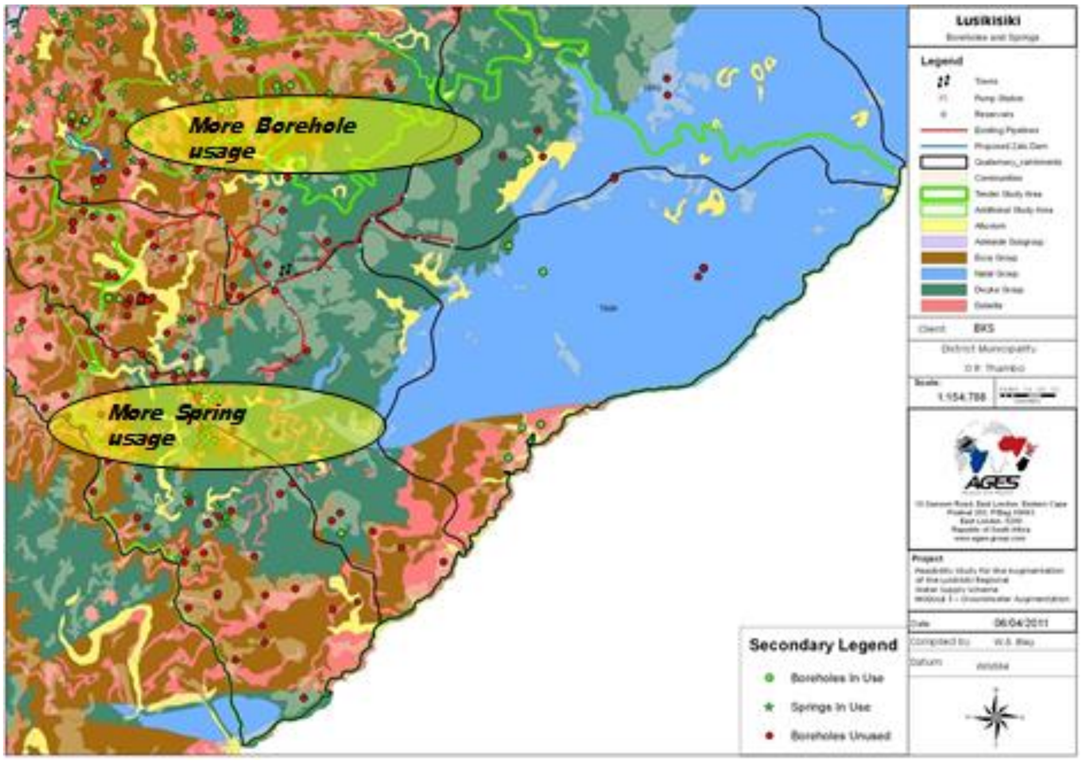

Figure 3.5: Borehole and spring usage

In the northern sections of the study area the use of boreholes is very abundant compared to the south where the usage of springs is more common. The main reason for this is due to the topography of the study area in these regions. The southern section is dominated by rolling hills while the northern sections are more flat with better access for drilling rigs to drill boreholes.

Blow yields of the boreholes are higher in areas where dolerite dykes and faults were targeted and on contact zones between geological formations as indicated in **Figure** 3.6. The Natal Group Sandstones have the highest yielding boreholes followed by the Dwyka and lastly and lowest yielding Ecca Formation.

There is a strong correlation between the blow yields of the boreholes in **Figure 3.6** and their sustainable yields in **Figure 3.7** that is an indication of good fracture networks with no- or limited boundary conditions.

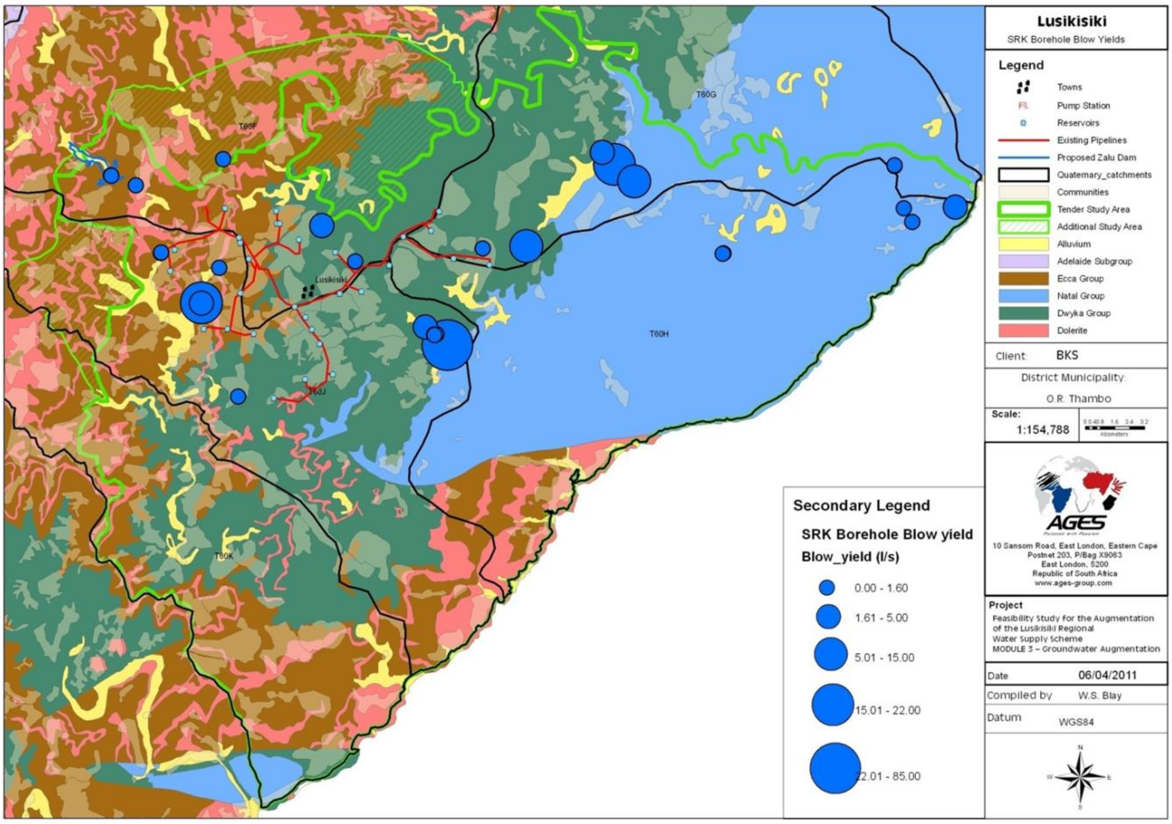

Figure 3.6: SRK boreholes with blow yields

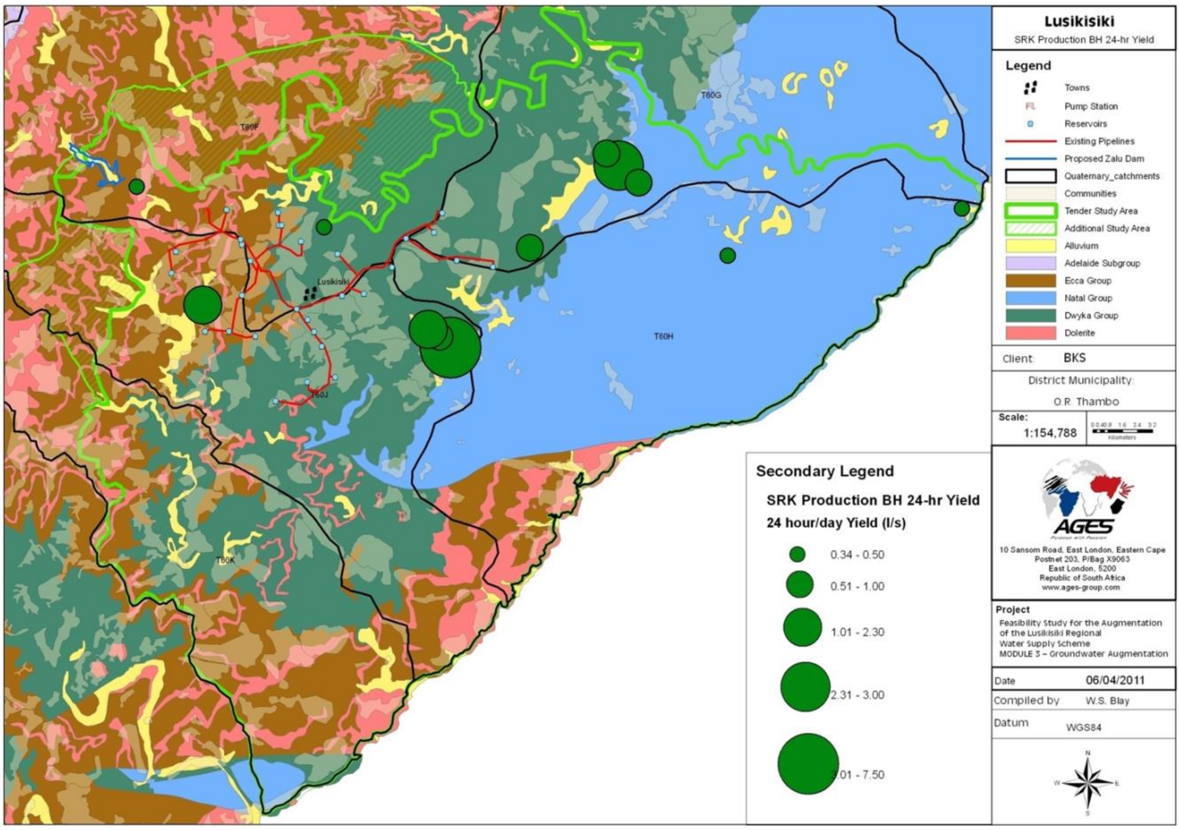

Figure 3.7: SRK production boreholes ranked according to their 24 hour sustainable yield

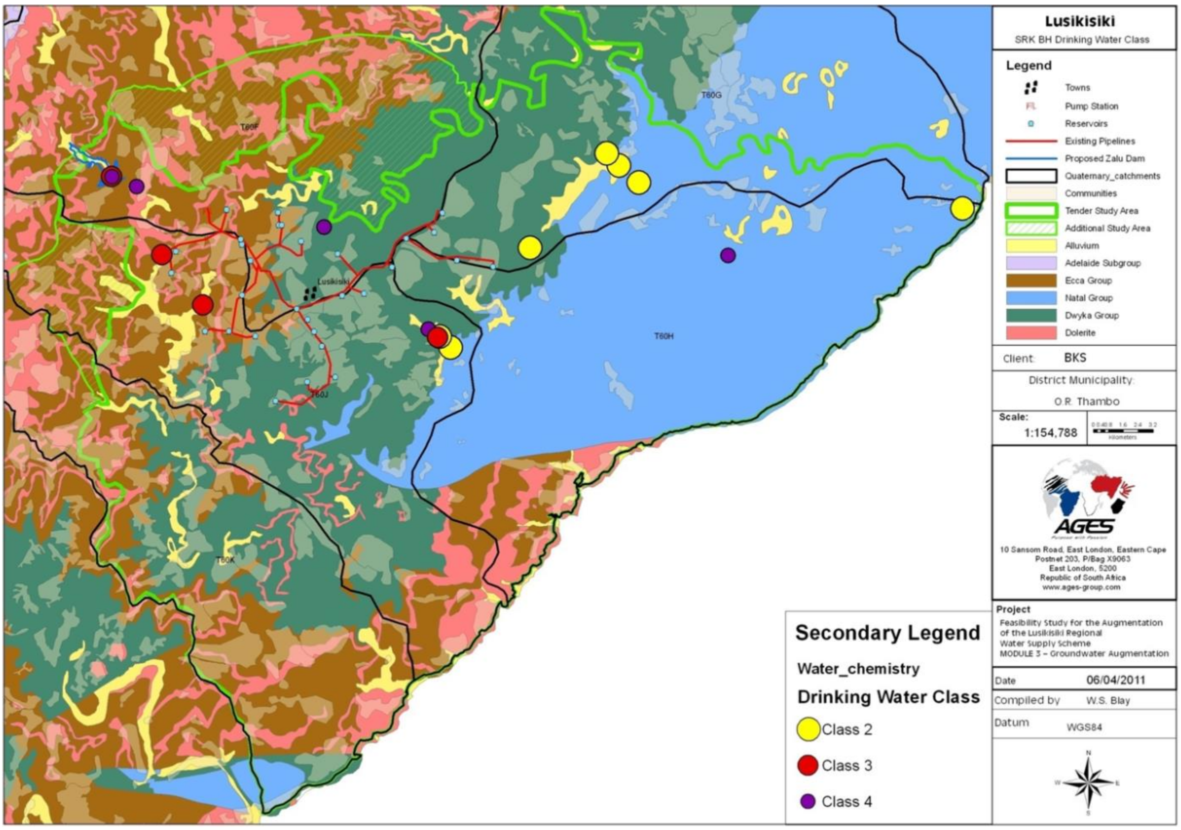

Figure 3.8: Groundwater quality

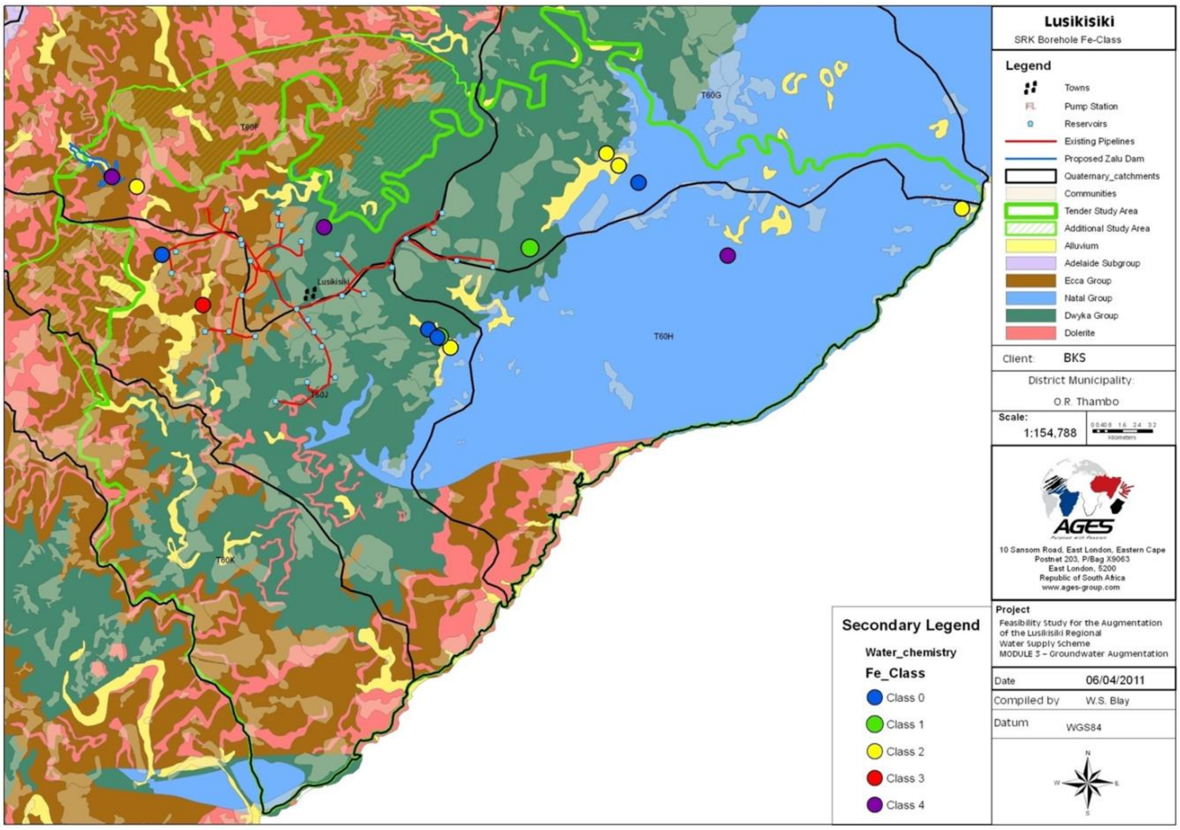

Figure 3.9: Iron classification over the study area

The groundwater from existing geosites (SRK Feasibility Study boreholes) can be classified as DWAF Class 2, 3 and 4 over the entire study area. The Ecca group is dominated by Class 3 and 4 groundwater while the Dwyka formation has Class 2 to 4 water quality. The Natal Group Sandstones seem to have the best water quality with only one geosite with Class 4 water quality.

From existing groundwater chemistry data the Iron concentrations range from DWAF Class 0 to 4 through all of the geological formations. The data was obtained from the boreholes drilled during the *SRK Feasibility Study Phase 2*. The Iron concentrations are generally Class 0 to 2 with some localised boreholes with Class 3 and 4 throughout the study area.

The difference in groundwater characteristics is evident as indicated on the piper diagram, groundwater from the Ecca Group, NGS and Dwyka formation is of the sodium-bicarbonate (Na-HCO3) type of water that is typical of deeper fresh groundwater that has undergone ion exchange. The groundwater from the NGS and the Dwyka formation tends to be more calcium–sulphate (Ca-SO4) that is typical of gypsum groundwater and mine drainage.

The overall classification as indicated in **Figure 3.10** of the water samples is more Sodium-Bicarbonate (Na-HCO3) that indicates fresh groundwater of deep origins that has infiltrated aquifers and has undergone ion exchange.

The following tables are summaries of figures from the SRK July 2006 *Lusikisiki Groundwater Feasibility Study* and May 2009 *Lusikisiki Groundwater Feasibility Study Phase 2* report.

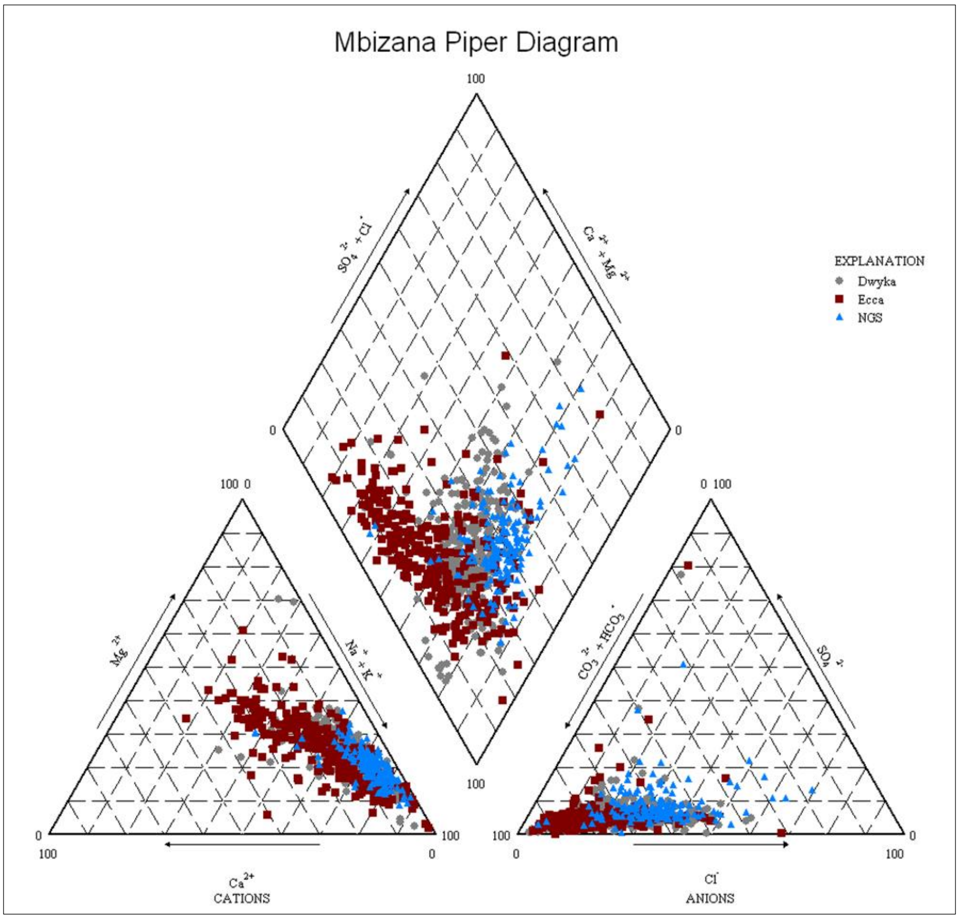

Figure 3.10: Piper diagram of Mbizana water chemistry data

Table 3.3: Projected groundwater usage per quaternary catchment

Quaternary sub-catchment	Projected groundwater usage (million m^3/a)			
	2000	2010	2020	2030
T60F	0.000	0.000	0.000	0.000
T60G	0.000	0.000	0.000	0.000
T60H	0.000	1.231	1.573	2.354
T60J	0.000	0.000	0.004	0.011
T60K	0.000	0.000	0.000	0.000
TOTAL	0.000	1.231	1.577	2.365

Table 3.4: Area and MAP per quaternary catchment

Quaternary catchment	Area (km^2)	MAP (mm)
T60F	464	940
T60G	360	1 116
T60H	322	1 277
T60J	294	1 101
T60K	242	1 075

3.2.2 Groundwater resource directed measures (GRDM)

A preliminary groundwater reserve determination was carried out using the Groundwater Resource Directed Measures software version 3.3.0.6 from the Department of Water Affairs and Forestry. The tender study area and the additional study area fall within quaternary catchments T60F, T60G, T60H, T60J and T60K. The catchments were delineated in the GRDM for the reserve determination. The catchments versus the study areas can be seen in **Figure 3.11**.

The quaternary catchments with surface areas and Mean annual precipitation (MAP) values retrieved from the GRDM software are indicated in **Table 3.5**. The MAP values in **Table 3.5** indicated by the GRDM software are the same as those in the SRK reports as indicated in

Table 3.4.

A basic human need of 60 ℓ/c/d was used for the population of 220 616 with a total water use of 4.8 million m^3/a. The GRDM calculated a recharge of 278.7 million m^3/a, and a baseflow of 102 million m^3/a for all of the quaternary catchments as mentioned above.

The total allocatable groundwater is 171.8 million m^3/a minus the current abstraction of 0.92 million m^3/a, thus the available groundwater is 170.9 million m^3/a, or 5 420 ℓ/s.

Table 3.5: GRDM calculated and database values

Quaternary catchment	Area (km^2)	Mean anual precipitation (mm)	Mean annual runoff (mm/a)	Baseflow (mm/a)	Human population	Basic human need (l/c/d)	Recharge (mm/a)
T60F	463.2	940	174	41	77 841	4 670 460	119.37
T60G	359.4	1 116	282	59	48 672	2 920 320	167.99
T60H	321.6	1 277	390	86	7 615	456 900	223.33
T60J	293.4	1 101	266	63	40 421	2 425 260	164.46
T60K	242	1 075	250	60	46 067	2 764 020	171.83

The rapid GRDM was completed for each catchment as indicated in **Table 3.5**.

Table 3.6: GRDM results

Quaternary catchment	Area (km^2)	Protected area (km^2)	Allocatable groundwater (million m^3/a)	Current abstraction (million m^3/a)
T60F	463.2	0	34.8	0.3
T60G	359.4	10.1	38.6	0.16
T60H	321.6	0	44.0	0.06
T60J	293.4	0	28.6	0.23
T60K	242	0	25.8	0.17
Total	**1 679.6**	**10.1**	**171.8**	**0.92**

Table 3.7: Resource quality objectives (quantification of the Reserve)

Human Need	
Population	220 616
Basic human need (ℓ/c/d)	60
Basic human need total (million m^3/a)	4.8
Recharge	
Recharge (million m^3/a)	278.67
Baseflow	
Baseflow (million m^3/a)	102

Reserve	
Reserve as % recharge	38.3
Allocatable groundwater (million m³/a)	171.8
Current abstraction (million m³/a)	0.92

Quaternary catchment T60J has the highest reserve as a percentage of the recharge (41%) in the catchment followed by T60H, T60K, T60F and T60G in descending order with values of 39%, 38%, 37% and 36% respectively as indicated in **Figure 3.11**.

The stress index percentage was calculated for each of the catchments and displayed in **Figure 3.12**. Catchments T60F, T60J and T60K are more stressed than T60G and T60H never the less all the catchments have stress index percentages of less than 1% indicating that the catchments are unstressed with regards to groundwater abstraction.

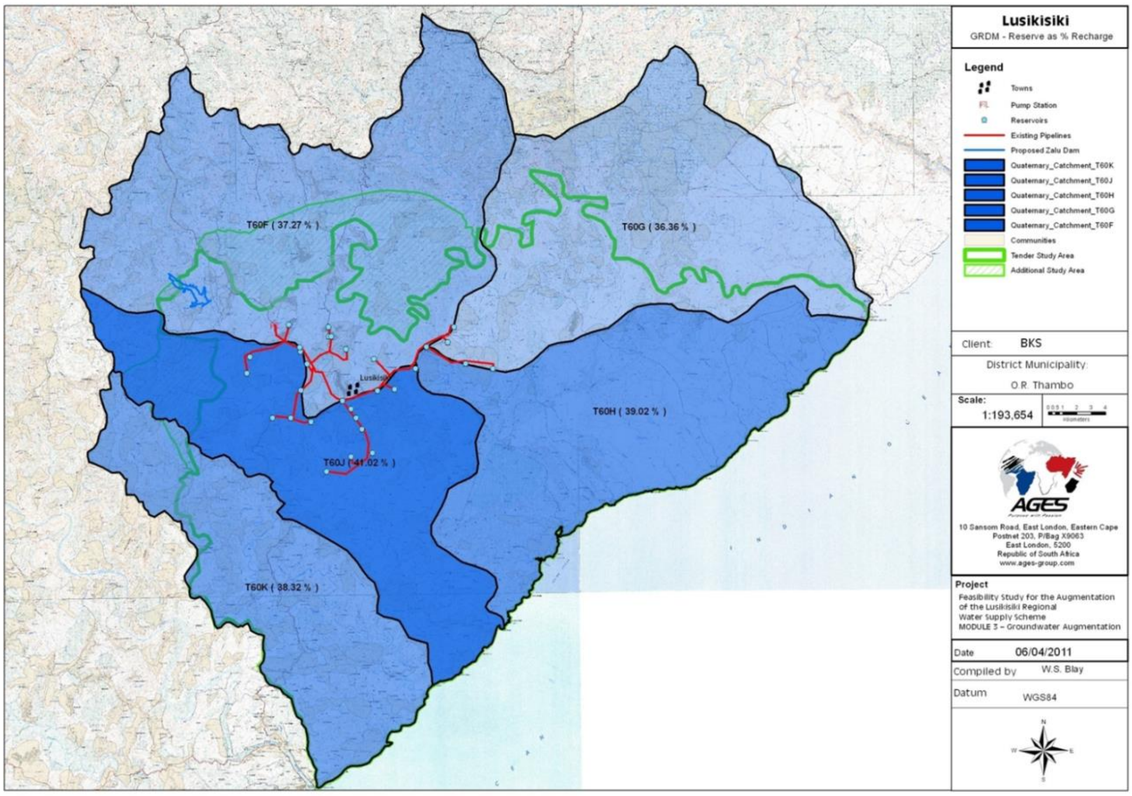

Figure 3.11: Groundwater Reserve as a % of recharge

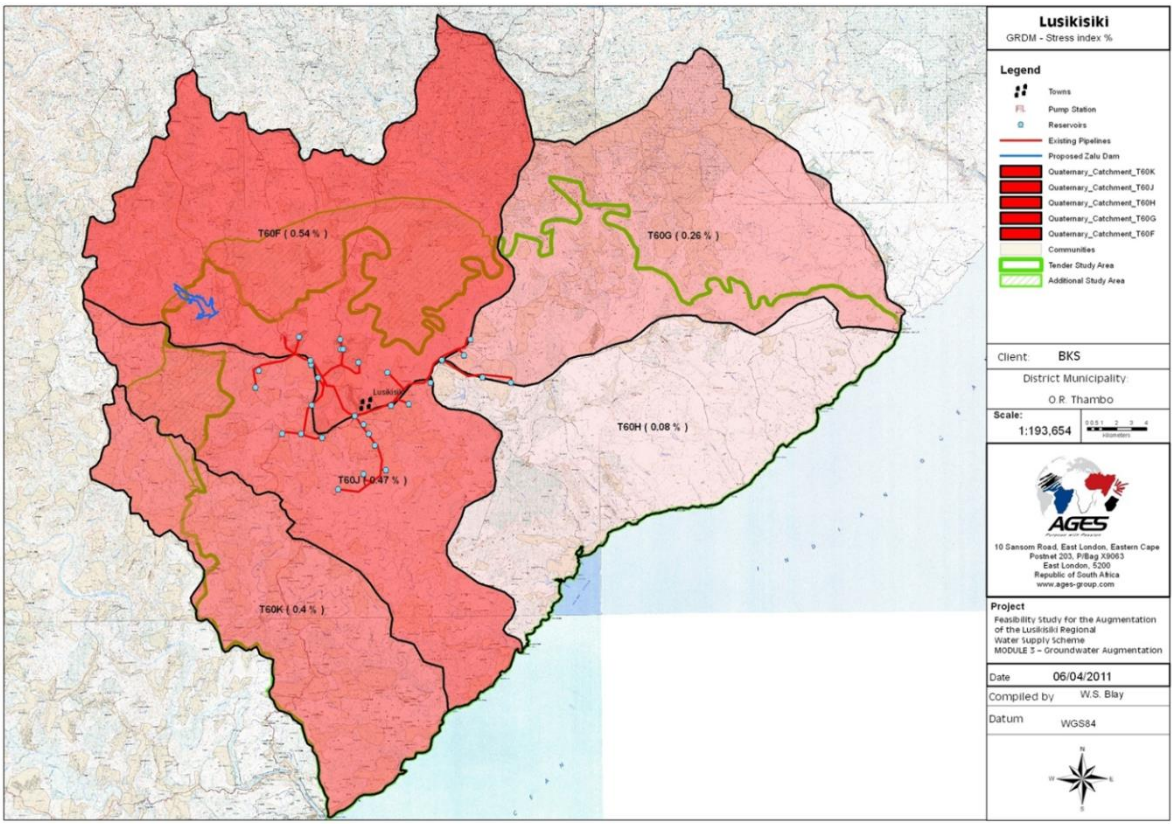

Figure 3.12: GRDM Stress index %

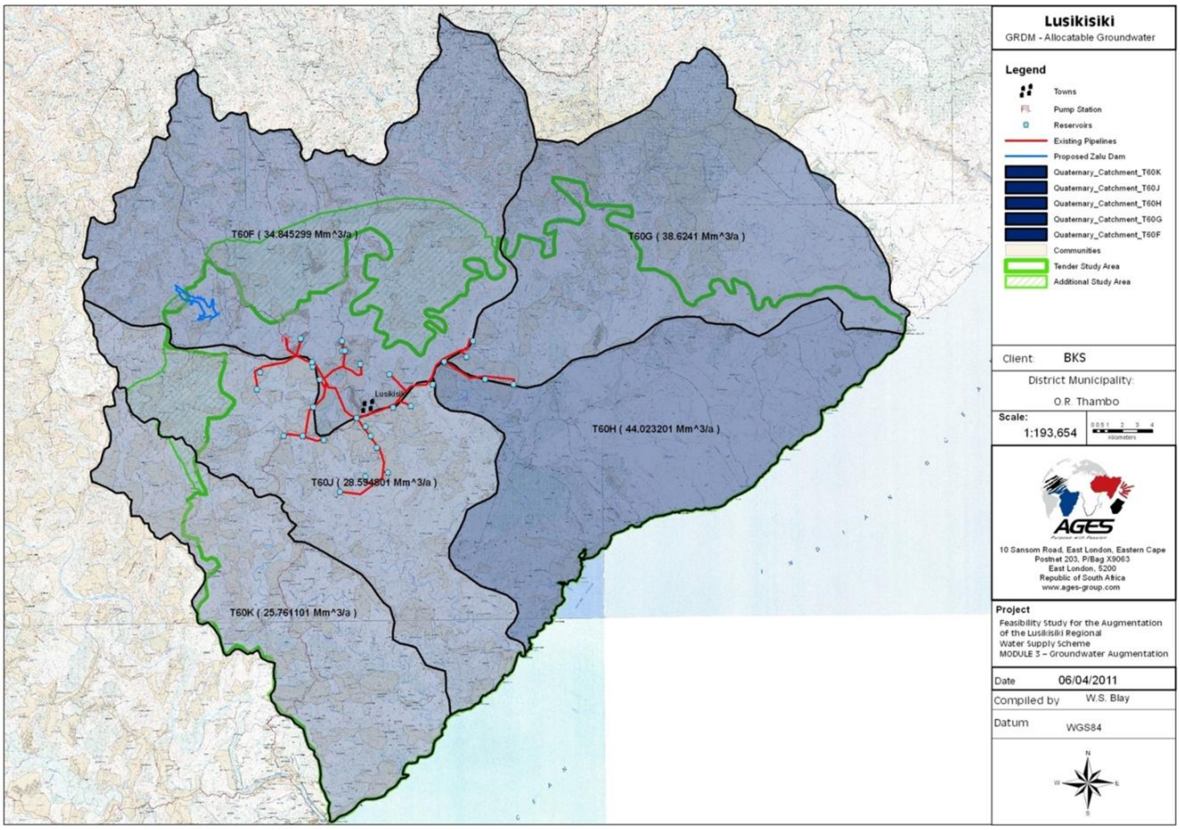

Figure 3.13: GRDM - Allocatable groundwater

The GRDM results indicate that catchment T60H has the highest volume of allocatable groundwater 44 million m³/a as indicated in **Table 3.6** and the catchment has the highest groundwater potential as discussed in the SRK report (May 2009). Rainfall in this catchment is significantly higher than in the other catchments and the geology is primarily Natal Group Sandstone that can deliver high yielding boreholes.

Preliminary groundwater abstraction- or high potential zones were identified in **Figure** 3.14 using the following available information: Catchment T60H having the highest allocatable groundwater volume of 44 million m³/a, the underlying geology, lineaments, faults and dolerite dykes striking through the Natal Group Sandstone (NGS), groundwater classification being generally Class 2 in catchment T60H as well as having the lowest stress index. These zones are indicated in **Figure 3.14** and were further identified with reference to Groundwater Management Units identified in the earlier feasibility study. Preliminary proposed abstraction zones that must be investigated for possible additional production boreholes are also indicated in this map.

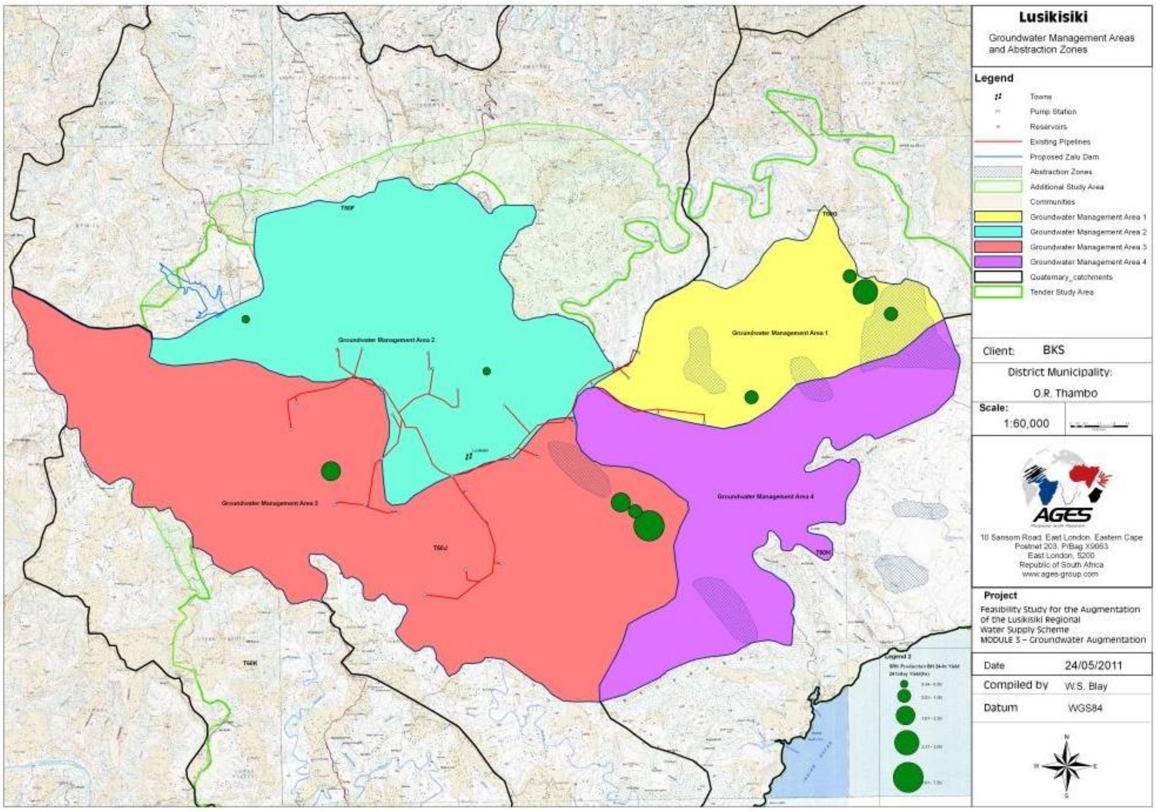

Figure 3.14: Preliminary groundwater management areas and proposed abstraction zones

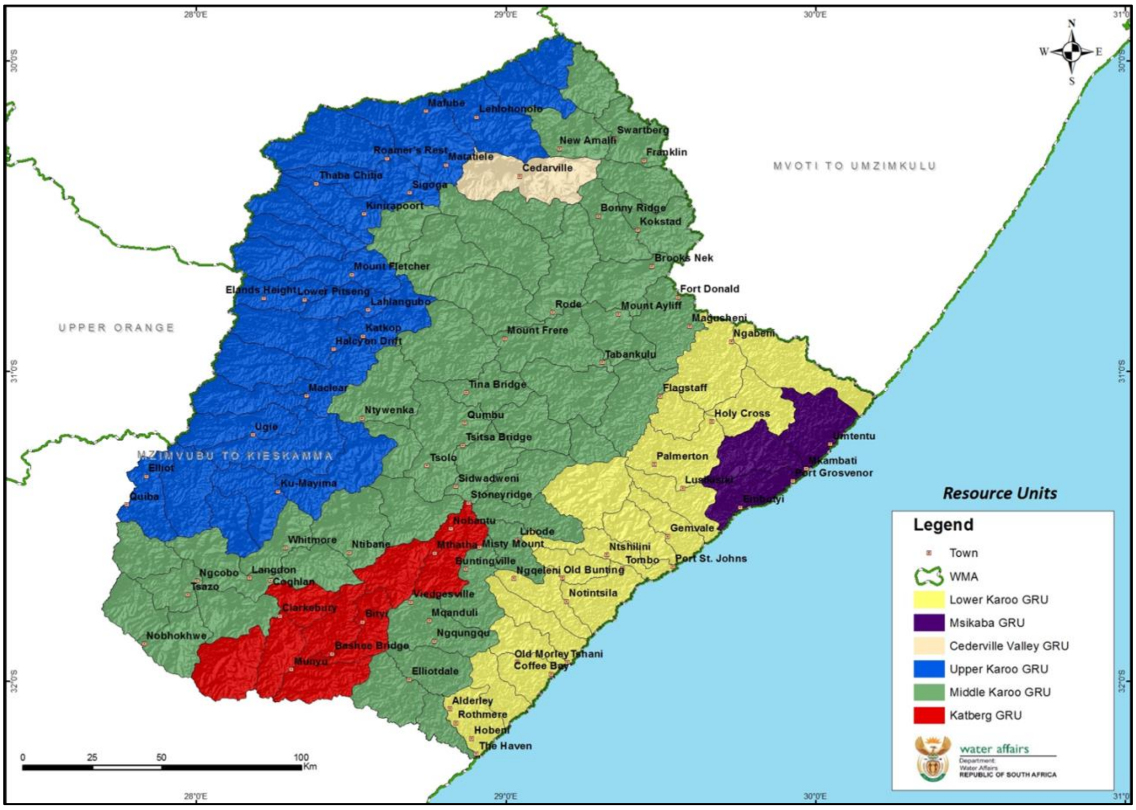

Figure 3.15: Groundwater management areas (Bay Technologies 2012)

The determination of the groundwater component of the Reserve for the Mzimvubu to Keiskamma Water Management Area (WMA) conducted by Bay Technologies and Umvoto Africa was performed at intermediate level and indicate that overall groundwater is under-utilised in the study area and that groundwater quality was found to be good to very good. Larger Groundwater Units of Analysis were delineated but the groundwater ratios (percentages) of the units in which the *Lusikisiki RWSS Groundwater Reserve Study* falls could be compared.

The groundwater contribution to baseflow was in each GUA case found to use the largest percentage of groundwater recharge. The WMA groundwater study and Lusikisiki RWSS and Msikaba Catchment Groundwater Reserve study compare well in that both studies indicate groundwater is largely under-utilised and there are still appreciable volumes of groundwater available for allocation after the groundwater Reserve has been accounted for.

The instream maintenance flows (IMF) from the WMA groundwater Reserve study should be compared to the Lusikisiki RWSS IMFs for the ecological requirement for the Reserve (EWR), when they are available for the study. The WMA Groundwater Reserve Study found a generally larger groundwater recharge percentage than the *Lusikisiki RWSS Reserve Study* as the literature sources on which the WMA groundwater Reserve study were based used non-conservative methods. The conclusion is that the current Lusikisiki RWSS and Msikaba intermediate groundwater Reserve study yielded more conservative groundwater volumes and the sustainability of the groundwater yields from existing and planned boreholes for the *Lusikisiki RWSS*, were thoroughly tested in the numerical groundwater model.

The conservative approach used during the Lusikisiki RWSS Groundwater Reserve study means that more groundwater should be available than stated in the report and that there is already enough groundwater available for the future planned use from existing boreholes even with the conservative figures used.

3.2.3 Conclusions

During the hydrocensus conducted by SRK a total of 90 villages were visited including those that fall within the areas identified for the feasibility drilling program.

According to the SRK Lusikisiki Groundwater Feasibility Study report (Report P WMA 12/000/00/1507) the groundwater development potential for the study area is the highest towards the eastern portions of the project area underlain by dolerite dykes, faults and lineaments intersecting the Natal Group Sandstones followed by the Dwyka Formation and Ecca Group in descending groundwater development potential.

A preliminary groundwater Reserve determination was carried out using the Groundwater Resource Directed Measures software Version 3.3.0.6 from the DWA. The total allocatable groundwater volume for the catchments covering the project area is 171.8 million m^3/a.

Quaternary catchment T60J has the highest reserve as a percentage of the recharge (41%) in the catchment followed by T60H, T60K, T60F and T60G in descending order with values of 39%, 38%, 37% and 36% respectively as indicated in **Figure 3.11**.

The stress index percentages of each of the catchments are less than 1% indicating that the catchments are currently unstressed with regards to groundwater abstraction.

From groundwater chemistry of the 30 boreholes drilled in the SRK Feasibility Study the Ecca group is noted to have DWAF Class 3 and Class 4 groundwater while the Dwyka formation has Class 2 to 4 water quality. The Natal Group Sandstones seem to have the better water quality in general with only one geosite with Class 4 water quality. The main problem constituent has been noted to be Iron with elevated coliform bacteriological counts noted in some areas.

The overall groundwater classification from work done in adjacent catchments in similar geological terrains is more Sodium-Bicarbonate (Na-HCO3) that indicates fresh groundwater of deep origins that has infiltrated aquifers and has undergone ion exchange.

Preliminary groundwater abstraction- or high potential zones were identified using the following available information: Catchment T60H having the highest allocatable groundwater volume of 44 million m^3/a, the underlying geology, lineaments, faults and dolerite dykes striking through the Natal Group Sandstone (NGS), the contact between the Dwyka and NGS, groundwater classification being generally Class 2 in catchment T60H as well as having the lowest stress index.

One of the main shortcomings in previous studies was that a groundwater balance was never completed for any of the catchments, or for the study area. This will have to be addressed during the next phase.

3.3 Groundwater Yield Model for Reserve Determination

The full report detailing the results of the reserve determination process and yield model outcomes is given in **Appendix A** with the following summary given for the purpose of the main report.

3.3.1 Background

Groundwater Yield Model(s) for the Reserve (GYMR) were done on quaternary catchments T60E, T60F, T60G, T60H, T60J and T60K, as well as for the study area as a whole, to get some idea of the groundwater volumes involved for the study area as a whole. During the calculation of the Groundwater flow balance and GYMR, the assumption was made that all water necessary for the various water uses in a quaternary catchment, should come from groundwater to (1) determine if groundwater can sustain all the necessary water uses and (2) determine how much groundwater is left thereafter and would it be possible to use groundwater, given the BHN and EWR Reserve needs. Another assumption was that some of the water inflow and outflow figures obtained during the Eastern Pondoland Basin Study (2001) for 2010 are acceptable estimates for the present day GYMR scenarios. In the absence of real observed data, these were the best available figures. Where these figures have been used it has been designated in the Inflows and Outflows section.

In determining many of the water inflows and outflows, as well as water levels for the study area, quaternary catchment surface area was used and a spatial weighted average was applied to calculate the percentage surface area contribution to the total study area. These percentages were then used to calculate for instance the recharge and water level for study area.

3.3.2 Results

The mean water level in the study area was calculated at 10.1 m below ground level based on old and new NGDB data as well as GRIP data for T60F. Shallow water level results from saturated aquifer conditions and very little groundwater abstraction. Numerous springs and seeps are also a testament of the saturated groundwater conditions. Water level data in the study area is very sparse and it would be good if some additional water levels could be obtained for a good water level distribution across the study area for modelling. Also, no groundwater monitoring of water levels in the study area is currently being conducted. Monthly groundwater levels are also for instance required in order to apply the EARTH method for recharge estimation.

Recharge is estimated to be 8.25% for the total Tender study area. Recharge is based on a weighted mean of quaternary catchment coverage of study area. Recharge estimates for quads in the Eastern Pondoland Basin study (2001) was noted by Woodford to probably be in the order of his lower variable recharge estimates. SRK estimated a mean percentage of recharge for the study area of 12.8%. This recharge estimate is seen as possibly too high.

Due to sparse borehole water quality info (basically only newly drilled SRK boreholes), the chloride method cannot be applied with enough confidence to estimate recharge. Evaluation by means of the chloride method for the study area based on newly drilled SRK boreholes equates to a recharge percentage of 3.8%.

The numerous springs (and not seeps) in the study area present a unique way of gaining a lot of high quality representative chloride values and general chemical water quality for groundwater. As springs represent moving groundwater of the aquifers in the study area, they are regarded as the best possible points for obtaining chloride values for recharge estimates. Some hyper saline springs do occur in the study area near large tectonic structures as noted by Woodford (2001). Woodford (2001) also states that EC and other macro- and isotopic-constituents of the water may be used to obtain a first order approximation of the sustainability of the resource (i.e. whether it is a spring or a seep and thus perennial or not).

Very little information on boreholes and production boreholes are available for the southern part of the study area that was not covered by previous studies. Preliminary indication was that the Bulk Water Supply Scheme will not be able to reach this area and that it will be reliant on groundwater from springs and boreholes almost 100%. The extent and yield capacity of successful boreholes and groundwater quality need to be verified.

It was important during this study to distinguish between springs and seeps. Springs are normally located down in the lower valleys of incised rivers or at places where a shallow water table cuts the topography. Springs are perennial and especially in the study area due to the high MAP and very little groundwater use. Seeps are typically the discharge of infiltrated rainwater from the vadose zone or perched aquifer, where the infiltrated rainwater has not yet reached the water table or saturated aquifer (Woodford, 2001). Seeps are typically non-perennial, do not present sustainable supplies of groundwater for communities and will create the idea that groundwater is not sustainable. Seeps do not represent aquifer water quality characteristics

3.3.3 Groundwater Reserve scenarios

The Groundwater Yield Model for the Reserve (GYMR) was simulated to assess potential groundwater flow balances on an annual basis. Recommendations on management options based on the outcome of the assessments are made, for the DWA RDM office's decision making purposes.

The scenarios that were simulated are following:

1. Present day GYMR, 95% assurance of supply, GA's included – groundwater inflow from estimated recharge and rainfall at 95% assurance level; GYMR accounting for drought cycles, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).
2. Present day GYMR, 95% assurance of supply, GA's excluded - groundwater inflow from estimated recharge and rainfall at 95% assurance level; GYMR accounting for drought cycles, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).
3. Present day GYMR, MAP rainfall, GA's excluded - groundwater inflow from estimated recharge and rainfall at 95% assurance level; GYMR accounting for drought cycles, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).

4. Future 2020 GYMR scenario, 95% assurance of supply, GA's excluded - groundwater inflow from estimated recharge and rainfall at 95% assurance level; 2020 groundwater use and population figure estimates used predominantly from EPBS (2001); GYMR accounting for drought cycles, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).

It must be noted that this groundwater flow balance is based on the assumption that water is e.g. allocated to irrigation and basic human needs (community water supply). The "allocatable" groundwater balance will differ from the "actual" groundwater flow balance. In the absence of direct site information, conservative assumptions were made in the favour of the Reserve, for example riparian- and alien- vegetation surface areas that deplete groundwater until it can be proven otherwise.

In equilibrium, the recharge should be balanced by borehole abstraction, evapo-transpiration losses to the streams, springs, wetlands and groundwater base flow. The groundwater inflow components are recharge from rainfall and inflow from dam seepages.

The GYMR model process applied the following conservative approaches in this study:

1. Groundwater recharge was determined as a percentage of the lower 95th percentile of rainfall to cater for drought low flows.
2. The model simulated groundwater flow balances in which case storativity was assumed to be low.
3. The groundwater flow losses (evapotranspiration) were calculated by using a variable (2 to 3.5m) buffer width along both sides of the cumulative river lengths in each catchment.

The GYMR groundwater flow balance per quaternary catchment is shown in **Table 3.8**. The results are discussed in **Appendix A**.

Usable groundwater volumes were calculated for the different catchments based on two different percentages (40% and 80%) of baseflow required for the ecological requirement for the Reserve. This is indicated in **Table 3.9**.

Table 3.8: GYMR groundwater flow balance per quaternary catchment

Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)
Present Day - 95% Assurance - GA's Included										
T60E	198	885	709	6.03%	8.47	8.47	-3.40	-2.39	2.67	40%
T60F	463	940	753	6.63%	23.13	23.13	-7.20	-5.23	10.69	31%
T60G	359	1116	895	8.29%	26.65	26.65	-7.46	-6.35	12.84	28%
T60H	322	1277	1024	9.90%	32.59	32.62	-10.58	-5.37	16.67	32%
T60J	293	1101	882	8.23%	21.31	21.31	-5.32	-4.72	11.27	25%
T60K	242	1075	862	7.50%	15.64	15.64	-4.32	-4.93	6.39	28%
Total study area	1151	1114	893	8.25%	84.77	84.81	-24.32	-20.49	40.00	29%
Present Day - 95% Assurance - GA's Excluded										
Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)
T60E	198	885	709	6.03%	8.47	8.47	-2.51	-2.39	3.56	30%
T60F	463	940	753	6.63%	23.13	23.13	-5.12	-5.23	12.78	22%
T60G	359	1116	895	8.29%	26.65	26.65	-2.06	-6.35	18.23	8%
T60H	322	1277	1024	9.90%	32.59	32.62	-5.76	-5.37	21.49	18%
T60J	293	1101	882	8.23%	21.31	21.31	-3.12	-4.72	13.47	15%
T60K	242	1075	862	7.50%	15.64	15.64	-3.23	-4.93	7.48	21%
Total study area	1151	1114	893	8.25%	84.77	84.81	-13.55	-20.49	50.77	16%
2020 - 95% Assurance - GA's Excluded										
Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)
T60E	198	885	709	6.03%	8.47	8.47	-3.25	-2.39	2.82	38%
T60F	463	940	753	6.63%	23.13	23.13	-5.96	-5.23	11.94	26%
T60G	359	1116	895	8.29%	26.65	26.65	-2.21	-6.35	18.09	8%
T60H	322	1277	1024	9.90%	32.59	32.62	-7.88	-5.37	19.37	24%
T60J	293	1101	882	8.23%	21.31	21.31	-3.24	-4.72	13.35	15%
T60K	242	1075	862	7.50%	15.64	15.64	-3.36	-4.93	7.35	22%
Total study area	1151	1114	893	8.25%	84.77	84.81	-16.16	-20.49	48.17	19%

Table 3.9: Ecological requirement for the Reserve

Present Day - 95% Assurance - GA's Included														
Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)	Usable GW (l/s) Assuming 40% EWR	Usable GW (m3/d) Assuming 40% EWR	Usable GW (m3/d) Assuming 80% EWR	Proposed additional m3/d abstraction
T60E	198	885	709	6.03%	8.47	8.47	-3.40	-2.39	2.67	40%	50.8	4389.43	1463.14	0.00
T60F	463	940	753	6.63%	23.13	23.13	-7.20	-5.23	10.69	31%	203.5	17579.99	5860.00	549.50
T60G	359	1116	895	8.29%	26.65	26.65	-7.46	-6.35	12.84	28%	244.3	21106.53	7035.51	836.35
T60H	322	1277	1024	9.90%	32.59	32.62	-10.58	-5.37	16.67	32%	317.1	27399.16	9133.05	753.41
T60J	293	1101	882	8.23%	21.31	21.31	-5.32	-4.72	11.27	25%	214.4	18525.41	6175.14	1099.01
T60K	242	1075	862	7.50%	15.64	15.64	-4.32	-4.93	6.39	28%	121.6	10510.14	3503.38	0.00
Total study area	1151	1114	893	8.25%	84.77	84.81	-24.32	-20.49	40.00	29%	761.1	65759.88	21919.96	3238.27
Present Day - 95% Assurance - GA's Excluded														
Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)	Usable GW (l/s) Assuming 40% EWR	Usable GW (m3/d) Assuming 40% EWR	Usable GW (m3/d) Assuming 80% EWR	Proposed additional m3/d abstraction
T60E	198	885	709	6.03%	8.47	8.47	-2.51	-2.39	3.56	30%	67.7	5853.31	1951.10	0.00
T60F	463	940	753	6.63%	23.13	23.13	-5.12	-5.23	12.78	22%	243.1	21006.93	7002.31	549.50
T60G	359	1116	895	8.29%	26.65	26.65	-2.06	-6.35	18.23	8%	346.9	29969.59	9989.86	836.35
T60H	322	1277	1024	9.90%	32.59	32.62	-5.76	-5.37	21.49	18%	408.9	35329.77	11776.59	753.41
T60J	293	1101	882	8.23%	21.31	21.31	-3.12	-4.72	13.47	15%	256.3	22143.18	7381.06	1099.01
T60K	242	1075	862	7.50%	15.64	15.64	-3.23	-4.93	7.48	21%	142.4	12300.08	4100.03	0.00
Total study area	1151	1114	893	8.25%	84.77	84.81	-13.55	-20.49	50.77	16%	965.9	83452.70	27817.57	3238.27
2020 - 95% Assurance - GA's Excluded														
Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)	Usable GW (l/s) Assuming 40% EWR	Usable GW (m3/d) Assuming 40% EWR	Usable GW (m3/d) Assuming 80% EWR	Proposed additional m3/d abstraction
T60E	198	885	709	6.03%	8.47	8.47	-3.25	-2.39	2.82	38%	53.7	4636.93	1545.64	0.00
T60F	463	940	753	6.63%	23.13	23.13	-5.96	-5.23	11.94	26%	227.1	19620.75	6540.25	549.50
T60G	359	1116	895	8.29%	26.65	26.65	-2.21	-6.35	18.09	8%	344.2	29737.03	9912.34	836.35
T60H	322	1277	1024	9.90%	32.59	32.62	-7.88	-5.37	19.37	24%	368.5	31836.28	10612.09	753.41
T60J	293	1101	882	8.23%	21.31	21.31	-3.24	-4.72	13.35	15%	254.0	21945.61	7315.20	1099.01
T60K	242	1075	862	7.50%	15.64	15.64	-3.36	-4.93	7.35	22%	139.9	12084.77	4028.26	0.00
Total study area	1151	1114	893	8.25%	84.77	84.81	-16.16	-20.49	48.17	19%	916.4	79175.52	26391.84	3238.27

Working on a very conservative assumption of 80% of baseflow required for the Ecological Requirement of the Reserve, it can be seen in the last column of the table, that the proposed additional abstraction that was simulated in the groundwater model, is in general 10 times smaller than the usable groundwater volumes calculated during reserve determination. Preliminary water demand figures for the planning study area that have been reported in other modules of the study are approximately 9 000 m³/d for 2020. If this is compared to the 30 544 m³ that was calculated in the groundwater Reserve determination for 2020 (**Table 3.9**) it is clear that there is approximately 3 times the total project water requirement available from groundwater in the catchments in which the project area is located. The conclusion from the groundwater reserve determination exercise is therefore that there is enough groundwater available for usage in the Lusikisiki project area to meet the total project water demand without even having to rely on surface water should it be feasible.

3.4 GROUNDWATER FLOW BALANCE AND NUMERICAL MODELLING

The full report detailing the results of the groundwater flow balance and numerical modelling is given in **Appendix B** with the following summary given for the purpose of the main report.

3.4.1 Introduction

The groundwater flow model is constructed to assist in the decision making process during which the groundwater regime is impacted upon by an activity, in this case groundwater abstraction for water supply to the Lusikisiki project activities and schemes. The groundwater flow model is a simplification and numerical simulation of the real world system. The area delineated for the Lusikisiki groundwater flow model covers an area of 660.76 km^2. The modelled sub catchment within the larger project area was chosen due to physical boundaries such as drainages, watersheds, rivers and no flow boundaries as well as the positions of existing boreholes to be used and areas still to be explored in a groundwater supply capacity. Borehole and water level data used in the model is sourced from various data sets from SRK drilled boreholes, NGDB data, Grip data and geological maps. The amended data included historical and recently recorded hydrocensus data.

3.4.2 Model objectives

The aim of the groundwater flow model was to simulate the groundwater system to determine the groundwater flow balance, groundwater flow directions and sustainability of the local developed well fields as well as regional existing wells for water supply and the cumulative impact on the local environment, if any. The aim of this model was to gain an understanding of the groundwater flow dynamics and was used to:

- Evaluate the current state of the groundwater systems within the study area and to compare the steady state water balance to the GYMR model outcomes also done in this study.
- Estimate and evaluate proposed pumping rates taking into account temporal and spatial factors as well as transient long term abstraction of groundwater from the proposed region.
- Determine the radius of influence and impacts of well field pumping and dewatering on specified water users and the environment, and also to evaluate the impact of conceptual future groundwater abstraction points.

The aim is to simulate the groundwater flow dynamics in the context of the scale of the assessment. A conceptual model is done to illustrate the different aquifers and the effect of pumping on the regional groundwater level, but is however not a 100% accurate depiction of reality and is merely a simplification to understand the system. Based on the geological location of the project there are six geological units. The dolerite intrusions and sills that are scattered around the region are aquicludes which only allows recharge and groundwater flow through fractures and faults. The sandstones and weathered shale, mudstone and tillite sequences are identified as fractured aquifers holding water in storage in both pore spaces and fractures.

A two dimensional numerical groundwater flow model was developed for the sub catchment using the modelling package Feflow 5.4 (www.feflow.info). The groundwater model was developed using 216 568 elements and 109 095 nodes to generate a mesh that differentiates the model domain into a finite element mesh. The model was constructed with one layer, two dimensions.

3.4.3 Model summary

a) Conceptual model

- The main aquifers in the region are fractured rock aquifers with dolerite sills and dykes acting as aquicludes and groundwater flow boundaries throughout the modelled catchment.
- Recharge mainly occurs through rainfall seeping into the groundwater system with a minor amount occurring from streams and rivers.
- MAP is 1 103 mm/a for the modelled catchment with recharge being 8.2% of MAP
- Springs occur all over the modelled area at discharge points along elevated contacts.
- Abstraction from boreholes causes a radius of influence within the groundwater system which can affect neighbouring borehole abstraction volumes and sustainability.

b) Groundwater flow modelling

- The area delineated for the Lusikisiki groundwater flow model covers an area of 660.76 km^2
- The simulation of a groundwater flow model is to help the user and involved parties to manage the water resources of the region and to aid in decision making
- Objectives of the model is to:
  - Evaluate the current stat of the groundwater systems within the study area and to compare the steady state water balance to the GYMR model outcomes also done in this study.
  - Estimate and evaluate proposed pumping rates taking into account temporal and spatial factors as well as transient long term abstraction of groundwater from the proposed region.
  - Determine the radius of influence and impacts of well field pumping and dewatering on specified water users and the environment, and also to evaluate the impact of conceptual future groundwater abstraction points.
  - Generate a finite element mesh within the model boundaries and important modelling zones were chosen in the 2D framework.
  - Conservative assumptions based on aquifer tests, hydrocensus and historical data as well as analogue values from literature were used in the model.

3.4.4 Simulation of scenarios

Three scenarios were simulated:

- Scenario 1: Steady state present day water balance and flow conditions. This scenario was used to calibrate the flow model.
- Scenario 2: Transient state to evaluate and simulate impacts of proposed water supply from existing boreholes drilled by SRK.
- Scenario 3: Transient state to evaluate and simulate impacts of proposed water supply from both Scenario 2 boreholes and conceptual boreholes (sensitivity analysis on recharge values).

3.4.5 Model calibration and hydraulic zones

- Recharge and transmissivity values were used and adjusted accordingly to calibrate the model to a suitable level of correlation within a steady state simulation.
- The correlation between simulated heads and measured heads in 66 observation boreholes were used to calibrate the model to a level above R2 of 0.90.
- After correlation boreholes with abstraction rates were added to simulate the transient state scenarios.

3.4.6 Model conclusions and outcomes

- From the three scenarios, and sensitivity analysis, it is evident that enough water is available for abstraction from the SRK boreholes to supply water to the Lusikisiki water project.
- During dry periods, or droughts, the available water will be significantly smaller and can affect base flow and spring flow if abstraction is continued at the same rate as during normal periods of rainfall.
- Scenario 1 indicates a steady state simulation where inflow equals outflows with no abstraction influencing the available water to the groundwater system or evapotranspiration.
- The volume through recharge available in the model is less than that in the GYMR scenario.
- Scenario 2 shows the abstraction of groundwater from the SRK boreholes at the recommended sustainable rates.
- These rates are proven to be sustainable in the modelled environment over a period of 25 years with storage and recharge balancing the extra loss through abstraction.
- Scenario 3A and 3B shows the sensitivity of the groundwater system to a change in recharge.
- An average drop of 7.2 m is observed in all observation borehole water levels when a one in twenty year draught is simulated.

- Drawdown in the SRK and Conceptual boreholes pumped during Scenario 3 increases with an average of 5 m.
- Throughout all scenarios EWR was not taken into account and thus as more water is abstracted the lower the available water for EWR and will negatively affect the natural environment along riparian zones.
- The volumes simulated by the model are however well below that of the available groundwater volumes as indicated by the GYMR scenarios.
- With abstraction from SRK boreholes and conceptual boreholes a total daily volume of 3 081 m^3/d is needed.
- If the lower 95% assurance level is used to simulate a drought the available groundwater from the GYMR is 232 356 m^3/d, calculating 57% of this volume equates to 132 443 m^3/d available in the modelled catchment.

The following recommendations are proposed based on the groundwater flow model:

- Groundwater level monitoring is proposed to measure the effect of abstraction in both the SRK and monitoring boreholes, and to mitigate accordingly.
- An updated reserve and groundwater flow model should be conducted to evaluate the effectiveness of sustainable rates and recommendations made in this study every 2 years.

Abstraction rates of the water supply boreholes should be adjusted accordingly during dry periods.

3.5 GROUNDWATER COMMUNITY INTERDEPENDENCY SURVEY

The full report detailing the results of the Groundwater-Community Interdependency Survey is given in **Appendix C** with the following summary given for the purpose of the main report.

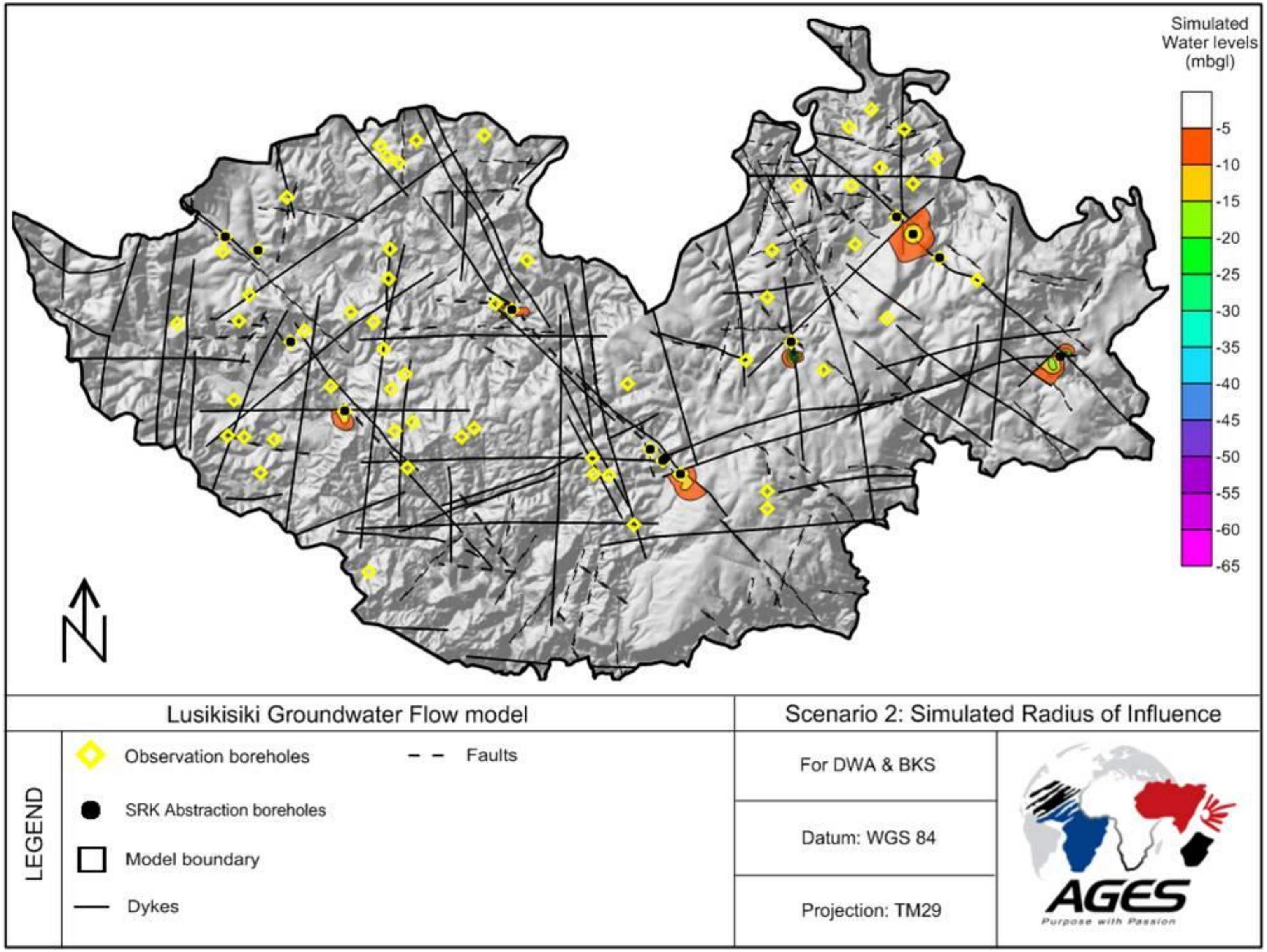

Figure 3.16: Lusikisiki Groundwater Flow Model – Scenario 2: Simulated radius of influence

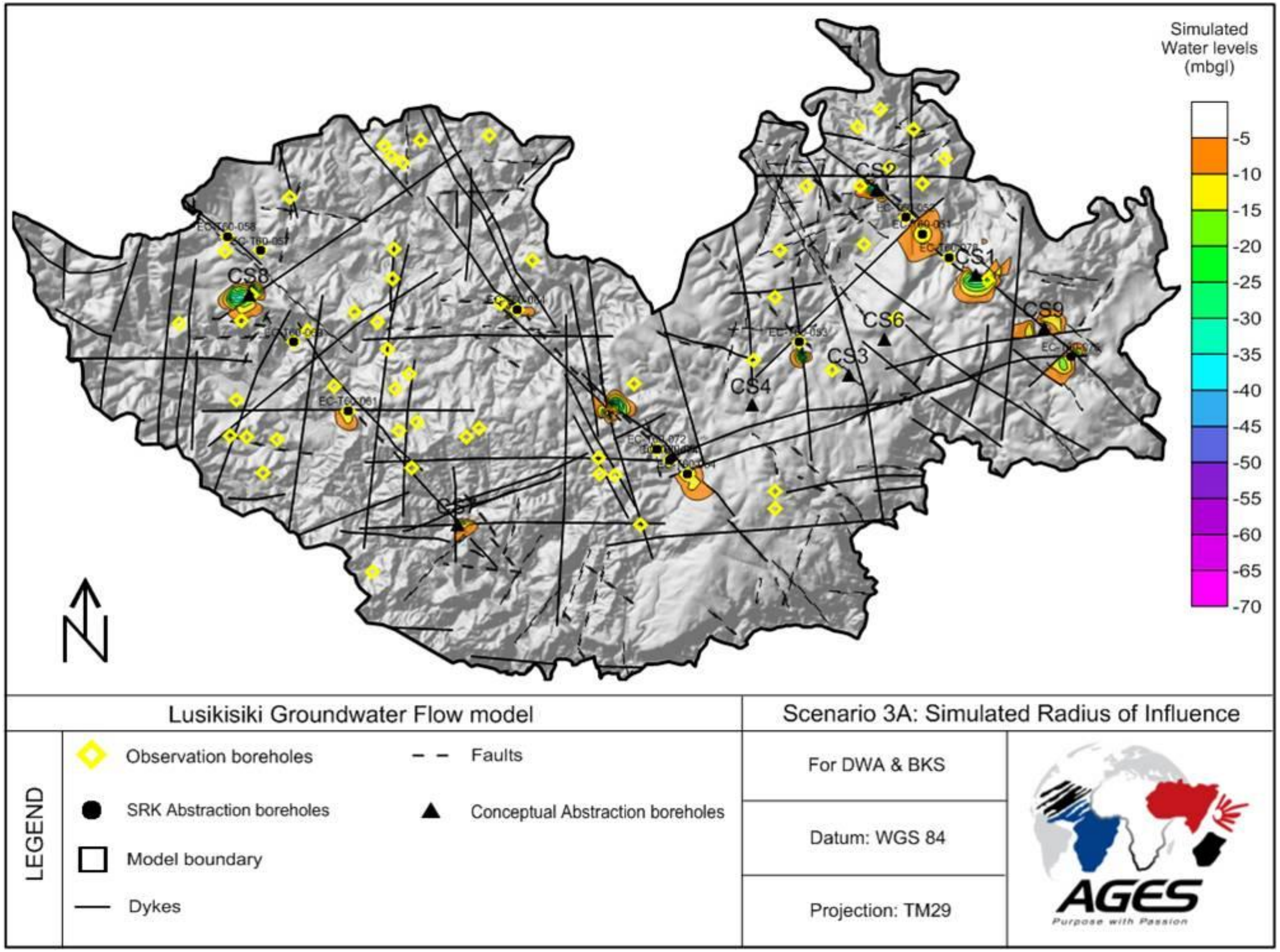

Figure 3.17: Lusikisiki Groundwater Flow Model – Scenario 3A: Simulated radius of influence

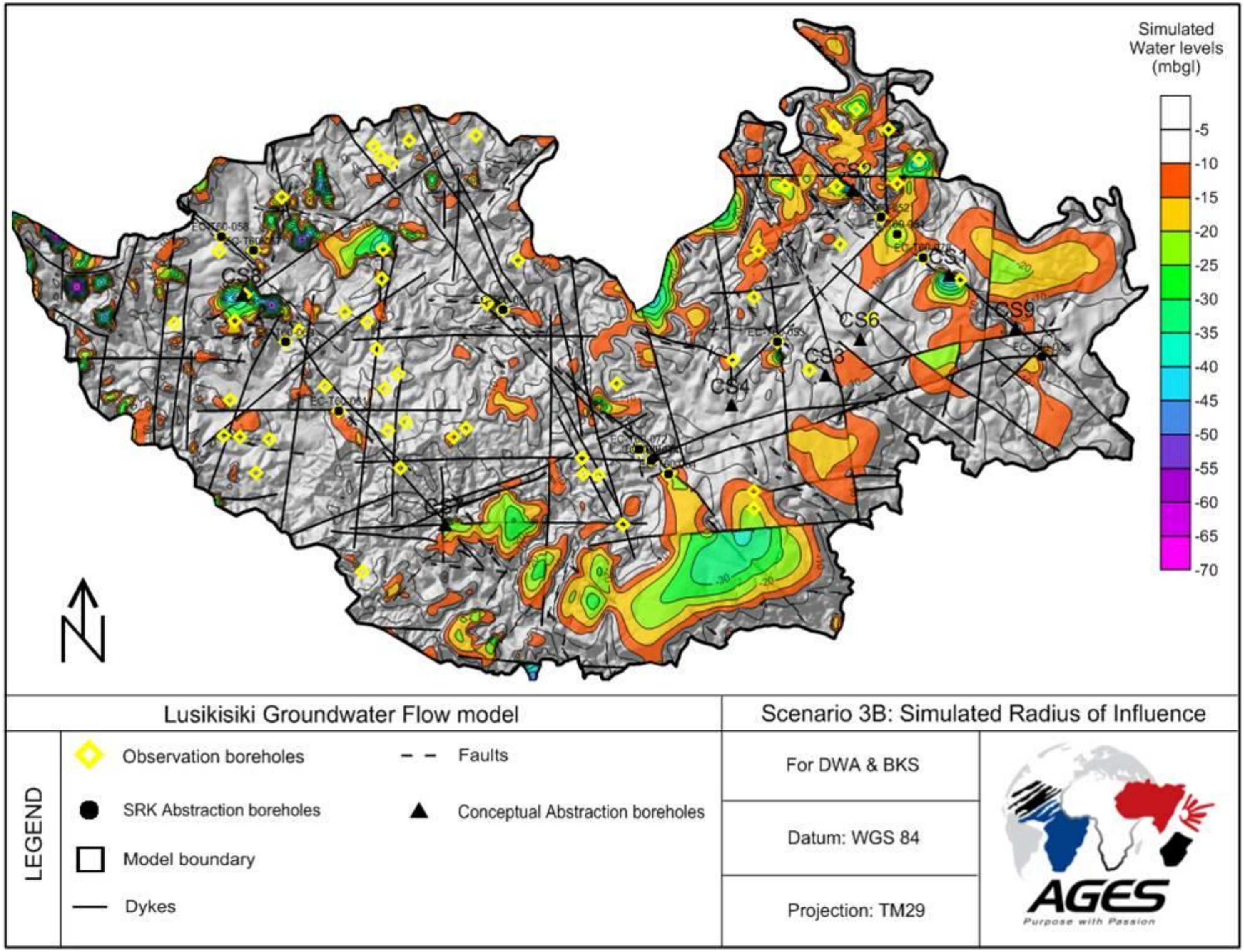

Figure 3.18: Lusikisiki Groundwater Flow Model – Scenario 3B: Simulated radius of influence

3.5.1 Introduction

The objectives of this study were to:

- Identify community dependencies and attitudes towards groundwater;
- Assess regional groundwater use and infrastructure statistic;
- Determine water source preference based on perceptions.

These factors aim to support the geohydrological study. In order to investigate these objectives, a desktop study was initiated and the questionnaire sheets from 360 participants in the Lusikisiki project area were analysed using statistical methods of analysis. In the survey analysis, three salient themes were identified namely: local groundwater knowledge, attitude towards groundwater, and source preference based on perceptions. The desktop study sourced and plotted regional groundwater use and infrastructure statistics.

AGES' Social Unit sought to explore the knowledge, attitudes and perceptions of community members, whom reside within the Lusikisiki Regional Water Supply project area, concerning surface and groundwater as a domestic water source. This was undertaken with the aim of discovering which factors might impinge on the sustainability of the Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme.

To address this water availability problem, the National Water Act (36 of 1998) proposes that water consultants adopt an approach that is strategic, deliberate and dictated by socio-political reforms and socio-economic development needs on a programmatic basis for long-term sustainability. To collaborate and support the National Water Act (36 of 1998) AGES conducted a ground- and surface water compatibility assessment of key areas in the larger project area to ensure that the development of water resources and systems be managed to achieve optimum long-term social and economic benefit for society from their use. The purpose of this report is to present the findings of this assessment and recommend future groundwater awareness enterprises.

The main objective of the groundwater—community interdependency study is to proactively determine the community members' attitude and their knowledge regarding surface and groundwater. Both these variables are of the essence towards ensuring the sustainability of the larger regional water supply project. Understanding those factors has implications for the development of sustainable ground- and surface water sources.

3.5.2 Groundwater usage

According to AGES database, there are 221 boreholes, 170 springs, 13 pans/dams, and 3 rivers/streams within the Lusikisiki groundwater feasibility study area. Of the 221 boreholes, 60 are in use, 37 are unused, 9 is destroyed and 115 are unknown. Of the boreholes in use, 17 are operational with a hand pump, 5 with mono-pumps, one has no equipment, three are submersible, 24 operate with a wind pump, and the statuses of 10 are unknown.

Three of the unutilised boreholes have hand pumps, one is equipped with a mono-pump, 12 have no equipment, one is submersible, two are wind pumps, and the statuses of 18 are unknown.

Of the boreholes destroyed, four have hand pumps, 3 no equipment, and two have wind pumps.

One hundred springs are in use and 70 statuses are unknown. None of the springs in use are equipped. Statistics however indicated that 10 springs abstract water from other measures unknown. All springs are in use by communities.

One pan/dam is in use; two unused and 10 are unknown. None of the dams have pumps or equipment. Data indicates that there are three rivers/streams in use but there are no pumps or equipment to extract water from the rivers/streams.

3.5.3 Groundwater community interdependency

The socio-economic survey recruited a small number (sample) of participants from the population (360). Participants were grouped in terms of their location within a predetermined area. Six areas were delineated as indicated in **Figure 3.19**. These six areas formed the focus of the community interdependency survey and are referred to as Zalu Dam, Lusikisiki, Network East, Network South, Remote South, and Remote West.

As indicated in **Figure 3.20**, the results predict that the Lusikisiki and Network East Region had the least groundwater knowledge while the Network South region had the most groundwater knowledge. The remaining three regions to the west and remote south had moderate groundwater knowledge.

In processing data relating to attitudes towards groundwater, it was noted that the Lusikisiki, Zalu Dam and Remote West Area have a more positive than negative attitude towards groundwater as a drinking water source, while it was noted that the Network East region has a negative attitude towards groundwater as drinking water source. The Network South and Remote South regions showed having a more negative than positive attitude towards groundwater as a source.

Six sub-themes constitute the main theme “Source preference based on perceptions”. This theme represents the respondents’ perceptions regarding various water sources. The six sub-themes covered quantity, quality, cost to develop, cost to maintain, sustainability and preference. Respondents had three options to rate namely, groundwater, springs or surface water. Each option had to be rated as Best/Highest, Medium and Worst/Lowest. **Figure 3.21** indicates in summary format, the mean source preference based on perceptions, per area.

Zalu Dam Region

The results indicate that 45% of respondents in the Zalu Dam area preferred borehole water, 39% prefer surface water and 16% are more in favour of spring water as a water source.

Remote West Region

The results indicate that 38% of respondents in the Remote West area prefers borehole water, 32% prefer surface water and 30% are more in favour of spring water as a water source.

Network South Region

Results indicates that 65% of respondents in the Network South area prefer borehole water, 20% prefer surface water and 15% are more in favour of spring water as a water source.

Lusikisiki Region

Results indicates that 42% of respondents in the Lusikisiki area prefer borehole water, 24% prefer surface water and 34% are more in favour of spring water as a water source.

Network East Region

Results indicates that 40% of respondents in the Network East area prefer borehole water, 30% prefer surface water and 30% are more in favour of spring water as a water source.

Remote South Region

Results indicate that 47% of respondents in the Remote West area prefer borehole water. 22% prefer surface water and 33% are more in favour of spring water as a water source.

In summary it can be concluded that in all regions covered by the survey, there is a preference towards groundwater and spring water as drinking water source. This is most probably due to the fact that communities have been relying on groundwater as a source through springs historically and possibly due to the existing surface water scheme not always meeting the full demand of the communities. The highest preference to surface water has been noted at the Zalu Dam site.

3.5.4 Recommendations

Based on the results of the groundwater community interdependency survey, the following are recommended by the technical team for incorporation during the implementation phase of the project:

1. The groundwater compatibility assessment team must be given the opportunity to present their findings in order to ensure that the engineering team incorporate the social trends that might influence the final design approach and layout.
2. Focussed groundwater awareness programmes must be carried out in the five distinct zones within the study area.

3. The afore mentioned zones are defined by clustering the following target areas as defined during the social survey:
   a. Target areas Lusikisiki and Network South: To be referenced as Awareness Zone 1 (AZ1)
   b. Target areas Remote West and Zalu Dam: To be referenced as Awareness Zone 2 (AZ2)
   c. Target area Remote South: To be referenced as Network East: Awareness Zone 3 (AZ3)
   d. Target area Network East: To be referenced as Network East: Awareness Zone 4 (AZ4)
4. The awareness programme in AZ1 should be extended to include the communities located directly east of the production boreholes drilled near the river. It is proposed to use the community and commercial centre in Lusikisiki as a central point for such an awareness workshop. This proposal should however first be discussed with local authorities and community leaders.
5. The awareness programme in AZ2 should be carried out in the direct vicinity of Zalu Dam.
6. Awareness creation workshops should have the following basic approach:
   a. Two hour workshop per zone.
   b. The focus will be on community leaders and role players that will be involved during the implementation phase as well as the O&M phase of the project.
   c. Emphasis will be placed on perceptions that were mapped out during the compatibility study which can negatively impact long term sustainable groundwater use.
7. Additional technical workshops should be scheduled during the implementation phase to address technical components in terms of long term pump operation and maintenance as well as the groundwater management and monitoring plan that have been planned for the project. This should be done with inputs from the engineering project management teams.
8. Cost estimates for the proposed meetings and workshops must be defined and finalised with inputs from the project management team to form part of the implementation stage of the project as soon as possible.

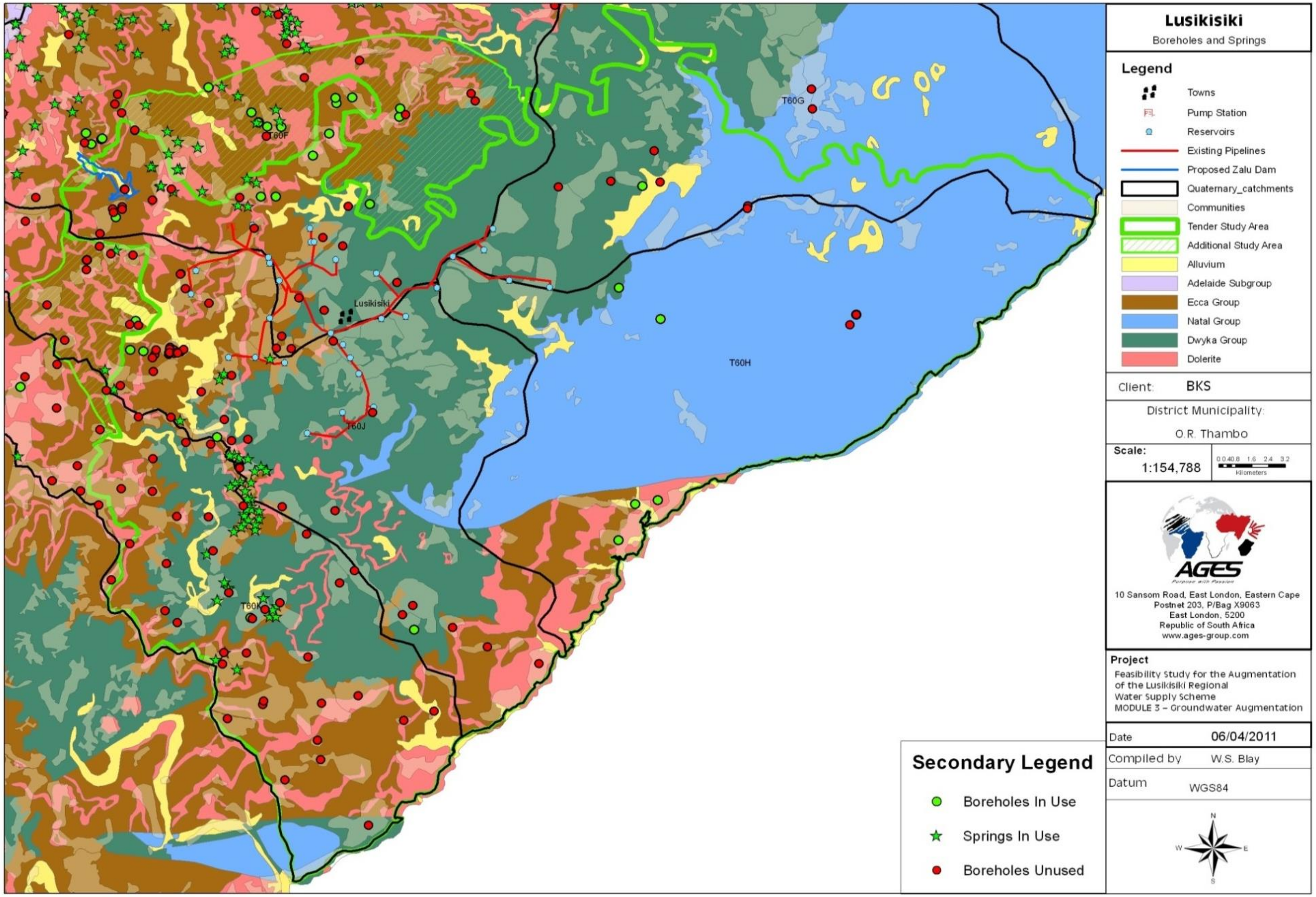

Figure 3.19: Boreholes and springs

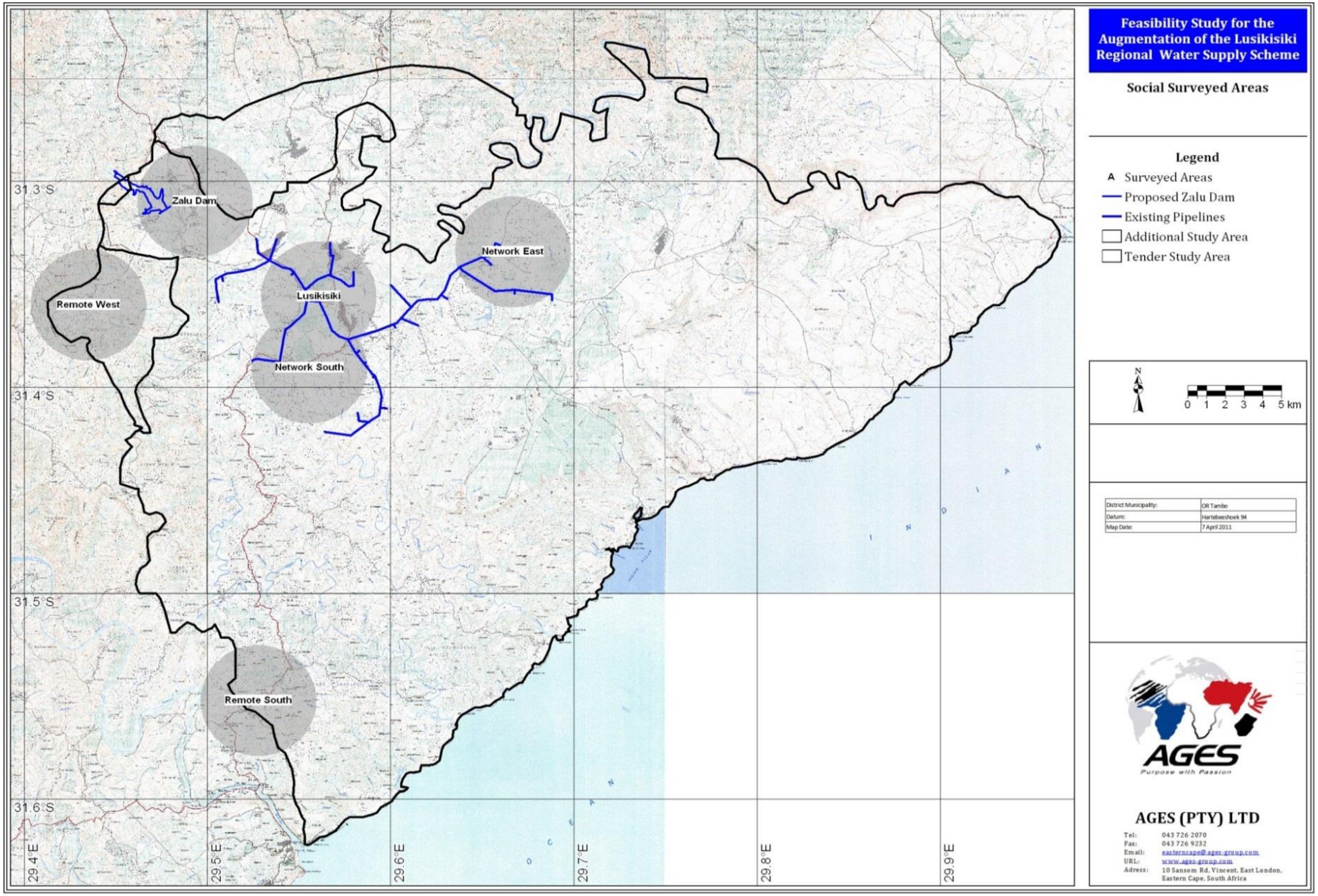

Figure 3.20: Social surveyed areas

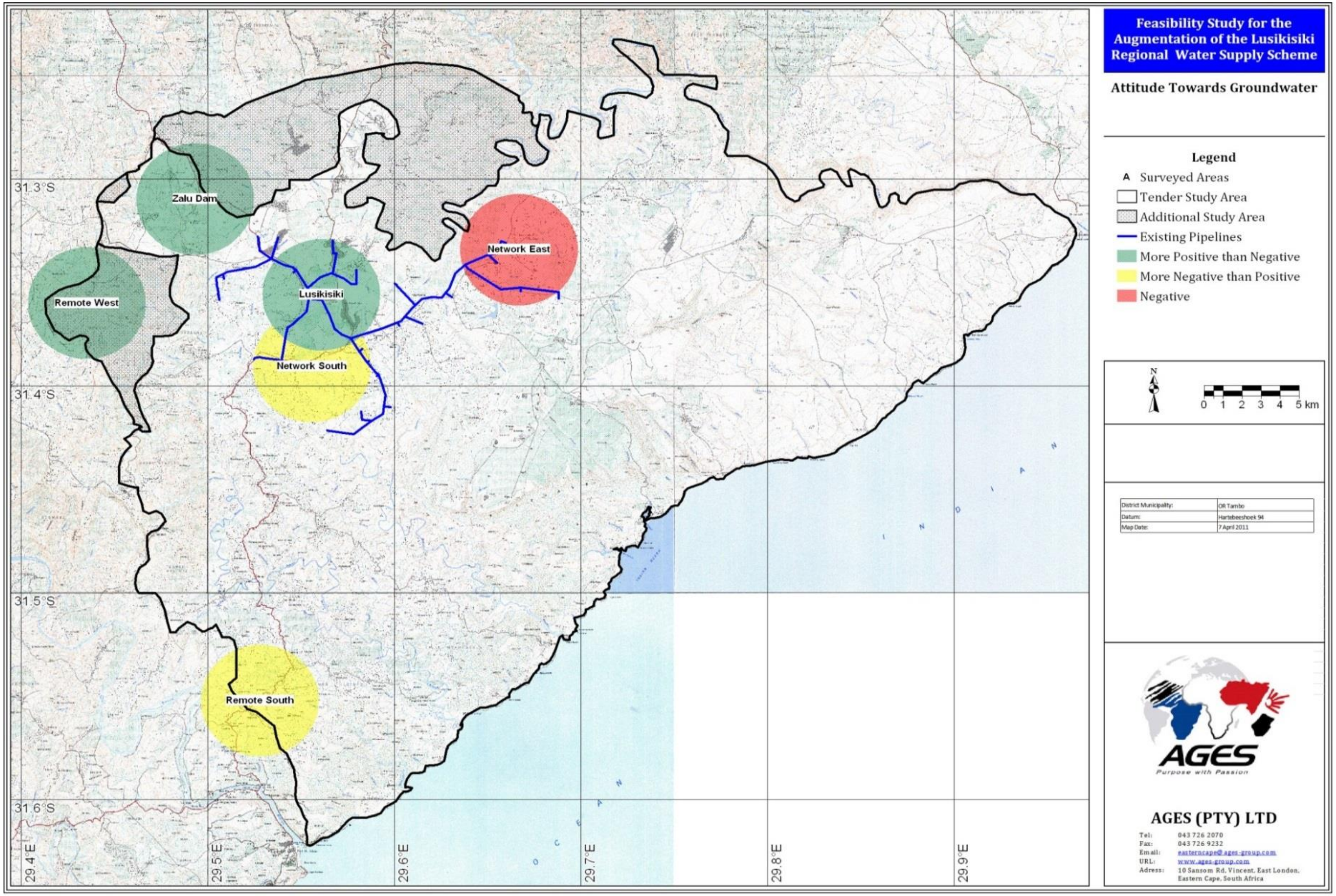

Figure 3.21: Attitude towards groundwater

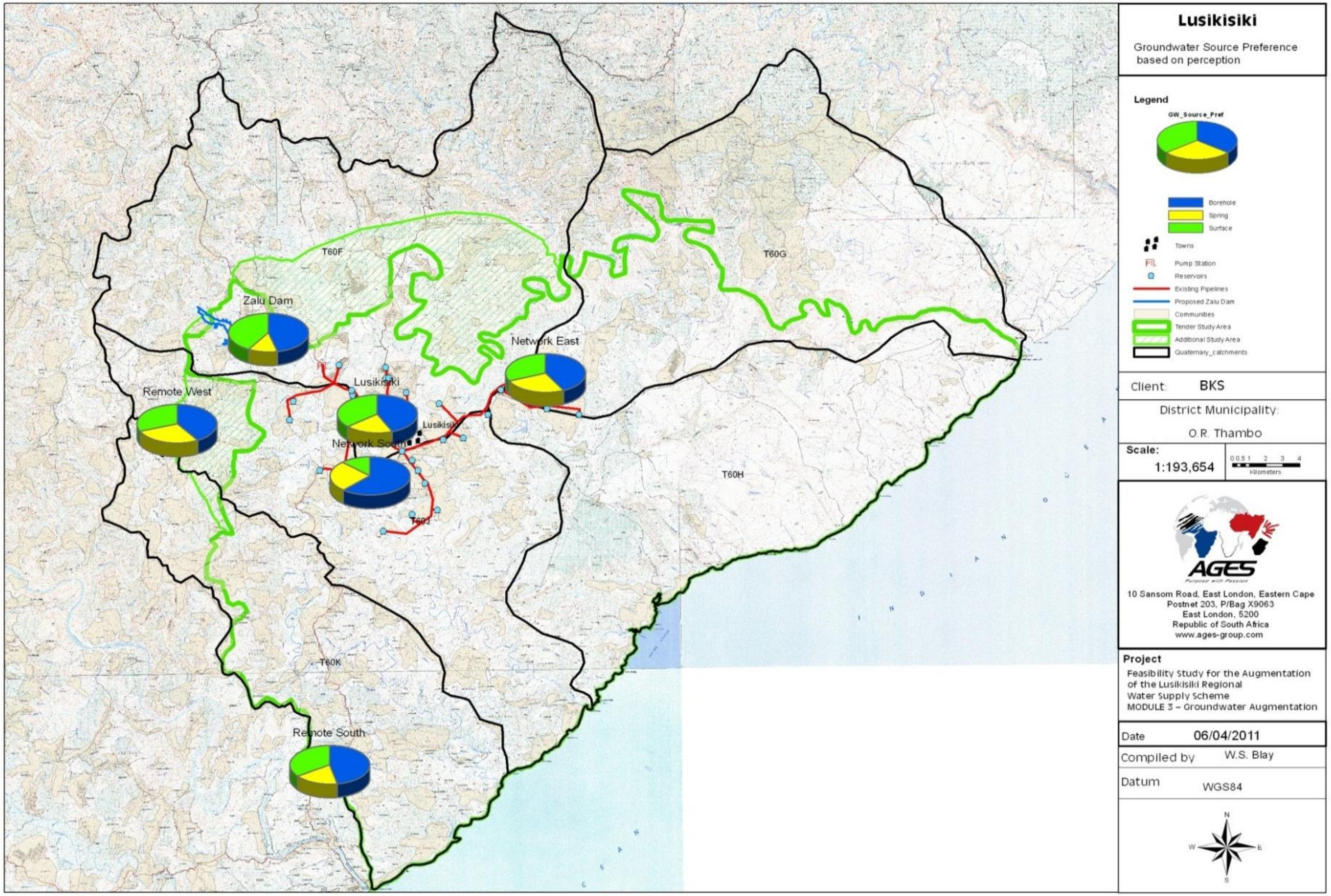

Figure 3.22: Groundwater source preference based on perception

3.6 Groundwater Awareness Creation

The full report detailing the results of the Groundwater Awareness programme is given in **Appendix D** with the following summary given for the purpose of the main report.

3.6.1 Introduction

The purpose of the water awareness initiative was to increase project sustainability through creating awareness around ground- and surface water, and, to stimulate sensitivity within participants concerning the importance of conserving water.

The water awareness initiatives were conducted in four wards (wards 20, 21, 22, and 23), which had previously been identified as having:

1. The least knowledge about groundwater, and
2. High negative perceptions and attitudes towards the use of groundwater as a water source. In a social survey conducted during phase 1 of the project (for more information, refer to AGES social report with reference no. 2011/03/14/SCL).

As part of the awareness initiative the following were performed:

1. Two awareness workshops were conducted to relevant prominent community members;
2. Three local schools were targeted (Mxhume High School; Maqulu Junior Secondary School; and Miqikela Senior Secondary School), and
3. The local radio station, Nkonjane Community Radio, gave AGES a slot to broadcast knowledge on ground- and surface water.

3.6.2 Awareness workshops

Four wards which had previously been identified as having the least groundwater knowledge and high negative perceptions of groundwater in the social survey conducted as part of Phase 1 of the project, were targeted as priority groups to receive the workshop. The selection criteria for participants were individuals who were socially active in their communities whether in sports initiatives, political activity or developmental projects. Basically, people who were highly likely to spread the new information they received at the end of the workshop. The newly elected ward councillors from Lusikisiki assisted greatly in this regard, also securing venues and local labour.

The workshops were well attended and received by the participants. The largest group was 50 participants from one ward only. The workshops were divided into two workshops, because of locality logistics of the participants. Therefore, wards 20, 21, and 22 were combined into one workshop. Ward 23 comprising of 8 large villages and the most isolated of the three wards, was given its own workshop day.

Three local schools were visited at Lusikisiki namely: Mxhume High School; Maqulu JSS and Mqikela Senior Secondary School. In each school, only the highest grade pupils in the school were prioritized to participate in the workshops. The total number of pupils interacted with in Lusikisiki was 148 pupils. This selection criterion was preferable because ideal workshop participants would be ones that share the knowledge they receive with others at large in their communities.

Fruit was distributed to all the students at all the schools visited who had attended the workshop as a token of good faith.

The local radio station, Nkonjane Community Radio, was approached and notified of the awareness effort that AGES was driving at in the local area. A slot to have the workshop broadcasted on air was secured for 22/07/2011. The slot about the workshop was aired was at 11:30 am and the response from the listeners was equally positive and engaging.

A number of ethical issues were raised by this ground- and surface water awareness initiative and were addressed as follows:

- Participation was voluntary.
- Information was given about the project with no distortion of detail.
- No harm, embarrassment, or offence was foreseen for the ground- and surface water awareness initiative although some of the discussions may have heightened participants' hopes of receiving piped water.

Care however was taken to explain to participants that this was only a ground- and surface water awareness initiative.

Research studies relating to the outcomes of workshops suggested that individuals can derive considerable psycho-educational benefit and demonstrate improved psychosocial functioning as a result of the workshop. However this does not mean that all workshops will necessarily achieved their defined objectives. In order to be accountable, therefore, it is desirable to take specific action to evaluate the outcome of the workshop.

Continuous assessment techniques were employed to evaluate the water awareness workshops presented by AGES. Continuous assessment relies predominantly on informal data gathering. Data collected reflected on participant's individual behaviour, cognition and emotions, and the influence of the group experience on the individual.

Participants seemed to find a lot of enjoyment out of the activities that were used to bring across points during the workshop. Participants seemed excited and laughed a lot during the workshop. Participants also seemed interested in what was being said and from their questions they posed it became quite evident that the content of the workshop was relevant.

At the end of each workshop, participants were given a sheet of paper in which they were asked to anonymously rate the workshop. 100% of attendees rated the workshop positively.

3.7 Optimisation of Groundwater Abstraction Network

The full report detailing the results of the Optimisation study is given in **Appendix E** with the following summary given for the purpose of the main report

3.7.1 Background

As part of the Module 3`s scope of work, AGES has done a comprehensive groundwater reserve determination on the quaternary catchments covering the extended project area as indicated. Details and results of this component of the study are reported in **Appendix A** of the Groundwater Report. Usable groundwater volumes were accurately defined per quaternary catchment from this study, based on high assurance levels.

A detailed groundwater flow model was then done for a delineated part of the project area, which evaluated the optimum number and localities of production boreholes within this regional well-field area (RWA). For this purpose, the uses of Feasibility Study boreholes, as well as several additional Conceptual Boreholes, were simulated to evaluate the impacts of long term abstraction. The location and distribution of these boreholes were defined within the regional hydrogeological model area (RWA) that was delineated based on an amended combination of Groundwater Resource Units identified during the initially conducted feasibility study of SRK.

The purpose of this component of the study is to report yields and positions of future production boreholes within the RWA. This will comprise conceptual boreholes as well as existing boreholes already drilled by SRK during feasibility studies. Final amended recommendations for abstraction rates of SRK boreholes are given since the model has indicated that some of these boreholes are too close to each other and will have to be utilised at reduced rates to minimise the influence between neighbouring boreholes.

Based on groundwater quality, specifically elevated iron concentrations, it will be important for groundwater from the regional well field to be blended with surface water as far as possible. The engineering team also need to look at optimum pipeline routes and lengths to decide which feasibility study and conceptual boreholes will be used in the end. Surface water quality need to be evaluated against groundwater quality to determine if suitable blending ratios can be achieved while still meeting the water demand. Treatment options must be found for the possible oxidation and precipitation of high-iron content water.

Communities that fall outside of the RWA need to be supplied by stand-alone schemes. These schemes will either supply single communities, or small clusters of communities, depending on local groundwater conditions. Water sources will involve springs as well as new boreholes that need to be developed. Detail regarding the clustering of these stand-alone communities, as well as a table summarising costs to develop groundwater sources for all these clusters and communities are given. Refer to **Appendix E**.

The design team will have to look at areas that cannot practically and affordably be reached by the bulk water supply pipeline infrastructure (from blended surface + groundwater), and should this implicate that there are additional communities that need to be served by stand-alone schemes than the ones listed in the table mentioned above, AGES should look at development potential and costs for this to be included in the cost tables for stand-alone schemes.

3.7.2 Groundwater Reserve determination outcomes

Usable groundwater volumes were calculated for the different catchments based on two different percentages (40% and 80%) of baseflow required for the Ecological Requirement for the Reserve.

Working on a very conservative assumption of 80% of baseflow required for the Ecological Requirement of the Reserve, it was observed that the proposed additional abstraction, which was simulated in the groundwater model, is in general 10 times smaller than the usable groundwater volumes calculated during reserve determination.

Preliminary water demand figures for the planning study area that have been reported in other modules of the study are approximately 9 000 m^3/d for 2020. If this is compared to the 30 544 m^3 that was calculated in the groundwater reserve determination for 2020, it is clear that there is approximately 3 times the total project water requirement available from groundwater in the catchments, in which the project area is located. The conclusion from the groundwater reserve determination exercise is therefore that there is enough groundwater available to supply the domestic demands in the Lusikisiki project area to meet the total project water demand without even having to rely on surface water should it be feasible.

Based on the known average abstraction rate that can be expected from a production borehole in the study area, it is determined however that it will not be feasible to abstract this total available groundwater volume from boreholes, as it would imply too many pump stations with associated high operation and maintenance costs. For this purpose, a numerical groundwater model was compiled to determine the optimum number and distribution of boreholes that can be developed within a Regional Well-field Area (RWA) without negatively impacting groundwater dependant springs and associated wetlands in this area.

3.7.3 Groundwater modelling outcomes

Abstraction at all 14 feasibility study boreholes that occur in the RWA, as well as the 9 conceptual boreholes were simulated. Based on one simulation it became apparent that groundwater level drawdowns at production boreholes may affect springs and wetlands if pumped under lower 95% assured recharge conditions, amendments were made to abstraction rates of feasibility study boreholes as well as conceptual boreholes.

The final recommendation is for only 9 Feasibility Study boreholes to be equipped and for an additional 8 conceptual boreholes to be drilled and equipped to finally abstract 2 553 m^3/d from the Regional Well-field Area. This is therefore the total volume of groundwater that is available for augmentation to the surface water scheme from the RWA and relates to 28% of the projected 2020 water demand of the Planning study area as reported in the Domestic Water Requirement Report.

3.7.4 Stand-alone schemes

Numerous communities fall outside of the RWA. These communities need to be supplied by stand-alone schemes. These schemes will either serve single communities or small clusters of communities depending on local groundwater conditions. Water sources will involve springs as well as new boreholes that need to be developed. Detail regarding the clustering of these stand-alone communities, as well as cost summaries to develop groundwater sources for all these clusters and communities, are given in **Appendix E**.

Several zones of higher groundwater potential were delineated outside the RWA, as indicated in **Figure 3-23**. These zones were used to cluster individual communities together where possible to minimise the number of stand-alone schemes. Six such clusters could be identified.

3.7.5 Cost estimates based on integrated approach

Appendix E indicates cost for the groundwater source development component of clustered stand-alone schemes as well as individual stand-alone schemes. These costs exclude infrastructure and engineering design costs. Costs are indicated for the groundwater source development component of developing the additional conceptual boreholes that were simulated and optimised in the numerical groundwater model.

The following summary is given for planning and budgeting purposes (excluding VAT):

- Conceptual borehole development cost - R 3 388 000
- Cluster stand-alone scheme source development cost - R 6 674 800
- Individual stand-alone scheme source development cost - R 37 218 800
- It is recommended that these cost scenarios be re-visited once the optimum balance between groundwater and surface water volumes have been defined based on the most cost-effective infrastructure layouts.
- **Figure 3.23** should be used as a planning tool to determine the optimum lay-out of pumping and pipeline infrastructure required to utilise the 9 feasibility study and 8

conceptual boreholes. It should be aimed for the supply from these 17 boreholes to be fed into the bulk surface water scheme to allow effective blending to decrease elevated iron concentrations that are noted in some boreholes.

- Integration with the surface water infrastructure planning team will determine the final lay-out of well fields versus stand-alone schemes to find the optimum balance that will result in the most cost effective approach in terms of capital expenditure as well as long term operation and maintenance costs.

3.8 HYDROCENSUS AND SPRING CHARACTERISATION

The full report detailing the results of the Hydrocensus and Spring Characterisation study is given in **Appendix F** with the following summary given for the purpose of the main report.

3.8.1 Background

AGES was appointed on the DWA Term Tender W0202WTE to carry out a hydrocensus at 62 communities that were not covered during the previous feasibility studies in order to determine the number of existing springs and boreholes. It further aimed to characterise springs and seeps towards optimisation of the groundwater yield model a numerical model as reported in **Appendices A** and **B**.

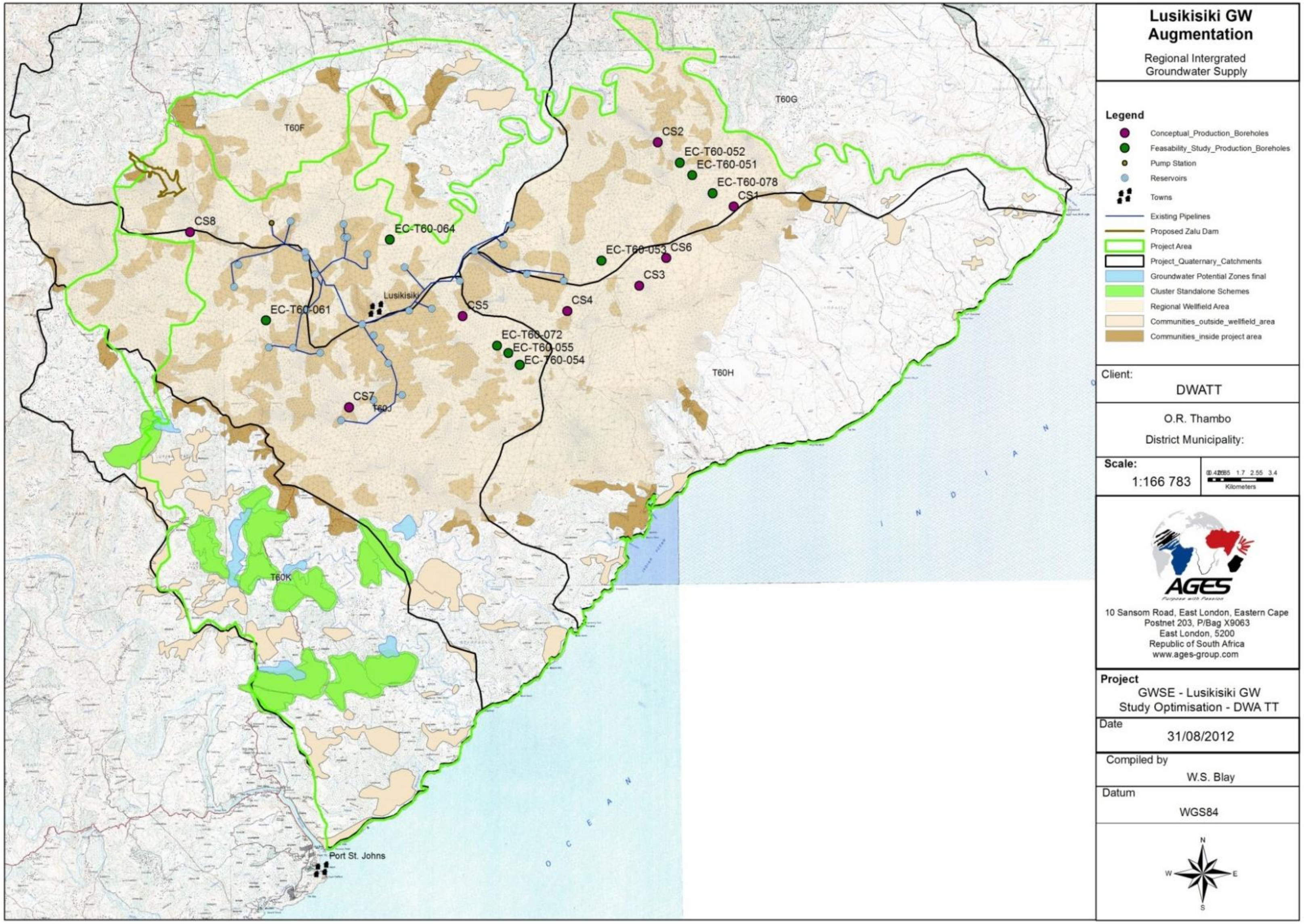

Figure 3.23: Regional integrated groundwater supply

3.8.2 Results

A total of 4 boreholes and 89 springs and seeps were identified during the survey.

The majority of springs 34% are located in the Dwyka formation followed by 33% in the Ecca formation. Pollution sources do occur in close proximity to springs and seeps although 72% of springs are expected to have a low chance of being polluted. In the project area there is a general absence, 89% of springs, in the protection/fencing of springs that can result in the source being polluted or damaged by animals to an extent where it can no longer be equipped for production purposes.

Springs are more abundant in the Lower Karoo GRU/GMU in comparison to the Msikaba River GRU/GMU which has more high yielding springs than low yielding springs.

Sampling was conducted at every fourth village in order to obtain representative values for the water chemistry in the study area. 40% of samples that were taken were classified as DWAF Class 2 (marginal water quality) due to moderate concentrations of chloride 228 mg/ℓ, Iron concentrations from 0.75 to 0.92 mg/ℓ, a fluoride concentration of 1.06 mg/ℓ and turbidity units ranging from 1.4 to 3.3 NTU. The water from two of the samples was classified as DWAF Class 3 Poor water quality due to turbidity units of 23.3 and 40.7 NTU.

"Springs are normally located down in the lower valleys of incised rivers or at places where a shallow water table cuts the topography. Springs are perennial and especially in the study area due to the high MAP and very little groundwater use. Seeps are typically the discharge of infiltrated rainwater from the vadose zone or perched aquifer, where the infiltrated rainwater has not yet reached the water table or saturated aquifer" (Woodford, 2001).

There is a definite difference in groundwater characteristics as indicated on a piper diagram, groundwater from the Ecca formation, NGS and Dwyka formation is of the sodium-bicarbonate (Na-HCO3) type of water that is typical of deeper fresh groundwater that has undergone ion exchange. The groundwater from the NGS and the Dwyka formation tends to be more calcium-sulphate (Ca-SO4) that is typical of gypsum groundwaters and mine drainage.

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Appendix A

Groundwater Yield Model for Reserve Determination

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A1 INTRODUCTION

Groundwater Yield Model(s) for the Reserve (GYMR) were done on quaternary catchments T60E, T60F, T60G, T60H, T60J and T60K as well as for the entire study area to get some idea of the groundwater volumes involved for the study area as a whole. During the calculation of the Groundwater flow balance and GYMR, the assumption was made that all water necessary for the various water uses in a quaternary catchment, should come from groundwater to (1) determine if groundwater can sustain all the necessary water uses and (2) determine how much groundwater is left thereafter and would it be possible to use groundwater, given the BHN and EWR Reserve needs. Another assumption made is that some of the water inflow and outflow figures obtained during the Eastern Pondoland Basin Study (2001) for 2010, are acceptable estimates for the Present Day GYMR scenarios. In the absence of real observed data, they are the best available figures. Where these figures have been used it has been designated in the Inflows and Outflows section.

In determining many of the water inflows and outflows as well as water levels for the study area, quaternary catchment surface area was used and a spatial weighted average applied to calculate the percentage surface area contribution to the total study area. These percentages were then used to quantify recharge and water levels for the study area for instance.

A2 INFLOW AND OUTFLOW COMPONENTS OF THE GROUNDWATER YIELD MODEL FOR THE RESERVE

A2.1 RAINFALL

Rainfall for the quaternary catchments was calculated based on the WR2005 MAP figures and the Rainzones as defined for the WR90 and WR2005 data sets. The rainzone approach presupposes that all quaternary catchments within a given rainzone, have exactly the same ratio of rainfall distribution throughout a hydrological year. Percentages of MAP is provided in a rainfile and the WR2005 MAP figure of each quaternary catchment multiplied by the rainfile monthly percentages of MAP for the available data set which was from January 1921 to the end of December 2005. All quaternary catchments fall within the same rainzone, T6B.

The MAP was calculated for each year of this 84 year rainfall dataset for each quaternary catchment. The 95% assured, total annual precipitation could be calculated and the figures are summarised in **Table A2-1**.

Table A2- 1: Summary of rainfall data per quaternary catchment

Quaternary catchment	Rainzone/ Rainfile	Dataset period	WR2005 MAP (mm)	95% assured total annual rainfall (mm)	Difference: MAP & 95% assured rainfall
T60E	T6B	1921 - 2005	885	709	176
T60F	T6B	1921 - 2005	940	753	187
T60G	T6B	1921 - 2005	1116	895	221
T60H	T6B	1921 - 2005	1277	1024	253
T60J	T6B	1921 - 2005	1101	882	219
T60K	T6B	1921 - 2005	1075	862	213

In the cases of T60G, T60H, T60J and T60K there is double the difference between MAP and 95% assured annual rainfall when compared with T60E and T60F. For the former mentioned catchments the larger difference is thought to be the effect of proximity to ocean vs. the more inland located catchments T60E and T60F.

A2.2 GROUNDWATER RECHARGE

The percentage of recharge to groundwater from rainfall is one of the most important parameters in the calculation of a minimum groundwater flow balance. Given the total volumes of water that falls annually within the borders of a quaternary catchment, this parameter is highly sensitive in the balance and it is then important to calculate and choose this parameter correctly.

The two main groundwater studies that were performed for the study area, namely the Eastern Pondoland Basin Study (EPBS) (2001) and the SRK Groundwater feasibility study (2006; 2009) various methods of groundwater recharge estimation have been used providing a range of different results. The SRK study estimated a mean recharge percentage for the area of 12.9% based upon the work of Schulze (1999) as well as some methods of Woodford (2001). The 12.9% obtained by SRK is considered to be a too high recharge estimate and this recharge cannot be justified by the chloride method, volume of baseflow where it can be calculated, nor spring seepage. During the Groundwater Resources module of the Eastern Pondoland Basin Study (EPBS), Woodford (2001) provided a number of estimates based on different generally accepted assumptions. This work and recharge figures was reviewed and finally an agreement with Woodford's (2001) work was reached in the "Lower Annual Recharge Variable" probably being the best recharge estimate. It is based upon a variable recharge rate calculated with formula, Re (%) = MAP (mm)/1 000 and the Schulze (1999) 1x1' grid of mean annual precipitation (mm). The mean variable recharge percentage calculated for all quaternary catchments concerned is in the region of 7.8%

The overall chloride method results from SRK water qualities also tend to support this estimate, with the chloride method results providing an even lower estimate of around 3.2%. The SRK chloride concentrations from the water quality sampling are however biased by some boreholes being in very impermeable formations. For this reason included in the AGES spring hydrocensus, was sampling of springs, not seepages, which can be regarded as good sources of accurate groundwater chloride concentrations or isotopes. Finally the numerical groundwater flow model this investigation provided one of the most accurate estimates of recharge for the study area.

A2.3 ASSURANCE LEVELS

The rainfall figures in the section above show the deviation between the lower 95th percentile (95% level of assurance) and the MAP for the quaternary catchments involved. The MAP does not account for dry periods and is markedly higher than the 95% level of assurance rainfall.

Using the available data from the rainfall records the lower 95th percentile was determined directly for the T60E, T60F, T60G, T60H, T60J and T60K quaternary catchments. The deviation of the lower 95th percentile from the average indicates on the severity of droughts. The more constant the rainfall, the closer the lower 95th percentile is to the MAP (AGES, 2010). A negligible difference (small difference between MAP and 95th percentile) would have been an ideal rainfall-recharge scenario in terms of aquifer sustainability. The lower 95th percentile, based on the WR2005 rainfall data, is 20% less than the MAP.

A2.4 WATER LEVELS

The GRIP and NGDB borehole databases were used to determine groundwater levels for the quaternary catchment and study area. Only borehole water levels were used, although springs and seeps also represent groundwater levels. This was done to not introduce large bias to the dataset, as there are many springs and seeps in the study area, used as sources by the community and normally picked up during a hydrocensus. Mountainous landscapes and areas where there are no boreholes usually have deep groundwater levels, but these will groundwater levels are not represented in the water levels dataset. Thus mean groundwater levels would be much shallower if springs and seeps were included. By using boreholes, there is still some well field bias, but much less than there would be if springs were included.

The mean water level in the study area is calculated at 10.1 mbgl. Basic water level statistics from boreholes can be viewed in **Table A2-2**. Shallow water level results from saturated aquifer conditions and very little groundwater abstraction. Numerous springs and seeps are also a testament of the saturated groundwater conditions. Water level data in the study area is very sparse and it would be good if some additional water levels could be obtained for a good water level distribution across the study area for modelling. Also, no groundwater monitoring of water levels in the study area is currently being conducted. Monthly groundwater levels are also for instance required in order to apply the EARTH method for recharge estimation.

Table A2- 2: Existing borehole water levels per quaternary catchment

Statistic	T60E	T60F	T60G	T60H	T60J	T60K	Study area
No. of water level boreholes (n)	11	35	3	5	10	3	-
Min static water level (mbgl)	0	0.1	4	2.4	2	3	2.2
Max static water level (mbgl)	27	42.7	12	14.5	26.9	9	21.5
Mean static water level (mbgl)	9.2	13.6	8.3	7.4	14.3	6	10.1

From the data reviewed it appears that there are no DWA monitoring boreholes in the study area. A recommendation is made that some groundwater level monitoring should be conducted at hydrogeologically chosen borehole locations. Perennial springs provide an automatic check in various places in the study area.

A2.5 DAM SEEPAGE

Surface area of the dams in the study area per quaternary catchment was used to calculate the dam seepage to groundwater. The WR2005 dataset was reviewed and finally the dam surface areas, measured during a detailed investigation for the EPBS (2001), were used. These results can be viewed in the detail in the GYMR tables in the Groundwater Reserve Scenarios for Lusikisiki RWSS section.

A2.6 GENERAL AUTHORISATION

General Authorisations (GA's) volumes as determined by DWA were used to calculate the total GA volume required per quaternary catchment if they were to be subtracted from available groundwater before other groundwater allocations to groundwater uses are made. These General Authorisation volumes were subtracted for the Present Day 95% assured groundwater GYMR and the results are shown in the Groundwater Reserve Scenarios Section.

A2.7 EXISTING ABSTRACTION BOREHOLES

The GRIP and NGDB existing borehole databases were used in determining existing abstraction volumes per quaternary catchment. Abstraction volumes were assigned based on site status and installation type specifications in the borehole databases. The results and number of abstraction boreholes can be viewed in the Groundwater Reserve Scenarios Section.

A2.8 SRK Boreholes in use and to be used

New boreholes drilled during the SRK groundwater feasibility study (2006; 2009) were used in calculating a groundwater use (outflow) volume for both the Present Day- and Future 2020 GYMR scenarios. After some telephonic and electronic correspondence with Mr W. Ketteringham (pers. comm.,) from UWP, who managed and conducted the Eastern Pondoland Basin Study (2001), it was determined that 3 of the newly drilled SRK boreholes are already in use or are equipped for use. These boreholes are EC-T60-052, EC-T60-054 and EC-T60-055 at 0.67 ℓ/s, 1.73 ℓ/s and 0.46 ℓ/s respectively, based on a 24 hour duty cycle. These boreholes were thus included as sinks in the Present Day GYMR scenarios. For the Future 2020 95% assurance of supply GYMR scenario, all SRK boreholes recommended for use by SRK were included as sinks (groundwater outflows), at their given sustainable yield rates per quaternary catchment as the boreholes are spatially located. These abstraction volumes can be reviewed in the GYMR table(s) in the Groundwater Reserve Scenarios Section.

A2.9 Livestock

There is livestock subsistence farming in the Lusikisiki study area by the various communities and the livestock and cattle get their water predominantly from springs and rivers. Allocations for this use have been made in the GYMR as detailed in the Groundwater Reserve Scenarios Section Springs are already accounted for as drains in the GYMR.

A2.10 Mining

No additional water use for mining activities is recognised in the study area.

A2.11 Basic Human Needs (BHN) Reserve and Community Groundwater Usage

This figure is conservatively calculated as the water demand for communities in the study area, based on typical water use volumes per person per day given their type of residence and based on estimates of the population per quaternary catchment. The assumed water use per person per day given their type of residence, as used for planning of the Lusikisiki RWSS during this Feasibility study, is given in **Table A2-3**. The population figure estimates per quaternary catchment used in both the Present Day and Future 2020 GYMR scenarios were obtained from the Eastern Pondoland Basin Study (2001).

For the study area, the SRK 2009 estimate for rural and urban population was used and a population growth rate of 0.82%/a for rural and 2.5%/ year for urban population applied. This final population growth estimates were then used in the 2020 GYMR community/ BHN estimates.

Table A2- 3: Community water use figures (2020) based on residence type connection

Catchment	Rural Population	Rural water use per capita/ day	Rural water use (m^3/a)	Urban Population	Urban water use per capita/ day	Urban water use (m^3/a)	Total water use (m^3/a)
T60E	39016	60	854,450	27878	150	1526321	2,380,771
T60F	97187	60	2,128,395	23339	150	1277810	3,406,206
T60G	65808	60	1,441,195	0	150	0	1,441,195
T60H	12149	60	266,063	0	150	0	266,063
T60J	51324	60	1,123,996	0	150	0	1,123,996
T60K	58493	60	1,280,997	0	150	0	1,280,997
Study Area	117022	60	2,562,782	17099	150	936176	3,498,958

A2.12 FARM IRRIGATION WATER USE

As mentioned, an assumption is made that all water necessary for the various water uses in a quaternary catchment, should come from groundwater to (1) see if all water necessary can come from groundwater and (2) how much groundwater is left thereafter and would it be possible to use groundwater, given the BHN and EWR Reserve needs.

A2.13 FORESTRY

Forestry water use figures for the Present Day and 2020 GYMR scenario were obtained from the EPBS (2010).

A2.14 WETLANDS

During the AGES spring hydrocenus, springs associated wetland sizes were estimated and the field estimates verified and confirmed by digitising wetland zones based on vegetation changes. The number of springs calculated per quaternary catchment, were then used in conjunction with the geometric mean surface area of a single spring wetland, to estimate the total wetland area per quaternary catchment. A wetland groundwater use volume was determined and the wetland water use per quaternary catchment calculated.

A2.15 SPRINGS

There are many springs and seeps (non-perennial) within the study are and they are still the most used and preferred source of water for many communities. There are many more springs in the study area when compared with boreholes. The springs are however often not protected and many times cattle can be destructive to the 'eye' of the spring. For this reason spring protection measures should be of great priority during the development of water supply in remote parts of the study area.

The number of springs per quaternary catchment was calculated by using the existing GRIP and NGDB geosite databases as a first step. Secondly due to the importance of springs in certain areas of the study area, such as the southwest portion, approximately where T60K is situated, AGES conducted specifically a spring hydrocensus. From the GRIP, NGDB and AGES springs, the number of springs per quaternary catchment was calculated as well as determining the ratio of springs to seeps. AGES during the hydrocensus also measured and estimated spring flows. Based on this combined information, spring flow losses per quaternary catchment were calculated.

A2.16 EVAPOTRANSPIRATION

Mean annual evapotranspiration figures per quaternary catchment were obtained from the WR2005 dataset and applied on estimated riparian zones associated with rivers and streams. The lengths of the rivers and streams were measured and a riparian zone width on each river bank estimated per quaternary catchment, based on the aridity of the applicable quaternary catchment. From these parameters, the amount of groundwater lost to evapotranspiration before it exits as baseflow to the rivers and streams could be calculated.

A2.17 BASEFLOW

There is only one River flow gauging station in the study area, T6H004, on the Xura River, a tributary of the Msikaba River. The DWA Cradock office confirmed that flow records for this station are considered to be of good quality from 1997 onwards. The catchment surface area for T6H004 is 92.9 km^2. BKS and Sherman Consulting delineated 4 sub-catchments for the hydrology module of this study. The T6H004 flow gauging station measures runoff from the Zalu dam sub-catchment and the T60F2 sub-catchment.

Groundwater contribution to baseflow was calculated by selecting very low flow records observed after long dry periods. Finally the groundwater contribution to baseflow was determined to be approximately 2.65% of MAP (mm) for the given sub-catchments involved in T60F.

This groundwater contribution to baseflow percentage was then used with the baseflow ratio increases and decreases between quaternary catchments, as derived from the EPBS (2001), to verify and calibrate the GYMR model per quaternary catchment.

A2.18 ECOLOGICAL REQUIREMENT FOR AQUATIC ECOSYSTEMS RESERVE (EWR)

The team of Sherman, Colloty and Associates were tasked with determining the ecological flow requirements for the Lusikisiki RWSS Feasibility and complete the EWR module. The percentage of baseflow required to sustain aquatic ecosystems, was noted in the desktop planning estimate for the Msikaba estuary, as a 100% (Bok et al., 1999). For the purpose of the GYMR, different scenarios of Ecological Flow Requirements were used as indicated in the tables in the Groundwater Reserve Scenarios Section.

A3 GROUNDWATER RESERVE SCENARIOS FOR LUSIKISIKI RWSS

The Groundwater Yield Model for the Reserve (GYMR) was simulated to assess potential groundwater flow balances on an annual basis. Recommendations on management options based on the outcome of the assessments are made, for the DWA RDM office's decision making purposes.

The following scenarios were simulated:

1. **Present Day GYMR, 95% assurance of supply, GA's included - groundwater inflow from estimated recharge and rainfall at 95% assurance level; GYMR accounting for drought cycles, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).**

1. **Present Day GYMR, 95% assurance of supply, GA's excluded - groundwater inflow from estimated recharge and rainfall at 95% assurance level; GYMR accounting for drought cycles, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).**

2. **Present Day GYMR, MAP rainfall, GA's excluded - groundwater inflow from estimated recharge and rainfall at 95% assurance level; GYMR accounting for drought cycles, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).**

3. **Future 2020 GYMR scenario, 95% assurance of supply, GA's excluded - groundwater inflow from estimated recharge and rainfall at 95% assurance level; 2020 groundwater use and population figure estimates used predominantly from EPBS (2001); GYMR accounting for drought cycles, groundwater losses and the resultant groundwater baseflow component (EWR volumes assumed to be 40% of net baseflow).**

A3.1 GROUNDWATER RESERVE DETERMINATION – GYMR APPROACH

It must be noted that this groundwater flow balance is based on the assumption that water is e.g. allocated to irrigation and basic human needs (community water supply). The "allocatable" groundwater balance will differ from the "actual" groundwater flow balance. In the absence of direct site information, conservative assumptions were made in the favour of the Reserve, for example riparian- and alien- vegetation surface areas that deplete groundwater until it can be proven otherwise.

In equilibrium, the recharge should be balanced by borehole abstraction, evapotranspiration losses to the streams, springs, wetlands and groundwater base flow. The groundwater inflow components are recharge from rainfall and inflow from dam seepages.

The GYMR model process applied the following conservative approaches in this study:

1. **Groundwater recharge was determined as a percentage of the lower 95th percentile of rainfall to cater for drought low flows.**

2. **The model simulated groundwater flow balances in which case storativity was assumed to be low.**

3. **The groundwater flow losses (evapotranspiration) were calculated by using a variable (2 – 3.5m) buffer width along both sides of the cumulative river lengths in each catchment.**

4. **The GYMR groundwater flow balance per quaternary catchment is shown in Tables A3-1 to A3-3 with detailed results indicated in Tables A3-4; A3-5 and A3-6.**

A3.2 OUTCOME OF GYMR RESULTS FOR STUDY AREA CATCHMENTS

Table A3- 1: Present day 95% assurance GA excluded

Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)
T60E	198	885	709	6.03%	8.47	8.47	-2.51	-2.39	3.56	30%
T60F	463	940	753	6.63%	23.13	23.13	-5.12	-5.23	12.78	22%
T60G	359	1116	895	8.29%	26.65	26.65	-2.06	-6.35	18.23	8%
T60H	322	1277	1024	9.90%	32.59	32.62	-5.76	-5.37	21.49	18%
T60J	293	1101	882	8.23%	21.31	21.31	-3.12	-4.72	13.47	15%
T60K	242	1075	862	7.50%	15.64	15.64	-3.23	-4.93	7.48	21%
Total study area	1151	1114	893	8.25%	84.77	84.81	-13.55	-20.49	50.77	16%

Table A3-2: Present day 95% assurance GA included

Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)
T60E	198	885	709	6.03%	8.47	8.47	-3.40	-2.39	2.67	40%
T60F	463	940	753	6.63%	23.13	23.13	-7.20	-5.23	10.69	31%
T60G	359	1116	895	8.29%	26.65	26.65	-7.46	-6.35	12.84	28%
T60H	322	1277	1024	9.90%	32.59	32.62	-10.58	-5.37	16.67	32%
T60J	293	1101	882	8.23%	21.31	21.31	-5.32	-4.72	11.27	25%
T60K	242	1075	862	7.50%	15.64	15.64	-4.32	-4.93	6.39	28%
Total study area	1151	1114	893	8.25%	84.77	84.81	-24.32	-20.49	40.00	29%

Table A3-3: 2020 95% assurance GA excluded

Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)
T60E	198	885	709	6.03%	8.47	8.47	-3.25	-2.39	2.82	38%
T60F	463	940	753	6.63%	23.13	23.13	-5.96	-5.23	11.94	26%
T60G	359	1116	895	8.29%	26.65	26.65	-2.21	-6.35	18.09	8%
T60H	322	1277	1024	9.90%	32.59	32.62	-7.88	-5.37	19.37	24%
T60J	293	1101	882	8.23%	21.31	21.31	-3.24	-4.72	13.35	15%
T60K	242	1075	862	7.50%	15.64	15.64	-3.36	-4.93	7.35	22%
Total study area	1151	1114	893	8.25%	84.77	84.81	-16.16	-20.49	48.17	19%

Table A3-4: Present Day 95% assurance GA excluded

No	Quaternary catchment	Surface Area (Km2)	Surface area (m2)	Surface area (ha)	Depth to water level GRAII (m)	Min depth to water level (m)	Max aquifer depth SRK study (m)	Water level management constraint (m)	Aquifer storativity	Groundwater volume in storage (m3)	Max usable groundwater volume in storage (m3)	MAP (mm/a) WR2005	MAE (mm/a) WR2005 Data	MAR WR2005 (%)	MAR (m3/a)	MAR (Mm3/a)	MAR (mm/a)	Recharge primary geology Chloride method NGDB (% of MAP)	Rainfall 95%ass. (mm/a)	Rainfall (m/a)	Recharge (mm/a) GRDM
	T60E	198	197895025	19790	-9.2	0.0	-36.0	-18.2	0.0010	3 180 965	3 603 668	885	1 150	50.4%	88 200 000	88.20	446	6.03%	709.4	0.7094	53
1	T60F	463	463272000	46327	-13.6	0.0	-36.0	-22.6	0.0010	6 229 155	10 465 314	940	1 150	20.5%	89 200 000	89.20	193	6.63%	753.4	0.7534	62
2	T60G	359	359446000	35945	-8.3	0.0	-126.0	-39.8	0.0010	25 377 606	14 316 734	1 116	1 150	24.0%	96 410 000	96.41	268	8.29%	894.5	0.8945	92
3	T60H	322	321630000	32163	-7.4	0.0	-55.0	-21.1	0.0010	9 191 542	6 792 826	1 277	1 150	30.0%	123 300 000	123.30	383	9.90%	1 023.6	1.0236	126
4	T60J	293	293441000	29344	-14.4	0.0	-88.0	-36.4	0.0010	12 967 158	10 666 580	1 101	1 150	23.6%	76 260 000	76.26	260	8.23%	882.5	0.8825	91
5	T60K	242	241973000	24197	-6.0	0.0	-80.0	-26.0	0.0010	10 743 601	6 291 298	1 075	1 150	22.6%	58 830 000	58.83	243	7.50%	861.7	0.8617	81
6	Total study area	1151	1151218757	115122	-10.1	0.0	-71.7	-28.0	0.0010	42 558 599	32 220 698	1 114	1 150	24.6%	315 626 130	315.63	274	8.25%	892.7	0.8927	92
	Total	**2831**								**64 509 063**	**48 532 753**	**5 509**	**5 750**		**444 000 000**	**444**			**143**		

No	Quaternary catchment	Surface Area (Km2)	Recharge based on 95% level of ass. (mm/a)	Recharge (m3/a)	Avg seepage (mm/a)	Dam Seepage Area WR2005 and Topo (km2)	Total dam seepage (m3/a)	General autho-rizations (m3/a)	General autho-rizations DWAF m3/ha/a	WARMS Volumes registered for Irrigation	Boreholes	Number of abstraction boreholes (Other)	Total borehole abstraction (m3/a)	All New SRK Boreholes (Count)	All New SRK borehole abstraction (m3/a)	Number of livestock farms	Total livestock farm usage (m3/a)	Number of mines	Total mine usage WARMS (m3/a)	No of comm-unities	People in community	Total community borehole usage WARMS and calculated (m3/a)
	T60E	198	42.78166	8 466 277	100	0.00	0.00	-890 528	45	-1 109 224	15	2	-18 922	0	0	0	0	0.0	0	1	50 888	-1 625 823
1	T60F	463	49.91719	23 125 238	100	0.00	0.00	-2 084 724	45	-1 109 224	15	43	-1 002 845	2	0	0	0	0.0	0	1	101 014	-2 640 308
2	T60G	359	74.13088	26 646 047	100	0.00	0.00	-5 391 690	150	-9 958 949	129	3	-113 530	4	-21 129	0	0	0.0	0	1	59 575	-1 304 693
3	T60H	322	101.316	32 586 263	100	0.38	37500.00	-4 824 450	150	-5 871 610	86	11	-104 069	2	0	0	0	0.0	0	1	10 998	-240 856
4	T60J	293	72.62843	21 312 159	100	0.00	375.00	-2 200 808	75	-3 694 279	47	9	-170 294	4	-68 906	0	0	0.0	0	1	46 463	-1 017 540
5	T60K	242	64.64229	15 641 688	100	0.00	0.00	-1 088 879	45	-11 611 331	91	4	-208 138	0	0	0	0	0.0	0	1	52 953	-1 159 671
6	Total study area	1151	73.63893	84 774 522	100	0.38	37875.00	-10 763 136		-23 156 983	91	53	-927 158	12	-90 035	0	0	0.0	0	1	120 000	-3 056 101
	Total	**2831**		**119 311 396**	**500**	**0.38**	**37 875**	**-15 590 550**				**123**	**-2 526 034**		**-180 070**	**0**	**0**	**0**	**0**	**6**	**391 003**	**-9 419 168**

No	Quaternary catchment	Surface Area (Km2)	Average Farm irrigation area (ha) EPBS	Farm irrigation water use WARMS (m3/a)	Average Forestry area (ha)	Average Forestry water use (m3/a)	Average Riparian veg & upland alien vegetation (km2)	Average Riparian & upland alien veg water use (m3/a)	Average Alien veg (km2)	Alien veg water use (m3/a)	Wetlands (Ground water) (km2) (Vlei areas on topo map)	Wetland water use (m3/a)	No of springs	Spring flow (m3/a)	Total inflow (m3/a)	Total outflow before losses (sinks) m3/a	Time (y) to reach GMC	Ideal Base flow (analytical) m3/a	Ideal Base flow (analytical) mm/a
	T60E	198	24	-49 146	699.8	-664 810	0.5	-520	0.0	0	0.02	-8 360	24.0	-145 470	8 466 277	-2 513 051	NA	-5 953 226	0.030
1	T60F	463	89	-165 579	473.0	-520 300	1.1	-1 136	0.0	0	0.14	-42 847	123.0	-745 534	23 125 238	-5 118 549	NA	-18 006 689	0.039
2	T60G	359	13	-7 726	295.7	-520 432	2.3	-2 301	0.0	0	0.02	-6 270	18.0	-109 103	26 646 047	-2 064 054	NA	-24 581 993	0.068
3	T60H	322	0	0	2 488.2	-5 225 220	1.7	-1 669	0.0	0	0.03	-10 102	29.0	-175 776	32 623 763	-5 757 692	NA	-26 866 071	0.084
4	T60J	293	17	-18 738	818.2	-1 554 580	2.1	-2 052	0.0	0	0.06	-19 508	56.0	-339 430	21 312 534	-3 122 142	NA	-18 190 392	0.062
5	T60K	242	8	-24 932	634.1	-1 249 177	2.1	-2 141	0.0	0	0.10	-32 048	92.0	-557 635	15 641 688	-3 233 742	NA	-12 407 945	0.051
6	Total study area	1151	24	-118 951	4 113.0	-8 155 873	7.4	-7 424	0.0	0	0.22	-70 018	201.0	-1 218 312	84 812 397	-13 553 839	NA	-71 258 558	0.062
	Total	**2831**	**150**	**-335 926**	**8 822**	**-17 225 582**	**17**	**-16 724**	**0**	**0**	**1**	**-180 794**	**519.00**	**-3 145 791**	**204 161 668**	**-32 850 019**		**-100 053 091**	

No	Quaternary catchment	Surface Area (Km2)	Cumulative length of drainages (km)	Base flow loss zone along drainage (m)	GW ET losses area (% of catchment area)	Evapo-transpiration flow loss 1 (m3/a) % of catchment	Evapo-transpiration flow loss 2 - streams (m3/a)	Net Base flow (analytical) - Woodford (m3/a)	Net Base flow (analytical) - Calibrate (m3/a)	Net Base Flow Ecological Water Requirement (EWR) (m3/a)	Minimum flow m3/a	Net Base flow - model calibrate (analytical) (m3/a)	Usable GW component from Base Flow (analytical) (m3/a)	Net usable base flow (analytical) calibrate (mm/a)	Balance test (m3/a)	Model error (%)	Potential stressed status total outflow before ET losses as % of inflow
	T60E	198	520	2.0	0.14%	-318 611	-2 392 464	**-666 334**	**-3 560 761**	**-3 560 761**	**1 799 999**	7 121 523	**0**	0.018	0	0.00%	30%
1	T60F	463	1 136	2.0	0.10%	-532 763	-5 227 472	**-1 995 384**	**-12 779 217**	**-12 779 217**	**1 800 000**	25 558 434	**0**	0.028	0	0.00%	22%
2	T60G	359	920	3.0	0.67%	-2 769 531	-6 350 496	**-2 851 490**	**-18 231 498**	**-18 231 498**	**1 800 000**	36 462 995	**0**	0.051	0	0.00%	8%
3	T60H	322	668	3.5	0.65%	-2 404 184	-5 373 796	**-4 111 423**	**-21 492 275**	**-21 492 275**	**1 800 000**	42 984 549	**0**	0.067	0	0.00%	18%
4	T60J	293	821	2.5	0.40%	-1 349 829	-4 719 960	**-2 286 345**	**-13 470 432**	**-13 470 432**	**1 200 000**	26 940 864	**0**	0.046	0	0.00%	15%
5	T60K	242	857	2.5	0.50%	-1 391 345	-4 925 396	**-1 620 156**	**-7 482 550**	**-7 482 550**	**1 700 000**	14 965 099	**0**	0.031	0	0.00%	21%
6	Total study area	1151	2 970	3.0	0.50%	-6 619 508	-20 491 498	**-9 590 529**	**-50 767 060**	**-50 767 060**	**1 700 001**	101 534 120	**0**	0.044	0	0.00%	16%
	Total	**2831**	**4 402**		**0.464%**	**-8 447 652**	**-26 597 120**	**-12 864 797**	**-73 455 971**	**-73 455 971**	**8 300 000**	**146 911 943**	**0**		**0**	0.00%	16%

Table A3-5: Present day 95% assurance GA included

No	Quaternary catchment	Surface Area (Km2)	Surface area (m2)	Surface area (ha)	Depth to water level GRAII (m)	Min depth to water level (m)	Max aquifer depth SRK study (m)	Water level management constraint (m)	Aquifer storativity	Groundwater volume in storage (m3)	Max usable groundwater volume in storage (m3)	MAP (mm/a) WR2005	MAE (mm/a) WR2005 Data	MAR WR2005 (%)	MAR (m3/a)	MAR (Mm3/a)	MAR (mm/a)	Recharge primary geology Chloride method NGDB (% of MAP)	Rainfall 95%ass. (mm/a)	Rainfall (m/a)	Recharge (mm/a) GRDM
	T60E	198	197895025	19790	-9.2	0.0	-36.0	-18.2	0.0010	3 180 965	3 603 668	885	1 150	50.4%	88 200 000	88.20	446	6.03%	709.4	0.7094	53
1	T60F	463	463272000	46327	-13.6	0.0	-36.0	-22.6	0.0010	6 229 155	10 465 314	940	1 150	20.5%	89 200 000	89.20	193	6.63%	753.4	0.7534	62
2	T60G	359	359446000	35945	-8.3	0.0	-126.0	-39.8	0.0010	25 377 606	14 316 734	1 116	1 150	24.0%	96 410 000	96.41	268	8.29%	894.5	0.8945	92
3	T60H	322	321630000	32163	-7.4	0.0	-55.0	-21.1	0.0010	9 191 542	6 792 826	1 277	1 150	30.0%	123 300 000	123.30	383	9.90%	1 023.6	1.0236	126
4	T60J	293	293441000	29344	-14.4	0.0	-88.0	-36.4	0.0010	12 967 158	10 666 580	1 101	1 150	23.6%	76 260 000	76.26	260	8.23%	882.5	0.8825	91
5	T60K	242	241973000	24197	-6.0	0.0	-80.0	-26.0	0.0010	10 743 601	6 291 298	1 075	1 150	22.6%	58 830 000	58.83	243	7.50%	861.7	0.8617	81
6	Total study area	1151	1151218757	115122	-10.1	0.0	-71.7	-28.0	0.0010	42 558 599	32 220 698	1 114	1 150	24.6%	315 626 130	315.63	274	8.25%	892.7	0.8927	92
	Total	**2831**								**64 509 063**	**48 532 753**	**5 509**	**5 750**		**444 000 000**	**444**			**143**		

No	Quaternary catchment	Surface Area (Km2)	Recharge based on 95% level of ass. (mm/a)	Recharge (m3/a)	Avg seepage (mm/a)	Dam Seepage Area WR2005 and Topo (km2)	Total dam seepage (m3/a)	General autho-rizations (m3/a)	General autho-rizations DWAF m3/ha/a	WARMS Volumes registered for Irrigation	Boreholes	Number of abstraction boreholes (Other)	Total borehole abstraction (m3/a)	All New SRK Boreholes (Count)	All New SRK borehole abstraction (m3/a)	Number of livestock farms	Total livestock farm usage (m3/a)	Number of mines	Total mine usage WARMS (m3/a)	No of comm-unities	People in community	Total community borehole usage WARMS and calculated (m3/a)
	T60E	198	42.78166	8 466 277	100	0.00	0.00	-890 528	45	-1 109 224	15	2	-18 922	0	0	0	0	0.0	0	1	50 888	-1 625 823
1	T60F	463	49.91719	23 125 238	100	0.00	0.00	-2 084 724	45	-1 109 224	15	43	-1 002 845	2	0	0	0	0.0	0	1	101 014	-2 640 308
2	T60G	359	74.13088	26 646 047	100	0.00	0.00	-5 391 690	150	-9 958 949	129	3	-113 530	4	-21 129	0	0	0.0	0	1	59 575	-1 304 693
3	T60H	322	101.316	32 586 263	100	0.38	37500.00	-4 824 450	150	-5 871 610	86	11	-104 069	2	0	0	0	0.0	0	1	10 998	-240 856
4	T60J	293	72.62843	21 312 159	100	0.00	375.00	-2 200 808	75	-3 694 279	47	9	-170 294	4	-68 906	0	0	0.0	0	1	46 463	-1 017 540
5	T60K	242	64.64229	15 641 688	100	0.00	0.00	-1 088 879	45	-11 611 331	91	4	-208 138	0	0	0	0	0.0	0	1	52 953	-1 159 671
6	Total study area	1151	73.63893	84 774 522	100	0.38	37875.00	-10 763 136		-23 156 983	91	53	-927 158	12	-90 035	0	0	0.0	0	1	120 000	-3 056 101
	Total	**2831**		**119 311 396**	**500**	**0.38**	**37 875**	**-15 590 550**				**123**	**-2 526 034**		**-180 070**	**0**	**0**	**0**	**0**	**6**	**391 003**	**-9 419 168**

No	Quaternary catchment	Surface Area (Km2)	Average Farm irrigation area (ha) EPBS	Farm irrigation water use WARMS (m3/a)	Average Forestry area (ha)	Average Forestry water use (m3/a)	Average Riparian veg & upland alien vegetation (km2)	Average Riparian & upland alien veg water use (m3/a)	Average Alien veg (km2)	Alien veg water use (m3/a)	Wetlands (Ground water) (km2) (Vlei areas on topo map)	Wetland water use (m3/a)	No of springs	Spring flow (m3/a)	Total inflow (m3/a)	Total outflow before losses (sinks) m3/a
	T60E	198	24	-49 146	699.8	-664 810	0.5	-520	0.0	0	0.02	-8 360	24.0	-145 470	8 466 277	-3 403 579
1	T60F	463	89	-165 579	473.0	-520 300	1.1	-1 136	0.0	0	0.09	-42 847	123.0	-745 534	23 125 238	-7 203 273
2	T60G	359	13	-7 726	295.7	-520 432	2.3	-2 301	0.0	0	0.01	-6 270	18.0	-109 103	26 646 047	-7 455 744
3	T60H	322	0	0	2 488.2	-5 225 220	1.7	-1 669	0.0	0	0.02	-10 102	29.0	-175 776	32 623 763	-10 582 142
4	T60J	293	17	-18 738	818.2	-1 554 580	2.1	-2 052	0.0	0	0.04	-19 508	56.0	-339 430	21 312 534	-5 322 950
5	T60K	242	8	-24 932	634.1	-1 249 177	2.1	-2 141	0.0	0	0.07	-32 048	92.0	-557 635	15 641 688	-4 322 621
6	Total study area	1151	24	-118 951	1 124.7	-8 155 873	7.4	-7 424	0.0	0	0.15	-70 018	201.0	-1 218 312	84 812 397	-24 316 975
	Total	**2831**	**150**	**-335 926**	**5 834**	**-17 225 582**	**17**	**-16 724**	**0**	**0**	**0**	**-180 794**	**519.00**	**-3 145 791**	**204 161 668**	**-59 203 705**

No	Quaternary catchment	Surface Area (Km2)	Time (y) to reach GMC	Ideal Base flow (analytical) m3/a	Ideal Base flow (analytical) mm/a	Cumulative length of drainages (km)	Base flow loss zone along drainage (m)	GW ET losses area (% of catchment area)	Evapo-transpiration flow loss 1 (m3/a) % of catchment	Evapo-transpiration flow loss 2 - streams (m3/a)	Net Base flow (analytical) - Woodford (m3/a)	Net Base flow (analytical) - Calibrate (m3/a)	Net Base Flow Ecological Water Requirement (EWR) (m3/a)	Minimum flow m3/a	Net Base flow - model calibrate (analytical) (m3/a)	Usable GW component from Base Flow (analytical) (m3/a)	Net usable base flow (analytical) calibrate (mm/a)	Balance test (m3/a)	Model error (%)	Potential stressed status total outflow before ET losses as % of inflow
	T60E	198	NA	-5 062 698	0.026	520	2.0	0.14%	-318 611	-2 392 464	**-666 334**	**-2 670 234**	**-2 670 234**	**1 799 999**	5 340 467	**0**	0.013	0	0.00%	40%
1	T60F	463	NA	-15 921 965	0.034	1 136	2.0	0.10%	-532 763	-5 227 472	**-1 995 384**	**-10 694 493**	**-10 694 493**	**1 800 000**	21 388 986	**0**	0.023	0	0.00%	31%
2	T60G	359	NA	-19 190 303	0.053	920	3.0	0.67%	-2 769 531	-6 350 496	**-2 851 490**	**-12 839 808**	**-12 839 808**	**1 800 000**	25 679 615	**0**	0.036	0	0.00%	28%
3	T60H	322	NA	-22 041 621	0.069	668	3.5	0.65%	-2 404 184	-5 373 796	**-4 111 423**	**-16 667 825**	**-16 667 825**	**1 800 000**	33 335 649	**0**	0.052	0	0.00%	32%
4	T60J	293	NA	-15 989 585	0.054	821	2.5	0.40%	-1 349 829	-4 719 960	**-2 286 345**	**-11 269 625**	**-11 269 625**	**1 200 000**	22 539 249	**0**	0.038	0	0.00%	25%
5	T60K	242	NA	-11 319 067	0.047	857	2.5	0.50%	-1 391 345	-4 925 396	**-1 620 156**	**-6 393 671**	**-6 393 671**	**1 700 000**	12 787 342	**0**	0.026	0	0.00%	28%
6	Total study area	1151	NA	-60 495 422	0.053	2 970	3.0	0.50%	-6 619 508	-20 491 498	**-9 590 529**	**-40 003 924**	**-40 003 924**	**1 700 001**	80 007 848	**0**	0.035	0	0.00%	29%
	Total	**2831**		**-84 462 541**		**4 402**		**0.464%**	**-8 447 652**	**-26 597 120**	**-12 864 797**	**-57 865 421**	**-57 865 421**	**8 300 000**	**115 730 843**	**0**		**0**	0.00%	29%

Table A3-6: 2020 95% assurance GA excluded

No	Quaternary catchment	Surface Area (Km2)	Surface area (m2)	Surface area (ha)	Depth to water level GRAII (m)	Min depth to water level (m)	Max aquifer depth SRK study (m)	Water level management constraint (m)	Aquifer storativity	Groundwater volume in storage (m3)	Max usable groundwater volume in storage (m3)	MAP (mm/a) WR2005	MAE (mm/a) WR2005 Data	MAR WR2005 (%)	MAR (m3/a)	MAR (Mm3/a)	MAR (mm/a)	Recharge primary geology Chloride method NGDB (% of MAP)	Rainfall 95% ass. (mm/a)	Rainfall (m/a)	Recharge (mm/a) GRDM
	T60E	198	197895025	19790	-9.2	0.0	-36.0	-18.2	0.0010	3 180 965	3 603 668	885	1 150	50.4%	88 200 000	88.20	446	6.03%	709.4	0.7094	53
1	T60F	463	463272000	46327	-13.6	0.0	-36.0	-22.6	0.0010	6 229 155	10 465 314	940	1 150	20.5%	89 200 000	89.20	193	6.63%	753.4	0.7534	62
2	T60G	359	359446000	35945	-8.3	0.0	-126.0	-39.8	0.0010	25 377 606	14 316 734	1 116	1 150	24.0%	96 410 000	96.41	268	8.29%	894.5	0.8945	92
3	T60H	322	321630000	32163	-7.4	0.0	-55.0	-21.1	0.0010	9 191 542	6 792 826	1 277	1 150	30.0%	123 300 000	123.30	383	9.90%	1 023.6	1.0236	126
4	T60J	293	293441000	29344	-14.4	0.0	-88.0	-36.4	0.0010	12 967 158	10 666 580	1 101	1 150	23.6%	76 260 000	76.26	260	8.23%	882.5	0.8825	91
5	T60K	242	241973000	24197	-6.0	0.0	-80.0	-26.0	0.0010	10 743 601	6 291 298	1 075	1 150	22.6%	58 830 000	58.83	243	7.50%	861.7	0.8617	81
6	Total study area	1151	1151218757	115122	-10.1	0.0	-71.7	-28.0	0.0010	42 558 599	32 220 698	1 114	1 150	24.6%	315 626 130	315.63	274	8.25%	892.7	0.8927	92
	Total	**2831**								**64 509 063**	**48 532 753**	**5 509**	**5 750**		**444 000 000**	**444**			**143**		

No	Quaternary catchment	Surface Area (Km2)	Recharge based on 95% level of ass. (mm/a)	Recharge (m3/a)	Avg seepage (mm/a)	Dam Seepage Area WR2005 and Topo (km2)	Total dam seepage (m3/a)	General autho-rizations (m3/a)	General autho-rizations DWAF m3/ha/a	WARMS Volumes registered for Irrigation	Boreholes	Number of abstraction boreholes (Other)	Total borehole abstraction (m3/a)	All New SRK Boreholes (Count)	All New SRK borehole abstraction (m3/a)	Number of livestock farms	Total livestock farm usage (m3/a)	Number of mines	Total mine usage WARMS (m3/a)	No of comm-unities	People in community	Total community borehole usage WARMS and calculated (m3/a)
	T60E	198	42.78166	8 466 277	100	0.00	0.00	-890 528	45	-1 109 224	15	2	-18 922	0	0	0	0	0.0	0	1	66 894	-2 380 771
1	T60F	463	49.91719	23 125 238	100	0.00	0.00	-2 084 724	45	-1 109 224	15	43	-1 002 845	2	-29 644	0	0	0.0	0	1	120 526	-3 406 206
2	T60G	359	74.13088	26 646 047	100	0.00	0.00	-5 391 690	150	-9 958 949	129	3	-113 530	4	-186 062	0	0	0.0	0	1	65 808	-1 441 195
3	T60H	322	101.316	32 586 263	100	0.38	37500.00	-4 824 450	150	-5 871 610	86	11	-104 069	2	-28 698	0	0	0.0	0	1	12 149	-266 063
4	T60J	293	72.62843	21 312 159	100	0.00	375.00	-2 200 808	75	-3 694 279	47	9	-170 294	4	-380 009	0	0	0.0	0	1	51 324	-1 123 996
5	T60K	242	64.64229	15 641 688	100	0.00	0.00	-1 088 879	45	-11 611 331	91	4	-208 138	0	0	0	0	0.0	0	1	58 493	-1 280 997
6	Total study area	1151	73.63893	84 774 522	100	0.38	37875.00	-10 763 136		-23 156 983	91	53	-927 158	12	-624 413	0	0	0.0	0	1	134 121	-3 498 958
	Total	**2831**		**119 311 396**	**500**	**0.38**	**37 875**	**-15 590 550**				**123**	**-2 526 034**		**-1 248 826**	**0**	**0**	**0**	**0**	**6**	**442 421**	**-11 017 414**

No	Quaternary catchment	Surface Area (Km2)	Average Farm irrigation area (ha) EPBS	Farm irrigation water use WARMS (m3/a)	Average Forestry area (ha)	Average Forestry water use (m3/a)	Average Riparian veg & upland alien vegetation (km2)	Average Riparian & upland alien veg water use (m3/a)	Average Alien veg (km2)	Alien veg water use (m3/a)	Wetlands (Ground water) (km2) (Vlei areas on topo map)	Wetland water use (m3/a)	No of springs	Spring flow (m3/a)	Total inflow (m3/a)	Total outflow before losses (sinks) m3/a	Time (y) to reach GMC	Ideal Base flow (analytical) m3/a	Ideal Base flow (analytical) mm/a
	T60E	198	24	-34 160	699.8	-664 810	0.5	-520	0.0	0	0.02	-8 360	24.0	-145 470	8 466 277	-3 253 013	NA	-5 213 264	0.026
1	T60F	463	132	-242 940	472.0	-520 300	1.1	-1 136	0.0	0	0.14	-42 847	123.0	-745 534	23 125 238	-5 961 808	NA	-17 163 430	0.037
2	T60G	359	13	-12 694	295.0	-520 432	2.3	-2 301	0.0	0	0.02	-6 270	18.0	-109 103	26 646 047	-2 205 525	NA	-24 440 523	0.068
3	T60H	322	0	0	3 495.0	-7 325 220	1.7	-1 669	0.0	0	0.03	-10 102	29.0	-175 776	32 623 763	-7 882 899	NA	-24 740 864	0.077
4	T60J	293	29	-32 469	817.0	-1 554 580	2.1	-2 052	0.0	0	0.06	-19 508	56.0	-339 430	21 312 534	-3 242 329	NA	-18 070 205	0.062
5	T60K	242	30	-34 588	632.0	-1 249 177	2.1	-2 141	0.0	0	0.10	-32 048	92.0	-557 635	15 641 688	-3 364 724	NA	-12 276 963	0.051
6	Total study area	1151	39	-178 048	5 116.2	-10 255 873	7.4	-7 424	0.0	0	0.22	-70 018	201.0	-1 218 312	84 812 397	-16 155 793	NA	-68 656 604	0.060
	Total	**2831**	**243**	**-500 739**	**10 827**	**-21 425 582**	**17**	**-16 724**	**0**	**0**	**1**	**-180 794**	**519.00**	**-3 145 791**	**204 161 668**	**-38 813 078**		**-96 691 986**	

No	Quaternary catchment	Surface Area (Km2)	Cumulative length of drainages (km)	Base flow loss zone along drainage (m)	GW ET losses area (% of catchment area)	Evapo-transpiration flow loss 1 (m3/a) % of catchment	Evapo-transpiration flow loss 2 - streams (m3/a)	Net Base flow (analytical) - Woodford (m3/a)	Net Base flow (analytical) - Calibrate (m3/a)	Net Base Flow Ecological Water Requirement (EWR) (m3/a)	Minimum flow m3/a	Net Base flow - model calibrate (analytical) (m3/a)	Usable GW component from Base Flow (analytical) (m3/a)	Net usable base flow (analytical) calibrate (mm/a)	Balance test (m3/a)	Model error (%)	Potential stressed status total outflow before ET losses as % of inflow
	T60E	198	520	2.0	0.14%	-318 611	-2 392 464	-666 334	-2 820 800	-2 820 800	1 799 999	5 641 599	0	0.014	0	0.00%	38%
1	T60F	463	1 136	2.0	0.10%	-532 763	-5 227 472	-1 995 384	-11 935 958	-11 935 958	1 800 000	23 871 917	0	0.026	0	0.00%	26%
2	T60G	359	920	3.0	0.67%	-2 769 531	-6 350 496	-2 851 490	-18 090 027	-18 090 027	1 800 000	36 180 054	0	0.050	0	0.00%	8%
3	T60H	322	668	3.5	0.65%	-2 404 184	-5 373 796	-4 111 423	-19 367 068	-19 367 068	1 800 000	38 734 136	0	0.060	0	0.00%	24%
4	T60J	293	821	2.5	0.40%	-1 349 829	-4 719 960	-2 286 345	-13 350 245	-13 350 245	1 200 000	26 700 491	0	0.045	0	0.00%	15%
5	T60K	242	857	2.5	0.50%	-1 391 345	-4 925 396	-1 620 156	-7 351 568	-7 351 568	1 700 000	14 703 135	0	0.030	0	0.00%	22%
6	Total study area	1151	2 970	3.0	0.50%	-6 619 508	-20 491 498	-9 590 529	-48 165 106	-48 165 106	1 700 001	96 330 213	0	0.042	0	0.00%	19%
	Total	**2831**	**4 402**		**0.464%**	**-8 447 652**	**-26 597 120**	**-12 864 797**	**-70 094 866**	**-70 094 866**	**8 300 000**	**140 189 732**	**0**		**0**	0.00%	19%

A3.3 RAINFALL DATA

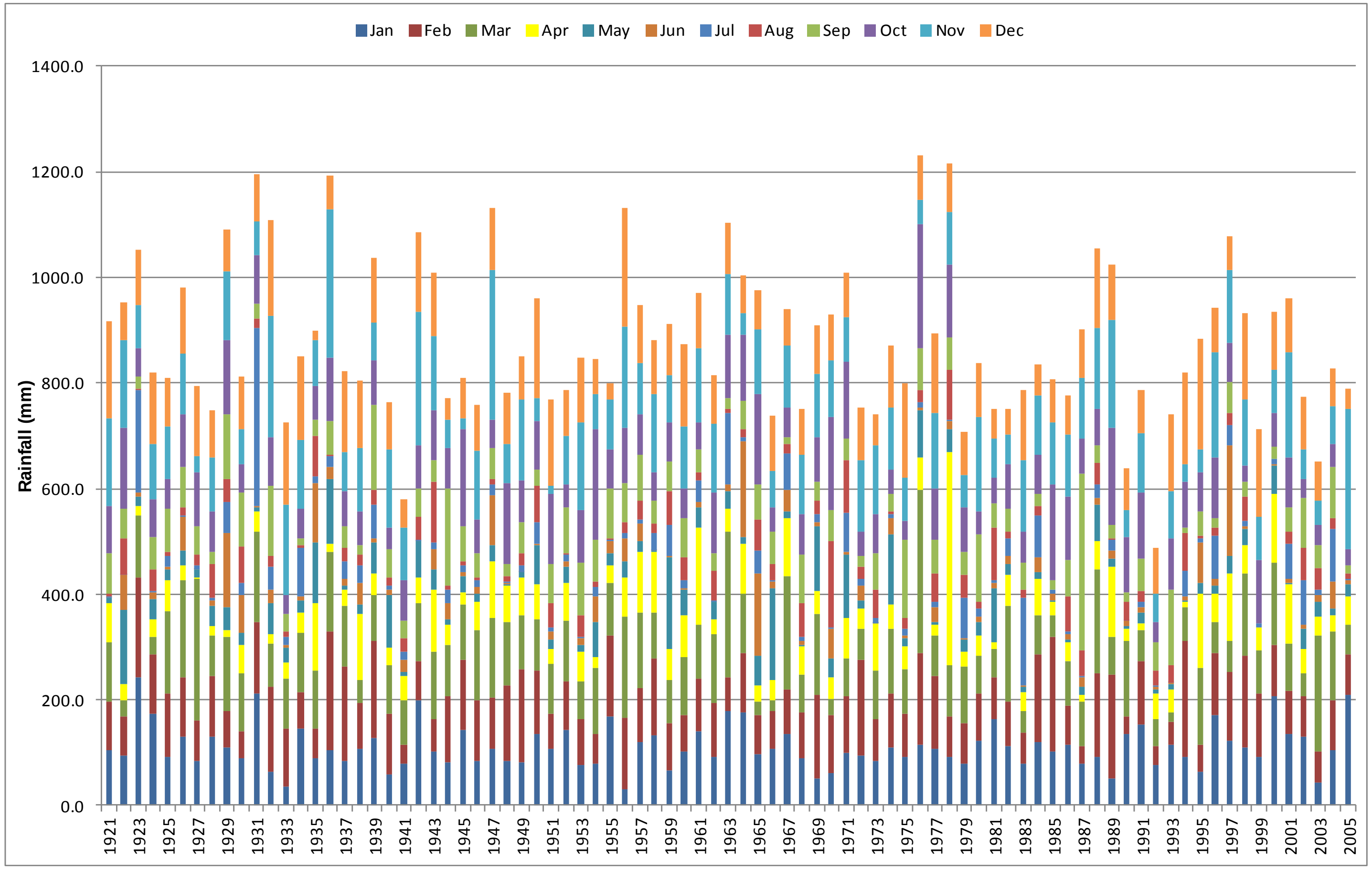

Figure A3-1: Monthly rainfall dataset (WR2005) for quaternary catchment T60E

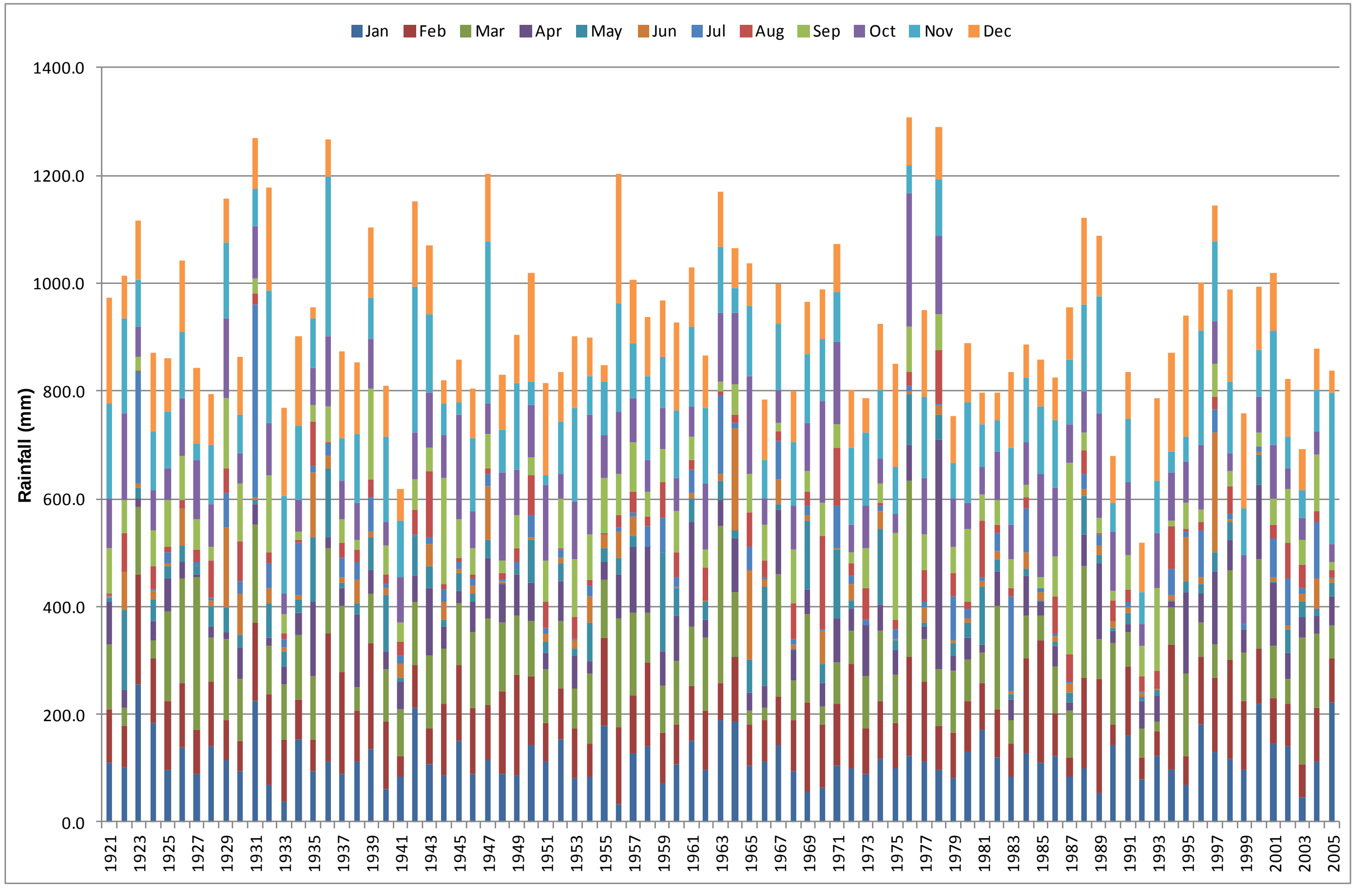

Figure A3-2: Monthly rainfall dataset (WR2005) for quaternary catchment T60F

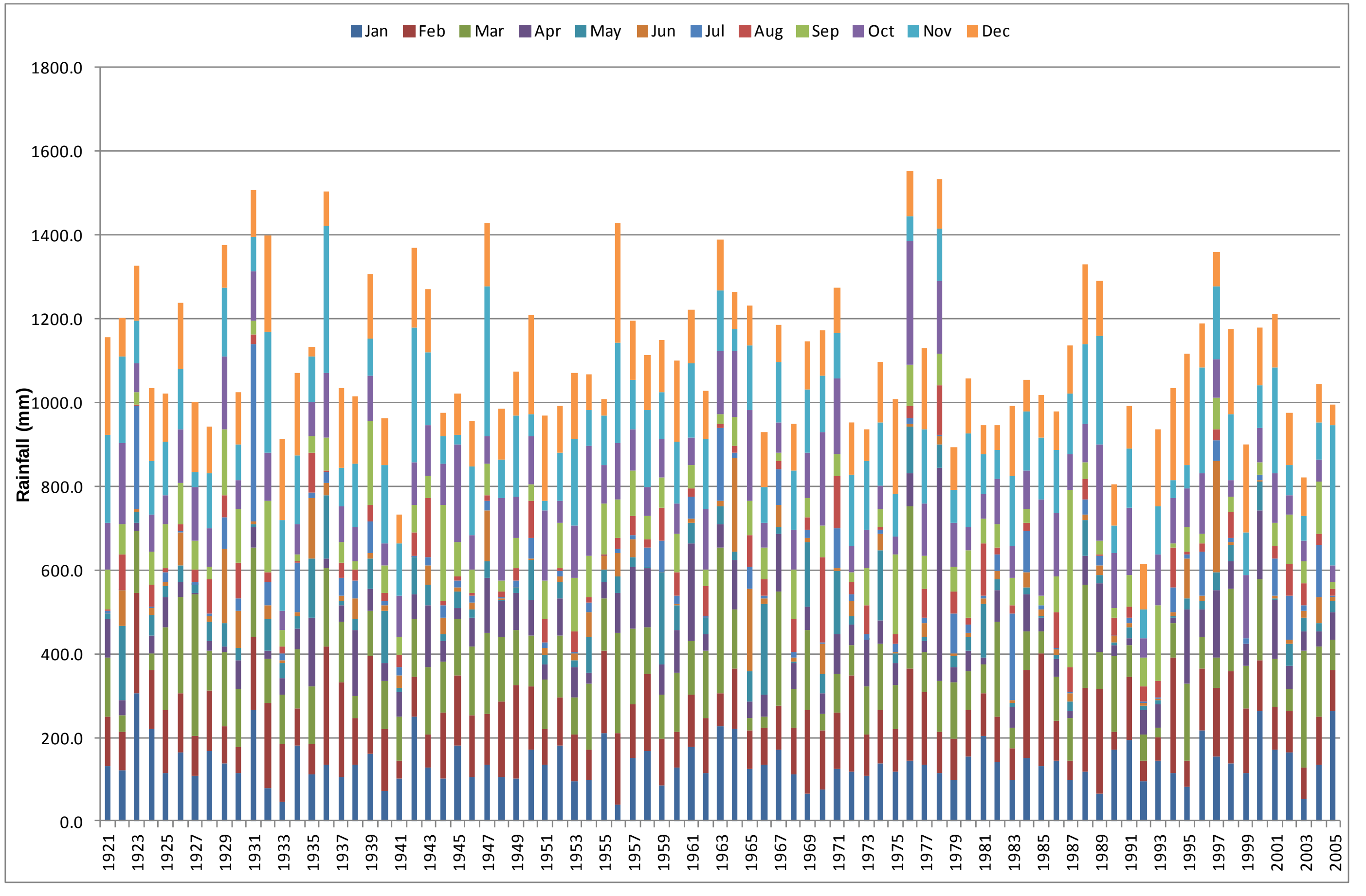

Figure A3-3: Monthly rainfall dataset (WR2005) for quaternary catchment T60G

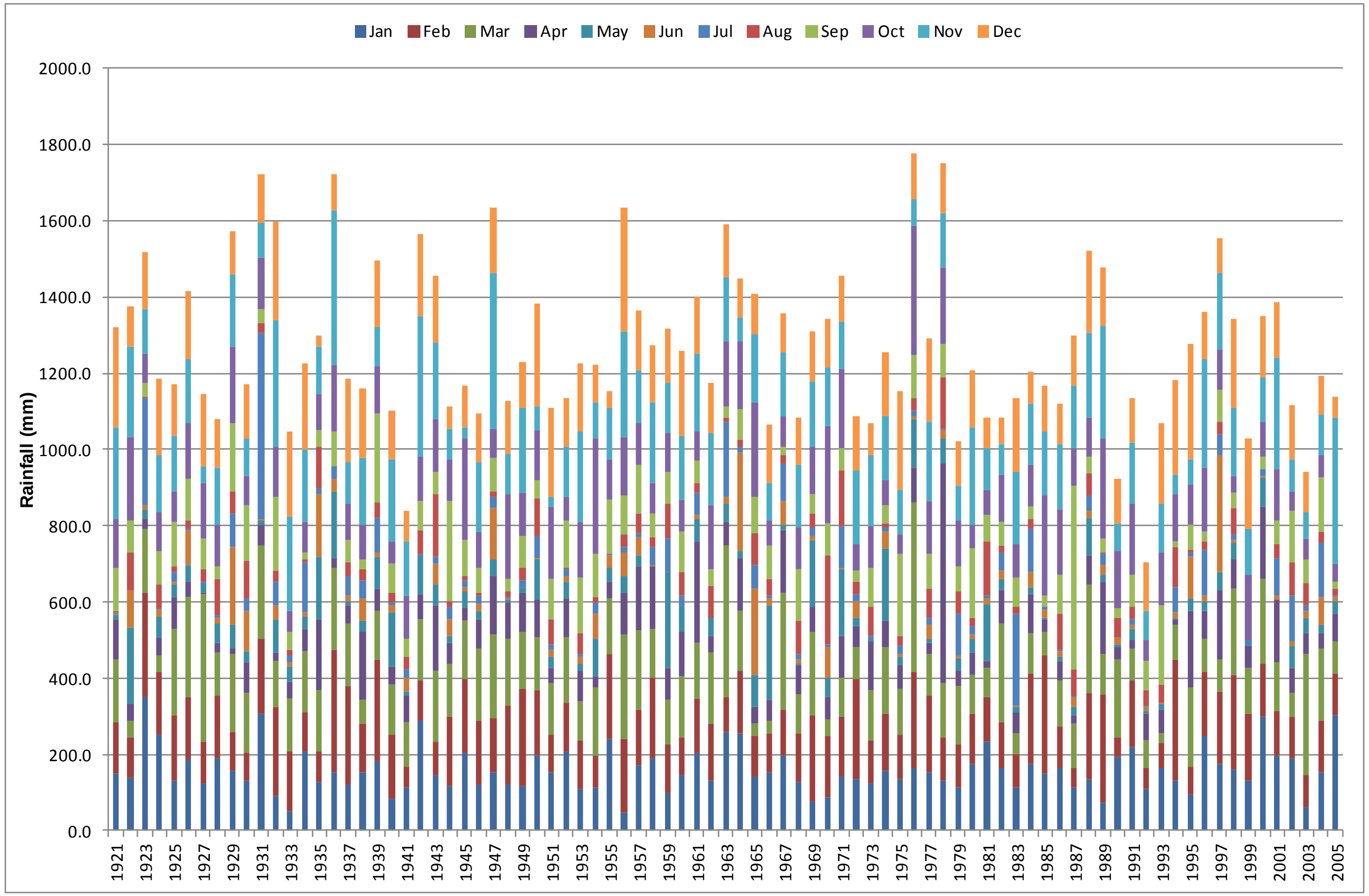

Figure A3-4: Monthly rainfall dataset (WR2005) for quaternary catchment T60H

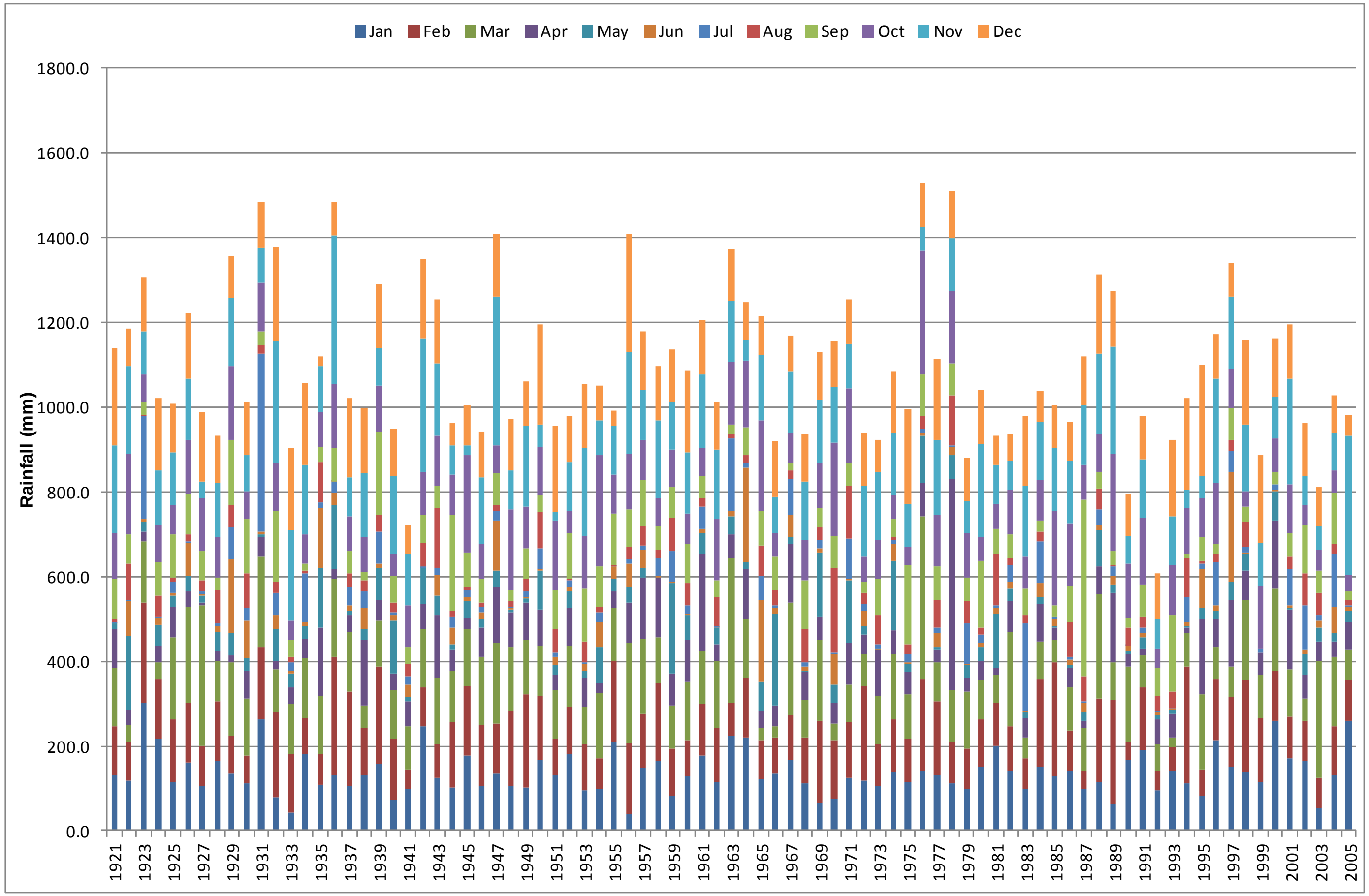

Figure A3-5: Monthly rainfall dataset (WR2005) for quaternary catchment T60J

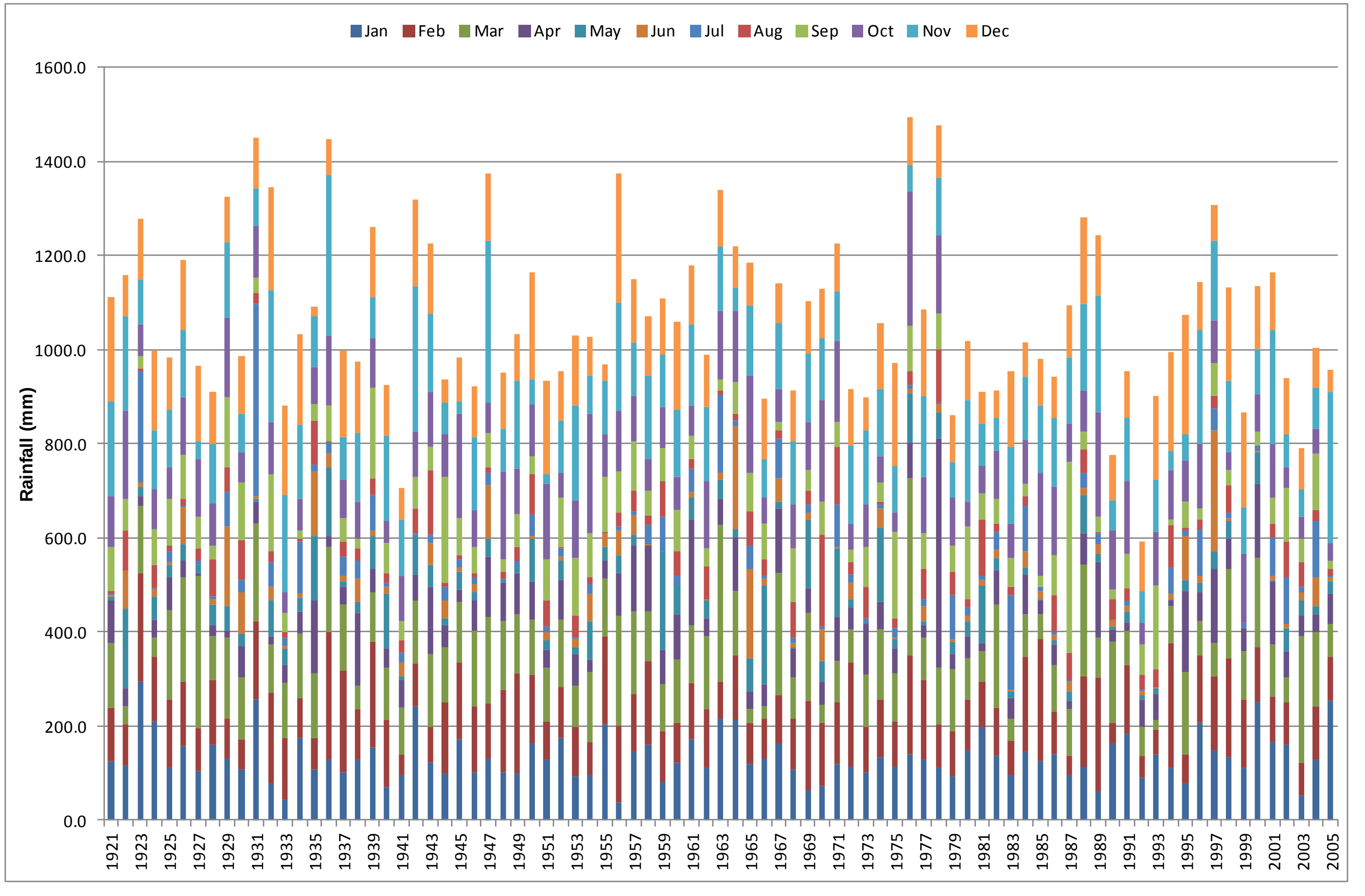

Figure A3-6: Monthly rainfall dataset (WR2005) for quaternary catchment T60K

A4 Groundwater Yield Model for the Reserve (GYMR) – Model Description

A4.1 Introduction

This section was taken from report no. RDM/K000/02/CON/0507, Reserve determination studies for selected surface water, groundwater, estuaries and wetlands in the Outeniqua catchment: Technical Component – Knysna and Swartvlei, K. Vivier, 2009.

The basic approach and model were developed since the Olifants River Water Resources Development Project: Groundwater Study Task (ORWRDP) (AGES, 2005). It was required to evaluate the groundwater potential of selected regional aquifers on a quaternary catchment scale. The normal approach to these assessments is to develop either numerical groundwater flow models or analytical water balance models. It was found that it is impractical to e.g. develop 114 numerical models for the Olifants River Water management Area (WMA) and obtain groundwater flow balances with assurance levels. A methodology and quantification model was developed that could address the groundwater management problem.

The outcome of the investigation was to provide assurance levels for the groundwater that is available on a quaternary catchment scale. In catchments where the inflow far exceeds the outflow (if losses are accounted for), the regional scale groundwater flow balance model provides sufficient information to allocate groundwater quantities. The model output is used to classify potentially (and not actual) stressed or sensitive catchments by accounting for all important inflow and outflow components, which includes losses. Through this process, catchments are identified, for which more detailed studies are required.

A4.2 Methodology

A model was developed termed the GYM that could be used to determine the groundwater balances on a number of quaternary catchments while accounting for variable recharge from rainfall. The variability in rainfall-recharge, aquifer storage and evapotranspiration potential was identified as one of the factors that influence sustainability of groundwater supply.

The purpose of the model is based on given assumptions, to simulate groundwater flow balances on a regional (primary) catchment scale with quaternary sub-catchment scale resolution, on annual or monthly time steps. The output provides statistical changes in groundwater volume based on rainfall recharge variations, which yields assurance levels for groundwater volumes.

The model was developed to simulate each catchment as a cell. Inflow and outflow components are calculated that must balance between time steps.

A4.3 THE GROUNDWATER FLOW BALANCE UNDER STEADY-STATE CONDITIONS

In a groundwater system that is used as a management unit, surface water drainages, or rivers, act as linear drains for groundwater seepage as indicated in **Figure A4-1**. The volume of groundwater contributing to the flow in rivers is termed the groundwater component of base flow. Base flow consists of both the groundwater component of base flow and a surface water component. The groundwater component of base flow can therefore not be more than base flow. Base flow is important to streams during low flow conditions, during which groundwater acts as a store and release mechanism.

In natural steady-state conditions, the net groundwater inflow from recharge is balanced by base flow (including spring flow if springs exist). In areas where springs exist, it usually supports downstream wetlands that are of environmental significance.

In its basic form, the groundwater flow balance is given by Qr – QGETL – QBF = 0, where;

Qr	**=**	**Recharge from rainfall**
QGETL	**=**	**Groundwater flow (evapo-transpiration) losses**
QBF	**=**	**Base and spring flow**

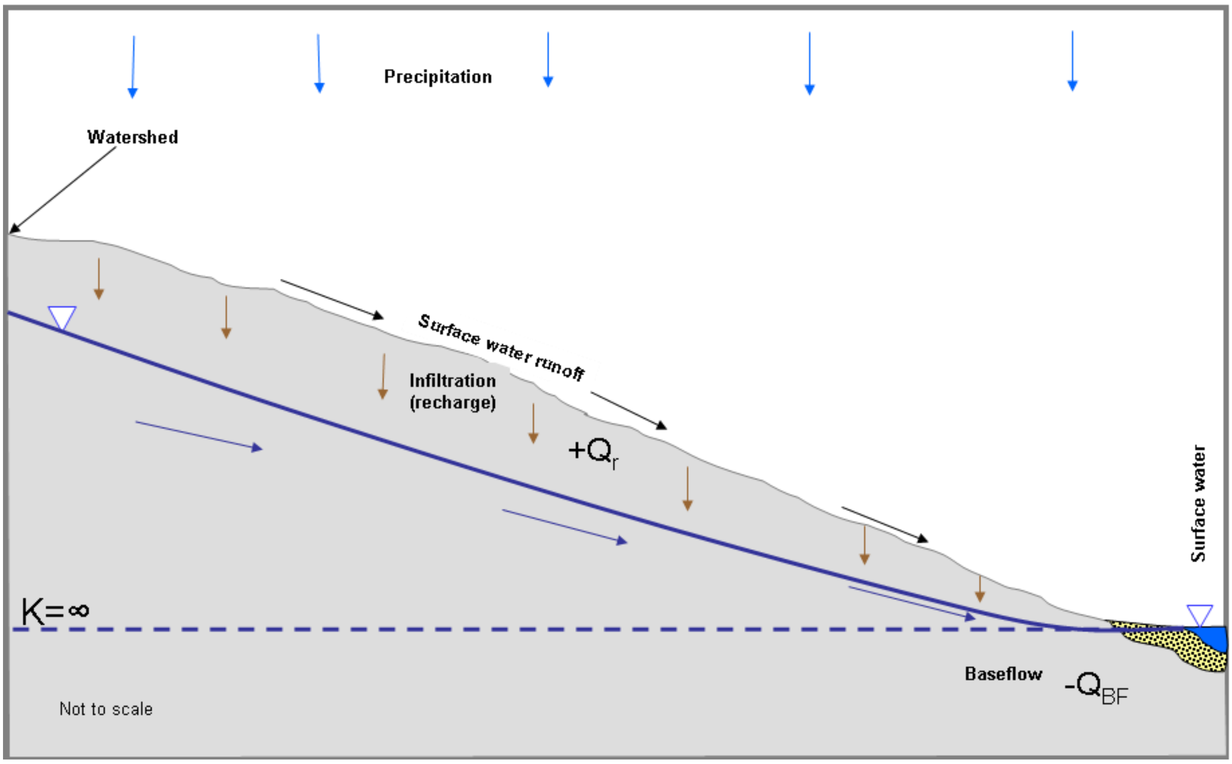

Figure A4-1: Geohydrological steady state conditions

Spring flow and the groundwater component of base flow are associated with evaporation and transpiration losses that will be discussed later.

The piezometric gradient, which can be measured from site characterization and monitoring boreholes are usually known. Boreholes can be pump tested to determine the transmissivity and hydraulic conductivity

The outflow per unit length (L) of aquifer is given by Darcy's law as, q = (K dh/dl) x D, where q is the Darcy flux in m/d (or $m^3/m^2/d$), K is the hydraulic conductivity, D the aquifer thickness and dh/dl is the piezometric gradient.

Since K, D and the head gradient can be measured, a steady-state model can be calibrated by changing the recharge value until the measured and simulated head gradients have a small (or acceptable) error. An acceptable error is usually considered as less than 10% of the aquifer thickness. If the aquifer is for example 40 m thick, then an error of less than 4 m between the measured and simulated head elevations would be considered as acceptable.

A perfectly flat natural head gradient of 0, would imply an infinite hydraulic conductivity (**Figure A4-1**).

A4.4 TRANSIENT FLOW AND EVALUATION OF GROUNDWATER STORAGE VOLUME BUFFERING CAPACITY DURING DRY PERIODS TO PROVIDE ASSURANCE LEVELS

The groundwater flow balance described in the previous section, can be differentiated in additional basic inflow and outflow components and into e.g. annual or monthly time steps.

The regional, quaternary catchment scale GYM was developed on this basis. The purpose is that it must be able to simulate groundwater volume availability based on assurance levels (typically 95%) through a large number of the sub-catchments. In the model, an aquifer was defined as its surface water quaternary catchment equivalent, which would form one cell in the system.

The output of the model should be able to account for the duration of variable rainfall-recharge periods obtained from statistical simulations based on historical rainfall records. It is therefore important to be able to evaluate the ability of the groundwater reservoir to buffer low recharge periods that are characterized by dry cycles (**Figure A4-2**). Stochastic generations of the monthly average rainfall-recharge and the standard deviation were used to determine inflow and accounting for outflow, it was used to evaluate the aquifer's ability to sustain supply. The output was then used to calculate the water balance of each quaternary catchment at a 95% assurance level.

The GYM model was adapted in 2007 and 2008 to account for the components that would be required for the groundwater reserve. The adapted version is known as the Groundwater Yield Model for the Reserve (GYMR).

A4.5 GROUNDWATER MANAGEMENT CONSTRAINT

The concept of a groundwater management constraint (GMC), which is similar to the surface water concept of a Dead Storage Level (DSL) was obtained from the management of surface water dams. The GMC is defined as the minimum level or management constraint to sustain the environment. The volume of the aquifer below that level is not considered as available for supply. This constraint is often selected by the groundwater specialist performing the assessment.

This concept was applied on all aquifers as a minimum level management constraint. As a guideline, 10% to 20% of the saturated thickness of the aquifer was used as the GMC level. If an aquifer is for example 50 m thick, then 5 m to 10 m available drawdown over the entire area was used as the GMC level (Figure A4-3).

In practice, there should be a relationship between the volume in storage (equated to the saturated thickness) of an aquifer and the variability in rainfall-recharge.

A4.6 ASSUMPTIONS

The following assumptions were made:

- In natural steady-state conditions, the recharge equals groundwater base flow minus losses (e.g. evapo-transpiration).
- Any abstraction would result in eventual reductions in groundwater base flow. This approach is conservative, since in reality there would be a time lag, which is longer for distances further away from the base flow or decant point. Under the approach that the model outcomes should be sustainable and to be used in Water Use License applications, this assumption is considered defendable.
- Interaction with surface streams (i.e. base flow) was considered as a net outflow. Inflow from surface water streams was shown as positive groundwater base flow, which indicates a severe depletion in groundwater storage.
- The model considers shallow aquifers (0-100 m). Deep groundwater inflow or outflow is not considered as information or evidence of these processes is not available or readily understood. It is assumed that inflow and outflow from deep groundwater balances.

The conservative assumptions used in the model will yield less water than in the actual case. This approach is in line with the environmental precautionary principle. The aim is not to determine actual groundwater flow balances as it is today, but rather to determine management scenarios that can be used for regulatory requirements and decision making.

A4.7 CONCEPTUAL MODEL

The conceptual groundwater flow model on which the analytical model was based, is shown in **Figure A4-5**. The inflow from groundwater recharge is balanced by outflow to springs, wetlands and groundwater base flow to rivers or streams under natural conditions. In areas where the recharge to evapotranspiration ratio is low, most or all of the groundwater could be lost with the result that the streambed is dry (**Figure A4-5**).

Where anthropogenic influences occur, other losses occur such as boreholes, riparian vegetation and mine dewatering were included.

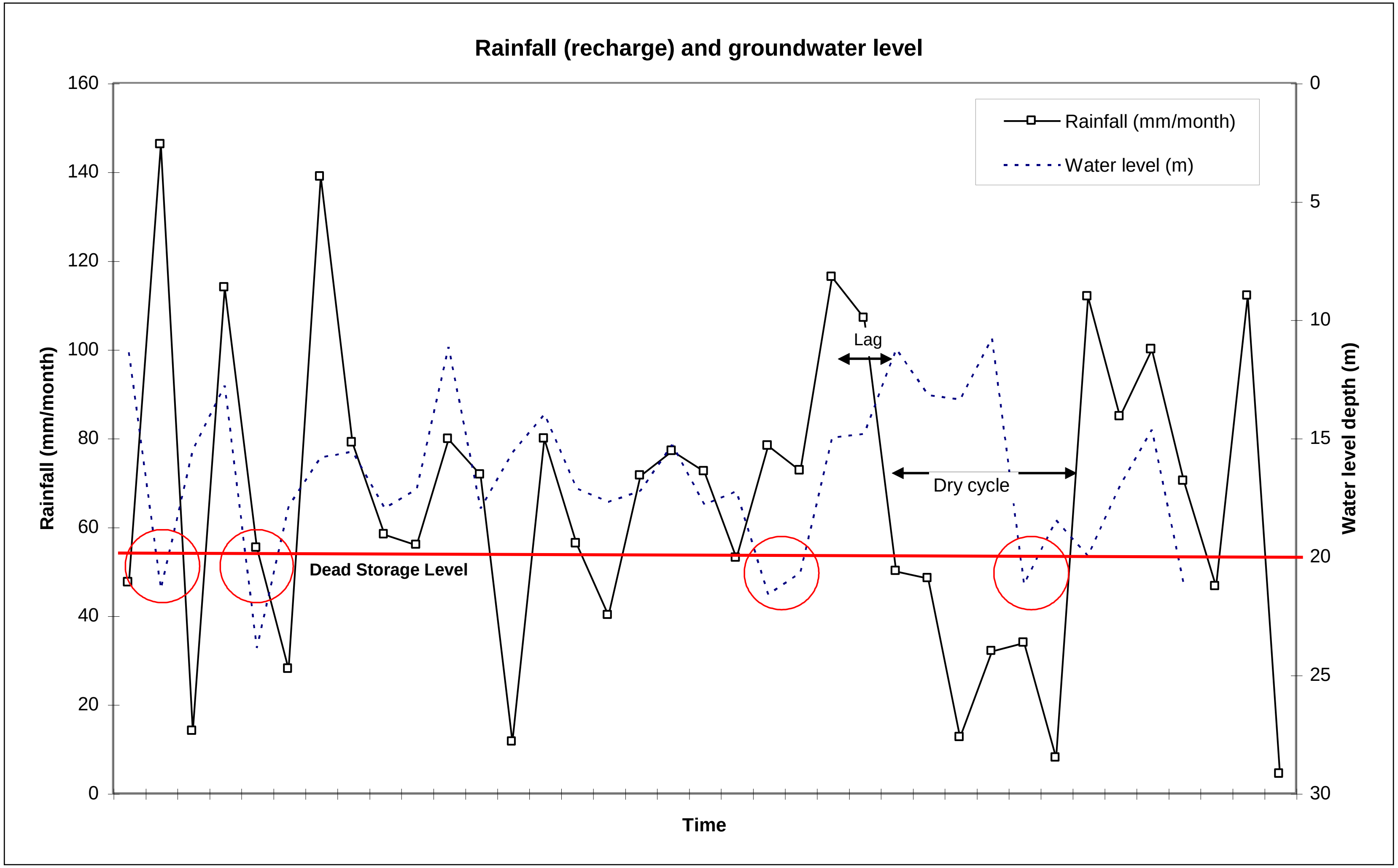

Figure A4-2: Time varying rainfall-recharge conditions showing system failure during dry cycles

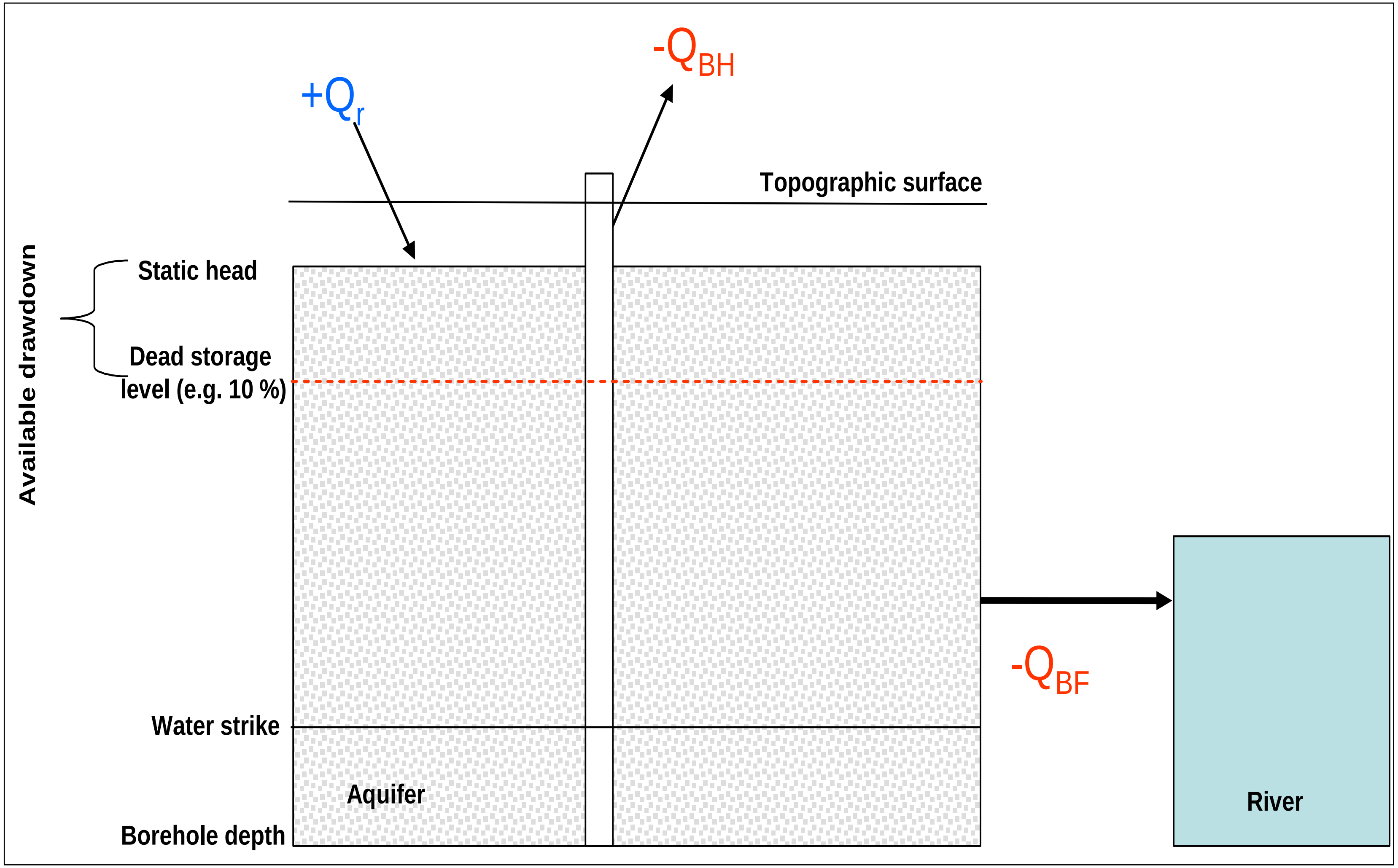

Figure A4-3: Schematic representation of the GYM conceptual model – dead storage level

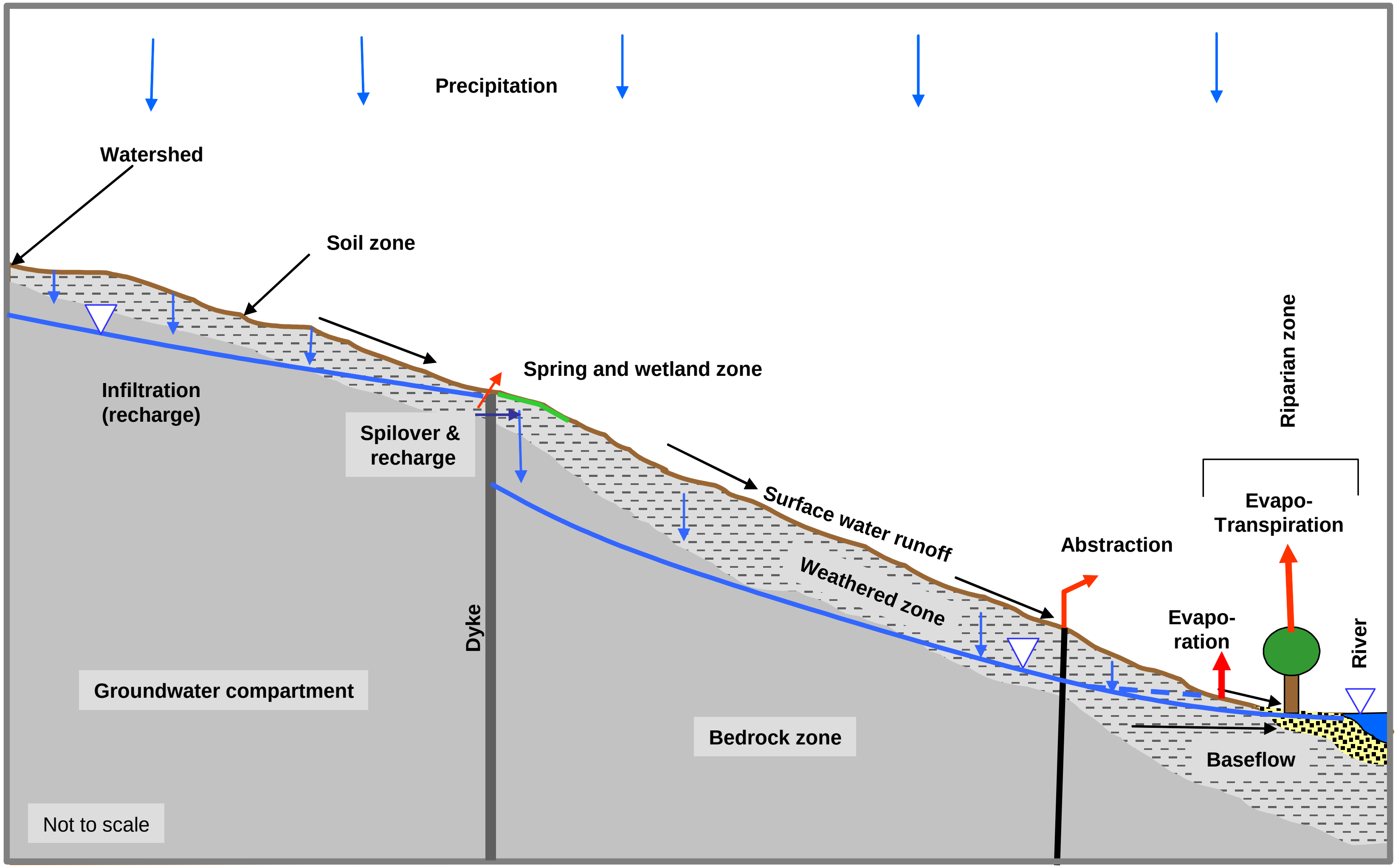

Figure A4-4: Schematic representation of the GYM conceptual model – field conditions (low baseflow loss case)

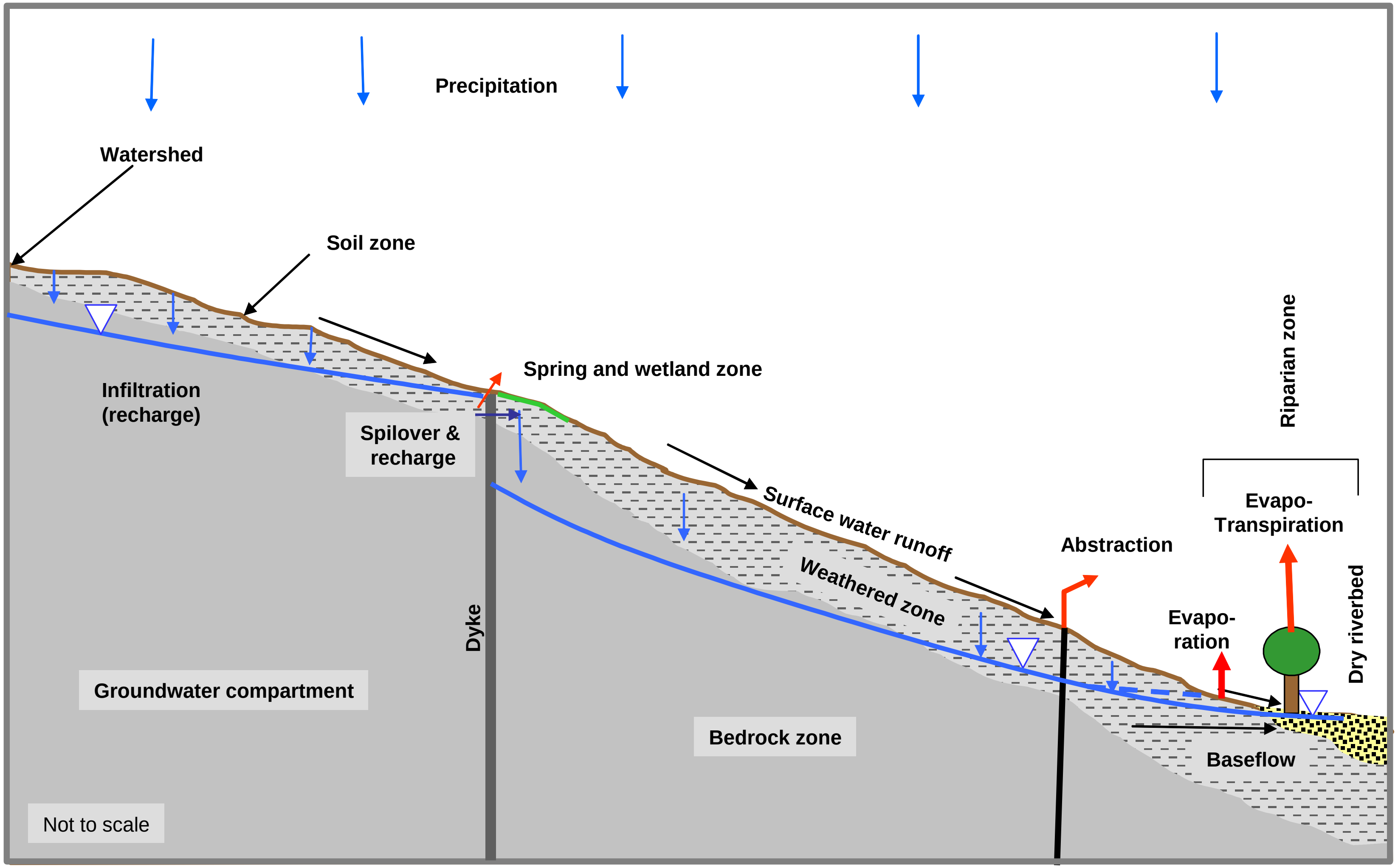

Figure A4-5: Schematic representation of the GYM conceptual model – field conditions (high baseflow loss case)

A4.8 ANALYTICAL MODEL

The transient model is a differentiation of the steady-state, basic case discussed in earlier sections. Distinction is made between natural and unnatural inflow and outflow components. Also between outflow components that are lost (e.g. evapotranspiration especially by alien vegetation) and outflow components where groundwater is used (e.g. Basic Human Need Reserve). Groundwater Loss Components (GLC) is less valuable than Groundwater Use Components (GUC). This is due to the fact that it is more sensible to use groundwater for basic human need purposes than to lose it to alien vegetation. Hence if one has the option to prioritise outflow, all outflow components are not considered of the same importance level.

The purpose of the model is to calculate the volume of groundwater in storage given that the volume of water required by natural systems is allocated for.

The various groundwater flow components are described by the following:

The groundwater inflow from natural systems ($+Q_{GINS}$).

$+Q_R$ = Recharge from rainfall $[L.T^{-1}]$[1]

The groundwater inflow from unnatural systems (+QGIUNS).

$+Q_{DS}$ = Inflow from Dam Seepages $[L.T^{-1}]$

$+Q_{IRR}$ = Return recharge from irrigation $[L.T^{-1}]$

Groundwater loss components (-QGLC).

$-Q_{AVEG}$ Alien vegetation $[L.T^{-1}]$

$-Q_{ETPL}$ Evapo-transpiration losses $[L.T^{-1}]$

$-Q_{MDW}$ Mine dewatering $[L.T^{-1}]$

Groundwater use by natural systems (-QGUNS)

$-Q_{SF}$ Spring flow $[L.T^{-1}]$

$-Q_{GBF}$ Groundwater base flow $[L.T^{-1}]$

$-Q_{WLD}$		**Wetland fed by groundwater**	**$[L.T^{-1}]$**
$-Q_{RVEG}$	=	**Riparian vegetation**	**$[L.T^{-1}]$**
$-Q_{EWR}$	=	**Ecological Water Requirement (component of groundwater base flow)**	**$[L.T^{-1}]$**

Groundwater use by unnatural systems (+QGUUNS)

$-Q_{BH}$	=	**Abstraction from boreholes e.g. well fields for water supply**	**$[L.T^{-1}]$**
$-Q_{LSF}$	=	**Abstraction from boreholes for livestock farming**	**$[L.T^{-1}]$**
$-Q_{BHN}$	=	**Allocation for basic human needs and communities**	**$[L.T^{-1}]$**
$-Q_{IR}$	=	**Abstraction for irrigation**	**$[L.T^{-1}]$**
$-Q_{F}$	=	**Forestry groundwater use**	**$[L.T^{-1}]$**

Volume of groundwater in storage (GVST)

$+GV_{ST}$	=	**Volume of groundwater in storage**	**$[L^3]$**

In a natural, steady-state situation, the groundwater balance equation for the model is given by:

$$\Delta GV_{ST} = Q_R - Q_{GETL} - Q_{GBF} \quad (2)$$

In an unnatural groundwater system, the groundwater flow balance per time step is given by:

$$\Delta GV_{ST} = Q_R + Q_{DS} - Q_{BH} - Q_{LSF} - Q_{BHN} - Q_{IR} + Q_{IRR} - Q_{MDW} - Q_F - Q_{AVEG} - Q_{WLD} - Q_{RVEG} - Q_{SF} - Q_{GETL} - Q_{GBF} - Q_{EWR} \quad (3)$$

It is evident that the groundwater used by natural systems (spring flow and groundwater base flow) is last in the flow sequence. This is because in the physical flow system, unnatural groundwater use such as from boreholes and mine shafts can utilise water before it has the opportunity to flow to a natural system. The flow sequence is therefore important. Groundwater base flow of which the Ecological Water Requirement (EWR) is a component, is the last component to receive groundwater. When outflow exceeds inflow in any given time step, water would be taken firstly from storage and then from base flow. A supplementary conservative assumption that can be made is to allocate a minimum volume to groundwater base flow in the model. If outflow exceeds inflow, water would be taken mainly from storage until the head declines to the defined management constraint. Once the volume in storage is used, it is possible for base flow to reverse (i.e. inflow into the groundwater system, which is implemented as positive base flow in the model, which must be activated in the model) and have a flow reduction effect on the river. A maximum volume was implemented as a constraint in the model as the user need to determine whether the specific surface water resource has a flow constraint prior to activation of the possibility of reverse base flow. This is because most surface water streams in South Africa is dry for most of the times of the year, which would not allow reverse base flow from the stream to the aquifer.

The groundwater balance from equation (3) is calculated for monthly time steps (Δt) to yield an annual or monthly groundwater balance at a chosen assurance level.

The model output is put into perspective for the groundwater component of the reserve. The various flow components are discussed in more detail in the following section.

Groundwater volume in storage (GVST)

The volume of groundwater in storage is determined from:

$$GV_{ST} = A \times D \times S_0 \qquad \textbf{(4)}$$

A	**=**	**Surface area of the aquifer**	**[L^2]**
D_{GMC}	**=**	**Saturated thickness of the groundwater management constraint (GMC)**	**[L]**
S_0	**=**	**Specific Storativity**	**[1]**

The volume in storage is calculated for each time step (Δt) and from which an average change in groundwater head is determined by:

$$\Delta \mathbf{h} = \frac{\mathbf{V}}{\mathbf{S_0}} \qquad \textbf{(5)}$$

Δh	**=**	**Change in head during time step**	**[L]**
V	**=**	**Net volume of water during time step**	**[L^3]**

The model output graphs are given in terms of average depth to groundwater level based on available volume within the management constraint.

A4.9 VARIABLE RECHARGE (+QR)

The groundwater recharge is calculated as a percentage of rainfall that is assumed to reach the aquifer, on a monthly basis. Data from the historical rainfall records is used to determine the monthly average rainfall (**Figure A4-6**). The standard deviation for a 95% assurance level is then used to obtain a range within which the monthly rainfall-recharge is sampled (**Figure A4-6**). It is important to note that the 95% assurance level is much lower than the average rainfall, which is typical for semi-arid and arid conditions, which is prevalent in South Africa.

The sampling is done on a random basis within the statistical rainfall distribution.

When the aquifer is full, no additional recharge is accepted in the model. In reality, piezometric levels could rise above the static levels during wet periods. Provision could be made to allow e.g. a 10% over saturation of the aquifer, which would increase the available volume of water.

A4.10 DAM SEEPAGE (+QDS)

Seepage from dams is determined by:

$$Q_{DS} = K_C \frac{dh}{dl} \times A_D \qquad (6)$$

K_C	**=**	**Hydraulic conductivity of the colmation layer formed by dam sediments**	**[$L\ T^{-1}$]**
$^{dh}/_{dl}$	**=**	**Head gradient (assumed to be 1 for vertical seepage)**	**[1]**
A_D	**=**	**Surface area of dam/s**	**[L^2]**

This component is used conservatively with known dams and parameters, otherwise it is considered to be zero to prevent an overestimation of the groundwater volumes. Provision is made to allow dam seepage for only the wet seasons or e.g. 30% of the hydrological year when it will have a positive head.

A4.11 ABSTRACTION FROM BOREHOLES FOR LIVESTOCK FARMING (-QBH)

Abstraction from boreholes that are used for farming is used as an outflow component. For the Lower Vaal reserve determination an average of one head of cattle per 20 ha was used and a consumption of 60 ℓ/c/d.

A4.12 ALLOCATION FOR BASIC HUMAN NEED (-QBHN)

Groundwater is an important source of water supply for basic human needs, especially for communities in rural areas. For areas that rely on groundwater as a source of supply, the allocation is made on between 25 ℓ/c/d to 60 ℓ/c/d. The population in the area is obtained from census and spatial GIS data bases, which is then used to calculate the basic human need allocation.

A4.13 BOREHOLE ABSTRACTION FOR IRRIGATION (-QIR)

Water use for irrigation is obtained from the total surface area that is used for irrigation. The water use is determined by using 1 ℓ/s/ha/d (80 m^3/ha/d) in the growing season. The irrigation areas are determined from GIS and remote sensing spatial data (satellite or aerial photographs).

In cases where Water Use Licensing information for sub-catchments is available, it will be considered as backup check. The licensed or registered volumes are usually higher than the actual use. In the Lower Vaal Study the WARMS registered data was used.

A4.14 RETURN RECHARGE FROM IRRIGATION (+QIRR)

The return flows from irrigation acts as a source of groundwater recharge. In some cases, surface water is abstracted which is then used to irrigate on aquifers located further away from the surface water sources. If irrigation is optimal, no through flow to the aquifer should occur. However, lower water quality (especially Na and Cl) and certain soil types (clay) pose risks of soil salinization. In these cases, over-irrigation is required to flush the salt load from the soils, which then contaminates the aquifer over time.

The default assumption is made that e.g. 10% to 20% of the volume used for irrigation, recharges the aquifer.

A4.15 MINE DEWATERING (-QMDW)

When mines operate below the groundwater level, it will induce inflow and cone of depression develops around it. Standard practice is to grout (i.e. seal) groundwater inflows, which is effective where the rock mass is competent and inflow occurs from isolated discrete fracture zones. Where the inflow occurs from homogeneously fractured or weathered rock units, sealing is in most cases ineffective or costly. High groundwater head pressure behind mine stopes could also cause failures. In these cases, the aquifer is dewatered to create a safe working environment.

The mine dewatering volume is determined by:

$$Q_{MDW} = K \frac{dh}{dl} \times A_{MS} \qquad \textbf{(7)}$$

K	**=**	**Hydraulic conductivity of mine workings**	**$[L\ T^{-1}]$**
dh/dl	**=**	**Head gradient (assumed to be 1 for vertical seepage)**	**[1]**
AMS	**=**	**Surface area of mine slopes and shafts**	**$[L^2]$**

The information from equation (7) is generally too detailed to obtain for a quaternary catchment scale model. Direct information on the volumes dewatered could be obtained from mines, as it is essential data to collect and could be included directly into the model as a flow volume and not a calculated parameter.

A4.16 ALIEN VEGETATION (-QAVEG)

Alien vegetation often accounts for large reductions in groundwater volumes by intercepting seepage along springs and in the riparian zone. The groundwater use by alien vegetation systems are determined by;

$$Q_{AVEG} = (Q_P - Q_{ET})\times A_{AVEG} \qquad \textbf{(8)}$$

Q_P	**=**	**Mean Annual Precipitation**	**$[L\ T^{-1}]$**
Q_{ET}	**=**	**Mean Annual evapo-transpiration (MAE) rate of alien vegetation**	**$[L\ T^{-1}]$**
A_{AVEG}	**=**	**Surface area covered by alien vegetation**	**$[L^2]$**

The areas covered by alien vegetation are determined from GIS and remote sensing and/or field mapping. It is important to determine the depth to groundwater in areas covered by alien vegetation, because the areas used in this component must use groundwater directly. The depth to groundwater in this case should not be greater than e.g. 10 m, because deeper groundwater is unlikely to experience losses due to alien vegetation.

A4.17 FORESTRY (-QF)

Forests that intersect the groundwater zone would have a similar effect on groundwater reduction than alien vegetation. The groundwater used by forests is determined in a similar way from:

$$Q_F = (Q_P - Q_{ET}) \times A_F \quad (9)$$

Q_P	=	**Mean Annual Precipitation**	**[L T^{-1}]**
Q_{ET}	=	**Mean Annual evapo-transpiration (MAE) rate of alien vegetation**	**[L T^{-1}]**
A_F	=	**Surface area covered by alien forests**	**[L^2]**

A4.18 WETLANDS FED BY GROUNDWATER (-QWLD)

Permanent wetlands that are sustained by groundwater would use water equal to the net evapotranspiration;

$$Q_{WLD} = (Q_P - Q_{ET}) \times A_{WLD} \quad (10)$$

QP	=	**Mean Annual Precipitation**	**[L3 T-1]**
QET	=	**MAE rate of wetland and wetland vegetation**	**[L3 T-1]**
AWLD	=	**Surface area of wetland**	**[L2]**

The information is obtained from GIS coverage and field mapping of the total surface area covered by wetlands that are supported by groundwater. Wetlands within 1 km from a river are assumed to be supported by surface water. Only those wetlands located away from surface water features are included in the groundwater assessment.

A4.19 RIPARIAN VEGETATION (-QRVEG)

Riparian vegetation also accounts for reductions in groundwater volumes by intercepting seepage along springs and in the riparian zone. Riparian vegetation is indigenous and in general does not use as much water as alien vegetation. Riparian vegetation has environmental importance because it supports ecosystems. The groundwater use by natural riparian vegetation systems are determined by:

$$Q_{RVEG} = (Q_P - Q_{ET}) \times A_{RVEG} \quad (11)$$

QP	=	**Mean Annual Precipitation**	**[L3 T-1]**
QET	=	**Potential MAE rate of riparian vegetation**	**[L3 T-1]**

ARVEG	**=**	**Surface area covered by riparian vegetation**	**[L2]**

A4.20 SPRING FLOW (-QSF)

The outflow to springs is directly determined by measuring the cumulative flow of springs (-QSF) in the catchment. It is assumed that there would be losses between the aquifer and the spring if e.g. groundwater seeps out in a zone around the actual spring eye and opportunity exists for evapotranspiration losses.

A4.21 GROUNDWATER EVAPOTRANSPIRATION LOSSES (-QGETL)

Groundwater evapotranspiration losses occur in the groundwater-surface water interaction zone, where the groundwater level is shallow, along drainages and streams, springs and at seepage zones. It was found that in the Olifants Catchment, the MAP is e.g. 600 mm, while the MAE is in the order of 1400-1800 mm. The MAE is more than double the MAP. Groundwater recharge is in the order of 2 - 4% (except dolomites, where it is much higher at 8 to 15%) of the MAP. The potential groundwater evapo-transpiration losses are therefore 50 to70 times higher than the recharge. It means that the total groundwater recharge could be lost over a groundwater evapotranspiration loss area of 1 to 2% of the catchment area.

The groundwater evapotranspiration loss is determined from:

$$Q_{GETL} = MAE \ x \ A_{ET} \qquad \textbf{(11)}$$

QGETL	**=**	**Groundwater evapo-transpiration loss**	**[L T-1]**
MAE	**=**	**Potential MAE**	**[L]**

A4.22 GROUNDWATER BASE FLOW (-QGBF)

Groundwater base flow is a function of the groundwater recharge minus losses in the aquifer system. Groundwater base flow is often the last component in the flow sequence to receive water. It is influenced by recharge and the hydraulic parameters of the aquifer.

Groundwater base flow can be determined from:

$$Q_{BF} = K \frac{dh}{dl} \times D \times L \qquad \textbf{(12)}$$

K	**=**	**Hydraulic conductivity of the general aquifer**	**[L T-1]**

dh/dl	**=**	**Head gradient (assumed to be correlated to topography)**	**[1]**
D	**=**	**Saturated thickness**	**[L]**
L	**=**	**Length of drainage system along which groundwater base flow occurs**	**[L]**

If the recharge, aquifer losses, aquifer thickness (D) and length of outflow (L) is known, the minimum transmissivity (or hydraulic conductivity) of the aquifer to allow groundwater base flow can be determined.

A4.23 GROUNDWATER BASE FLOW, ECOLOGICAL WATER REQUIREMENT (-QEWR)

The component of base flow that is required for the ecological reserve is determined by ecological water specialists. If this value is provided, it can and should be included in the model to determine whether it can be sustained by groundwater alone or which percentage of e.g. the drought low flow component could be sustained by groundwater. More research on the model implementation is required on this section.

The component of groundwater that could be utilised in a catchment would typically be the groundwater base flow minus the ecological water requirement. It is for now assumed that the flow loss component is fixed. In practice alien vegetation could be reduced to reduce the flow losses or groundwater could be used before it is allowed to undergo flow losses. This would be a management decision taken for each catchment based on the flow and environmental character.

A4.24 DEEP GROUNDWATER INFLOW AND OUTFLOW

There are possibilities for inflow from or outflow to deep seated aquifers, which stretches beyond the quaternary boundary. Provision is made for deep groundwater inflow and outflow as a flow component +QDGW and –QDGW. Unless data from e.g. shallow and deep boreholes with piezometric head elevations can be provided to prove that deep groundwater flows into or out of the system, the assumption is made that these two components are zero. The assumption could also be made that outflow to and inflow from deep aquifers balance with a zero effect.

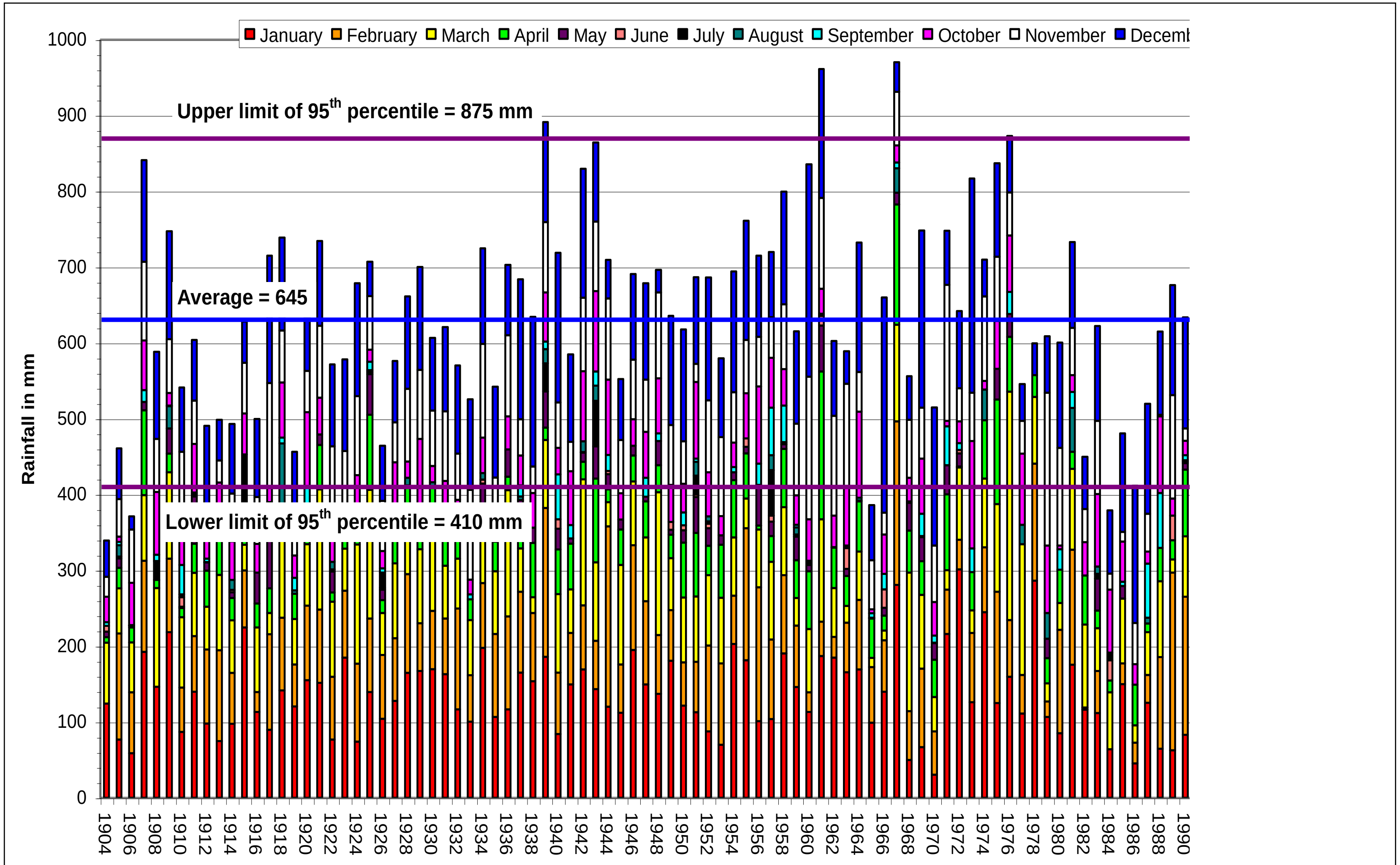

Figure A4-6: Monthly and annual rainfall data for station 0548280 (Saulspoort Hospital) from 1904 to 2002

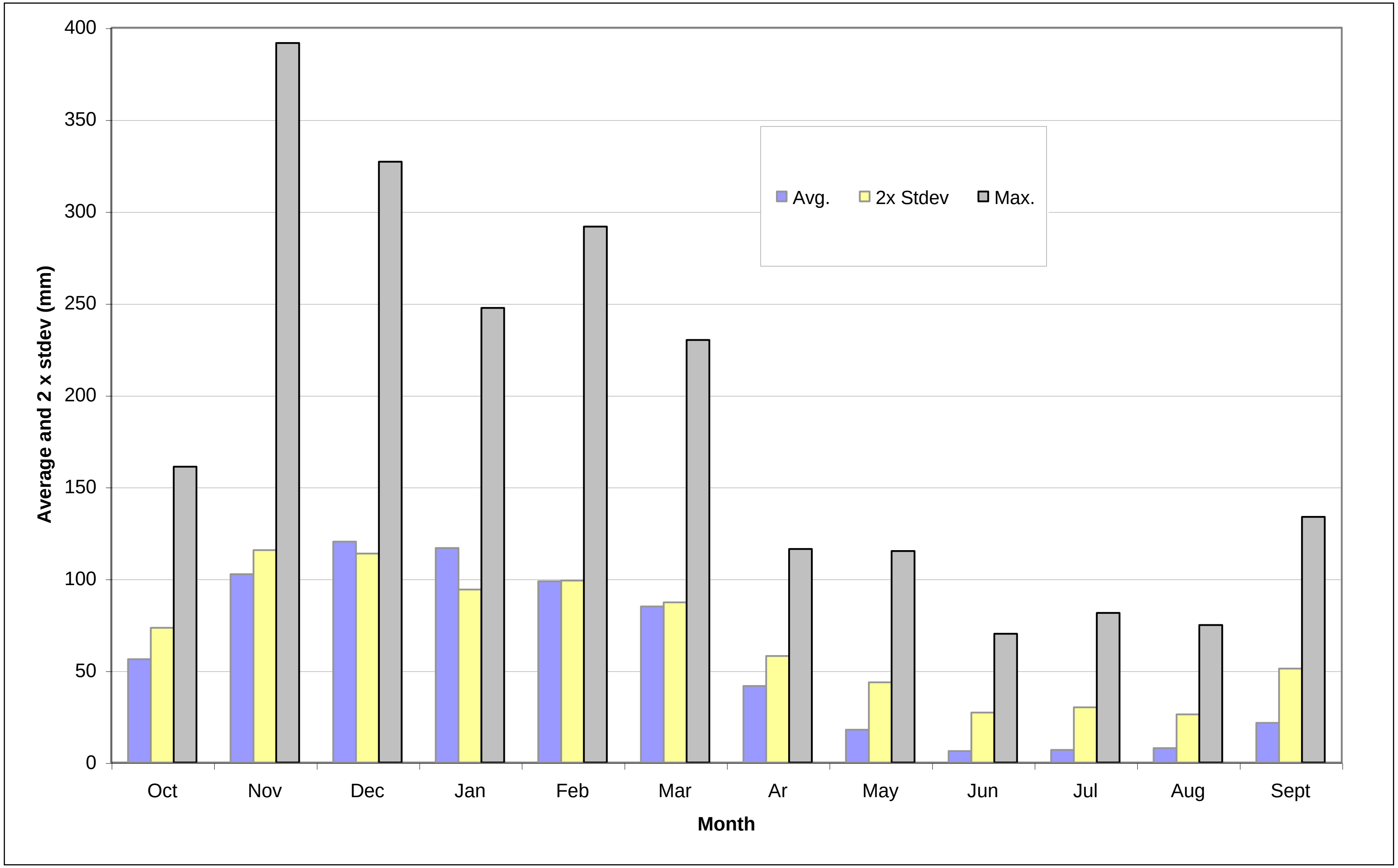

Figure A4-7: Average monthly rainfall and standard deviations – showing the variability

A5 REFERENCES

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Appendix B

Lusikisiki Numerical Groundwater Flow Model

Lusikisiki Groundwater Flow Model Report

02 April 2012

Conducted on behalf of:

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Notations and terms

Advection is the process by which solutes are transported by the bulk motion of the flowing groundwater.

Anisotropic is an indication of some physical property varying with direction.

Cone of depression is a depression in the groundwater table or potentiometric surface that has the shape of an inverted cone and develops around a borehole from which water is being withdrawn. It defines the area of influence of a borehole.

A **confined aquifer** is a formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

The **darcy flux**, is the flow rate per unit area (m/d) in the aquifer and is controlled by the hydraulic conductivity and the piezometric gradient.

Dispersion is the measure of spreading and mixing of chemical constituents in groundwater caused by diffusion and mixing due to microscopic variations in velocities within and between pores.

Drawdown is the distance between the static water level and the surface of the cone of depression.

Effective porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices that are connected.

Groundwater table is the surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

A **fault** is a fracture or a zone of fractures along which there has been displacement.

Hydrodynamic dispersion comprises of processes namely mechanical dispersion and molecular diffusion.

Hydraulic conductivity (K) is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured perpendicular to the area [L/T]. Hydraulic conductivity is a function of the permeability and the fluid's density and viscosity.

Hydraulic gradient is the rate of change in the total head per unit distance of flow in a given direction.

Heterogeneous indicates non-uniformity in a structure.

Karstic topography is a type of topography that is formed on limestone, gypsum, and other rocks by dissolution, and is characterised by sinkholes, caves and underground drainage.

Mechanical dispersion is the process whereby the initially close group of pollutants are spread in a longitudinal as well as a transverse direction because of velocity distributions.

Molecular diffusion is the dispersion of a chemical caused by the kinetic activity of the ionic or molecular constituents.

Observation borehole is a borehole drilled in a selected location for the purpose of observing parameters such as water levels.

Permeability is related to hydraulic conductivity, but is independent of the fluid density and viscosity and has the dimensions L2. Hydraulic conductivity is therefore used in all the calculations.

Piezometric head (ϕ) is the sum of the elevation and pressure head. An unconfined aquifer has a water table and a confined aquifer has a piezometric surface, which represents a pressure head. The piezometric head is also referred to as the hydraulic head.

Porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

Pumping tests are conducted to determine aquifer or borehole characteristics.

Recharge is the addition of water to the zone of saturation; also, the amount of water added.

Sandstone is a sedimentary rock composed of abundant rounded or angular fragments of sand set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material.

Shale is a fine-grained sedimentary rock formed by the consolidation of clay, silt or mud. It is characterised by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

Specific storage (S0), of a saturated confined aquifer is the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head. In the case of an unconfined (phreatic, watertable) aquifer, specific yield is the water that is released or drained from storage per unit decline in the watertable.

Static water level is the level of water in a borehole that is not being affected by withdrawal of groundwater.

Storativity is the two-dimensional form of the specific storage and is defined as the specific storage multiplied by the saturated aquifer thickness.

Total dissolved solids (TDS) is a term that expresses the quantity of dissolved material in a sample of water.

Transmissivity (T) is the two-dimensional form of hydraulic conductivity and is defined as the hydraulic conductivity multiplied by the saturated thickness.

An **unconfined, water table or phreatic aquifer** is different terms used for the same aquifer type, which is bounded from below by an impermeable layer. The upper boundary is the water table, which is in contact with the atmosphere so that the system is open.

Vadose zone is the zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table.

Water table is the surface between the vadose zone and the groundwater, that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

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B1 INTRODUCTION

B1.1 BACKGROUND

AGES (Pty) Ltd, here after referred to as AGES, was appointed by BKS and DWA to conduct a groundwater reserve determination and groundwater flow model within the Lusikisiki study area as set out in the inception report. The GYMR will serve the purpose of delineating and quantifying the availability of groundwater in the region as well as being a decision making tool in future resource management.

This section of the report however covers the data and summary of the groundwater flow model used in order to simulate the current and possible future state of the Lusikisiki groundwater systems. The outcome of the model simulations will be compared to the values calculated in the GYMR.

B1.2 INTRODUCTION TO GROUNDWATER FLOW MODEL

The groundwater flow model was constructed to assist in the decision making process during which the groundwater regime is impacted by an activity, in this case groundwater abstraction for water supply to the Lusikisiki project activities and schemes. The groundwater flow model is a simplification and numerical simulation of the real world system. The area delineated for the Lusikisiki groundwater flow model covers an area of 660.76 km^2. The modelled sub-catchment within the larger project area was chosen on the base of physical boundaries such as drainages, watersheds, rivers and no flow boundaries as well as the positions of existing boreholes to be used, and areas still to be explored in a groundwater supply capacity. Borehole and water level data for the model were sourced from various data sets from SRK drilled boreholes, NGDB data, Grip data and geological maps. The amended data included historical and recently recorded hydrocensus data.

B1.3 MODEL OBJECTIVES

The aim of the groundwater flow model is to simulate the groundwater system to determine the groundwater flow balance, groundwater flow directions, sustainability of the local developed well fields as well as regional existing wells for water supply and the cumulative impact on the local environment, if any. The aim of this model was to gain an understanding of the groundwater flow dynamics and was used to:

1. Evaluate the current state of the groundwater systems within the study area and to compare the steady state water balance to the GYMR model outcomes, which was also done as part of this study.

2. Estimate and evaluate proposed pumping rates, taking into account temporal and spatial factors as well as transient long term abstraction of groundwater from the proposed region.

3. Determine the radius of influence and impacts of well field pumping and dewatering on specified water users and the environment, as well as to evaluate the impact of conceptual future groundwater abstraction points.

4. The aim was to simulate the groundwater flow dynamics in the context of the scale of the assessment.

B1.4 MODEL OBJECTIVES

The following forms part of the scope of work for the Lusikisiki Groundwater flow model:

1. Evaluating and processing existing data on GIS, reports and hydraulic parameters.
2. Setting up spatial files and data sets to be used in the model.
3. Mesh generation and data input.
4. Model calibration.
5. Scenario simulations.
6. Sensitivity analysis.
7. Comparison between model outcomes and GYMR values.
8. Report on the model outcome with conclusions and recommendations.

B2 CONCEPTUAL MODEL

In concept the hydraulic system is dependent on recharge from rainfall and is driven by topographic elevation differences, which in turn gives piezometric head differences. There are several hydraulic zones each with a different hydraulic character and parameters.

The regional modelled catchment covers an area of 660.76 km^2. All geological sequences and aquifers are indicated in the conceptual model, with parameters not shown due to changes and adjustment of parameters in the groundwater flow model needed to simulate scenarios accurately. Most of the aquifers in the region are fractured rock aquifers with the exception of alluvial sequences.

The conceptual model was compiled to illustrate the different aquifers and the effect of pumping on the regional groundwater level, but it is however not a 100% accurate depiction of reality and is merely a simplification to understand the system. **Figure B2-1** depicts the current groundwater situation. Based on the geological location of the project there are six geological units. The dolerite intrusions and sills that are scattered around the region are aquicludes which only allows recharge and groundwater flow through fractures and faults. The sandstones and weathered shale, mudstone and tillite sequences are identified as fractured aquifers holding water in storage in both pore spaces and fractures.

The primary aquifers of the region are the alluvial sands, Natal group sandstones and Dwyka tillite with the highest recharge and transmissivity rates being in the alluvial aquifers. The water source for the specified aquifers mainly originates from recharge from rainfall. In a minor volume the seepage from the streams during the rainy season contribute to recharge as well. When the water table reaches a level near surface as observed in many locations across the study area, the water often discharges at surface. These points of discharge are called springs or fountains and usually occur along contacts between geological strata or where groundwater is captured and trapped due to impervious dolerite dykes. The numerous springs in the study area is also a supporting factor to the good correlation between surface elevation and hydraulic head **Figure B2-1**. The groundwater of the region follows the topography with a R2 of 0.99 indicating an almost 100% correlation, and thus the general flow of groundwater will follow topography towards the main catchments near the coast.

When higher than normal rainfall and a recharge event occurs, base flow in the drainage lines and spring flow which originates from increasing hydraulic heads i.e. a shallow groundwater table, allows water to be lost through evapotranspiration along the riparian zone. In **Figure B2-1**, the above conceptual model is visually represented. It is shown that pumping of water supply boreholes for the project will most probably cause a lowering of the water table in the area; this can only be confirmed with modelling and continuous monitoring.

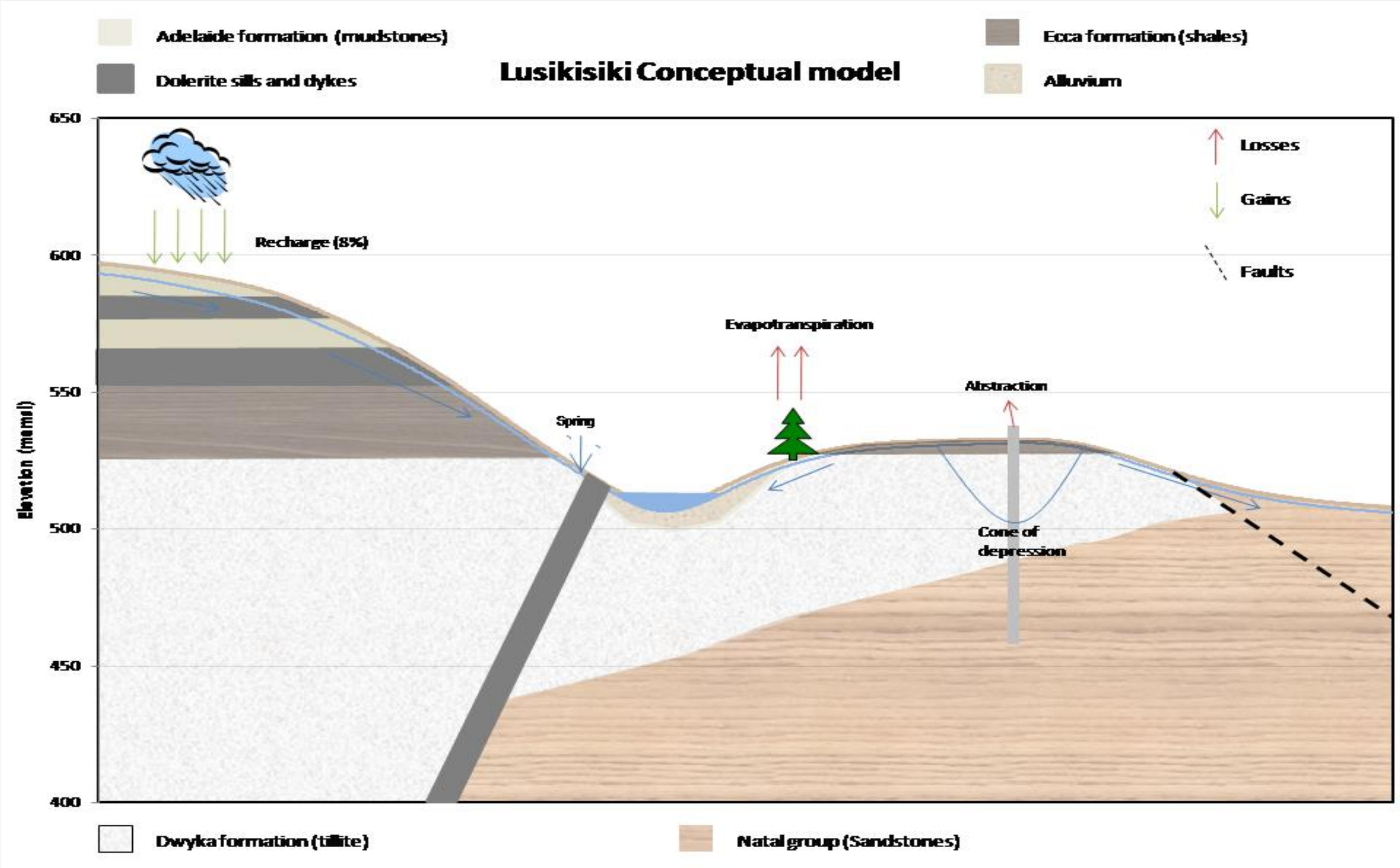

Figure B2-1: Conceptual Model

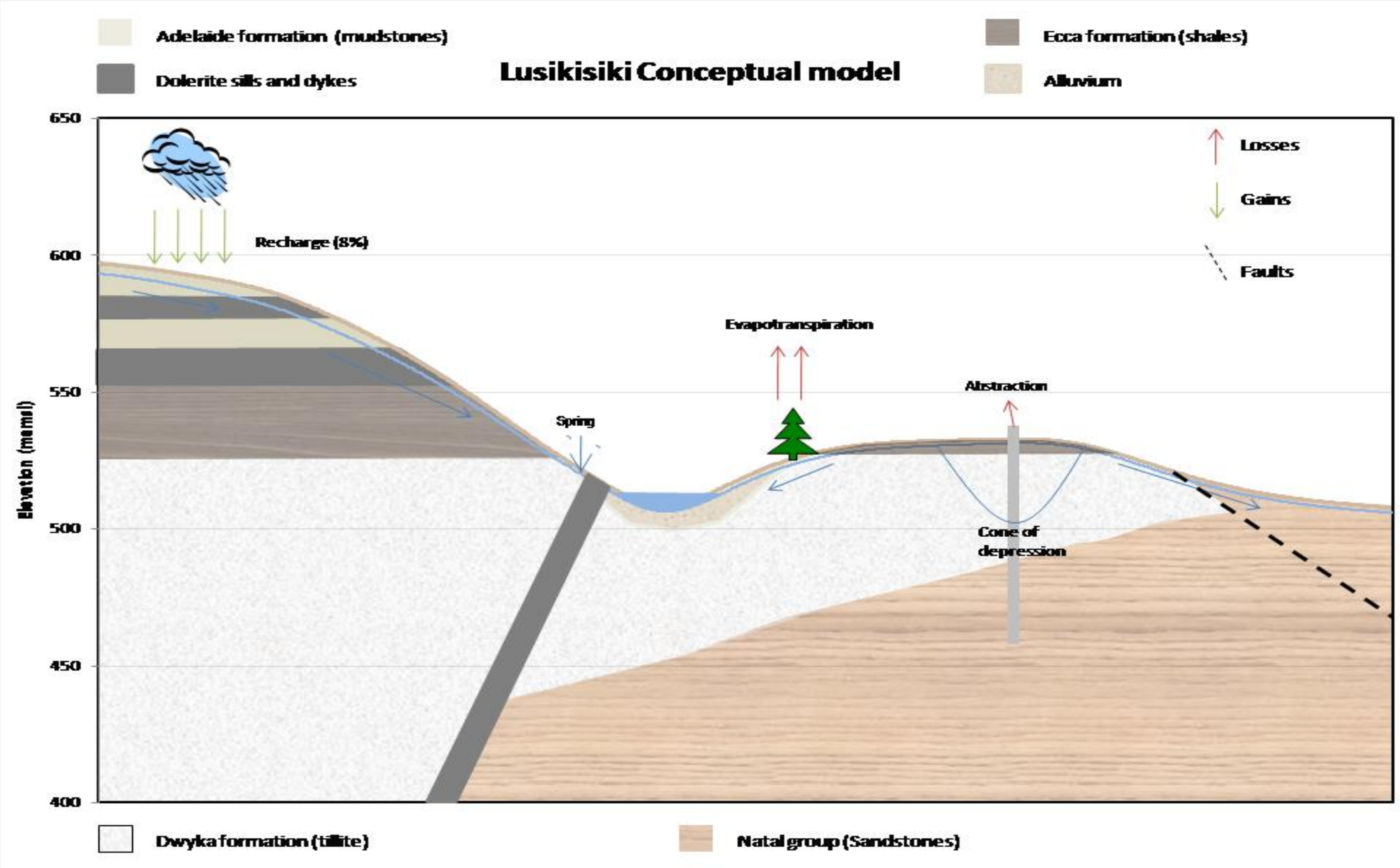

Figure B2-2: Correlation between the measured head in boreholes and the topographical elevation of the region

B3 GROUNDWATER FLOW MODELLING

MODEL SETUP

A two dimensional numerical groundwater flow model was developed for the sub-catchment using the modelling package Feflow 5.4 (www.feflow.info). The groundwater model was developed using 216 568 elements and 109 095 nodes to generate a mesh that differentiates the model domain (**Figure B3-2**) into a finite element mesh (**Figure B3-3**). The model was constructed with one layer, two dimensions.

The rivers were included explicitly to enhance simulation results and accuracy during calibration by constraining hydraulic heads along drainages to that of elevation. Important modelling zones were delineated to simulate the impact on groundwater flow more accurately, through identifying the different geological zones and the impact of rivers and topography. Recharge coefficients were estimated for each identified zone. Furthermore recharge and flow initials were adjusted accordingly at points and identified regions as it should be kept in mind that the system is not a homogeneous system, and thus parameters can vary regularly.

ASSUMPTIONS AND MODEL LIMITATIONS

The following assumptions were made for this model:

1. The geological structures (faults/dykes) were modelled as permeable linear zones based on data from geological map sheet 3128 Umtata map.
2. Prior to development, the system is in equilibrium and therefore in steady state.
3. The rivers and drainage lines are modelled as constraint head boundaries.
4. Transmissivity and recharge values were assumed based on field data and aquifer test analyses, with climatic impacts taken into account.
5. Where data was absent or insufficient, values were assumed based on literature studies and referenced accordingly.
6. The accuracy and scale of the assessment will result in deviations at point e.g. individual boreholes.
7. System inaccuracies were corrected based on estimations and assumptions at points as it is assumed that the system materials are not homogeneous.
8. Scenarios that were simulated were based on info supplied by the client i.e. duration of projects and abstraction and the volume of water to be abstracted from SRK drilled boreholes.

9. Conceptual boreholes were implemented at places of future exploration potential.

10. Comparisons between GYMR outcomes and the Groundwater Flow Model were made on the assumption that the modelled area will be comparable to 57% of the GYMR values due to the aerial extent differences.

When assumptions were made or reference values used, a conservative approach was followed.

Information Box B1 (refer to Figure B3-1)

In natural steady-state conditions, the net groundwater inflow from recharge is balanced by base flow and losses (+spring flow if springs exist) (Figure B3-1). The groundwater balance is given by $+Q_r - Q_{BF-} Q_{GFL} = 0$. The piezometric gradient, which can be measured from site characterization and monitoring boreholes are known and the boreholes can be pump tested to determine the transmissivity and hydraulic conductivity.

The outflow per unit length (L) of aquifer are given by Darcy's law as, $q = (K\frac{dh}{dl})xD$ ***where q is the Darcy flux in m/d (or m³/m²/d) and K is the hydraulic conductivity, D the aquifer thickness and dh/dl the piezometric gradient. Since K, D and the head gradient can be measured, a steady-state model can be calibrated by changing the recharge value until the measured and simulated head gradients have a small (or acceptable) error. An acceptable error is usually less than 10% of the aquifer thickness. If the aquifer is for example 40 m thick, then an error of less than 4 m between the measured and simulated head elevations could be considered as acceptable.***

Note that in a steady-state flow model, the term for aquifer storativity disappears making it easier to calibrate the model with less variables.

A perfectly flat head gradient of 0 will imply an infinite hydraulic conductivity. This process can be used to calibrate a regional steady-state model for recharge and transmissivity where a groundwater head distribution (i.e. head gradient) is known from field measurements. If e.g. transmissivity ranges are known from field tests, recharge can be quantified.

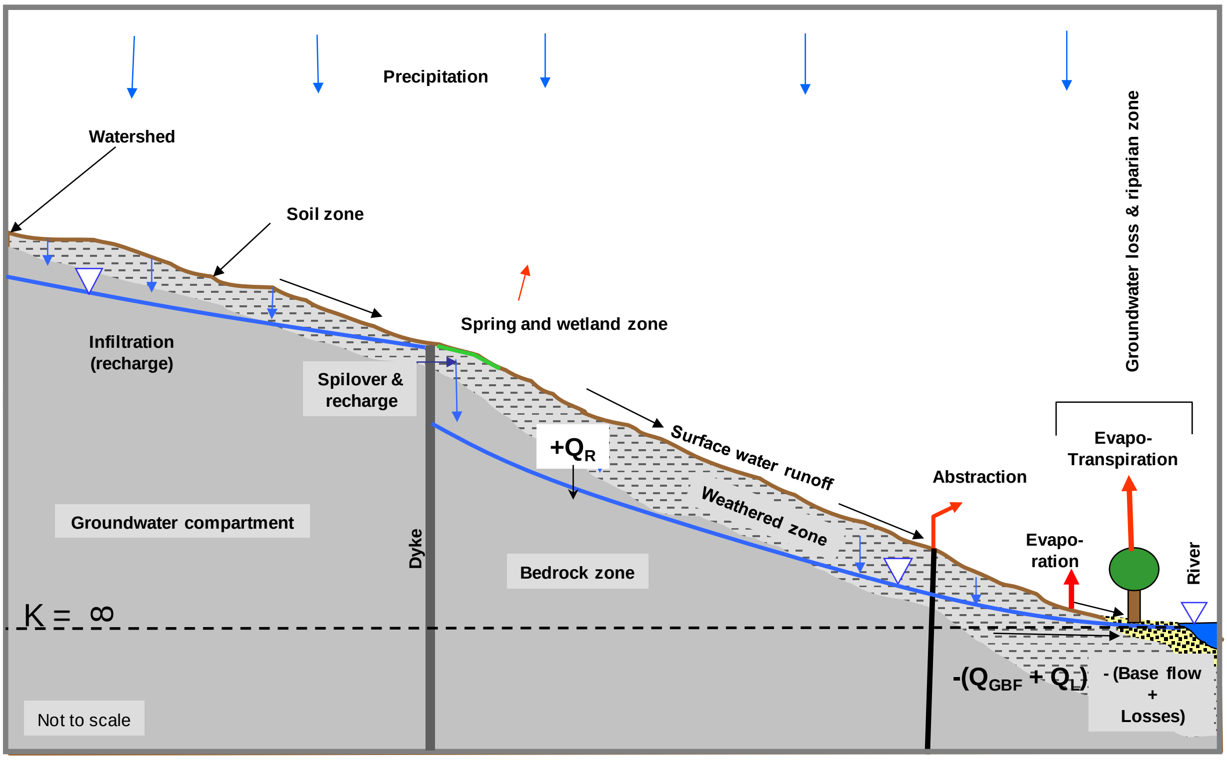

Figure B3-1: Conceptual model of the steady state flow scenario (refer to Information Box B)

Model Scale, Context and Accuracy

The regional model context and accuracy were based on existing 1:50 000 topographical GIS data with 1:250 000 scale geological data. Field data were gathered and analysed, and surveys were conducted during the initial phases of the project. The surveys included the hydrocensus data, historical report data, and aquifer test analysis on boreholes to obtain hydraulic parameters of the local aquifer system.

The groundwater flow model is a two-dimensional finite element flow model representing the model sub catchment consisting of six geological lithologies. The delineated groundwater flow model (659 km2) catchment is made up of:

- 53 km^2 intrusive dolerite sills and plates
- 141 km^2 shale from the Ecca group formations
- 198 km^2 sandstone from the Natal group formations
- 32 km^2 alluvial sands
- 235 km^2 tillite from the Dwyka group formations and mudstone from the Adelaide formation
- The groundwater flow model was simulated in steady state to calibrate, and to obtain initial simulated groundwater flow levels, velocities and directions. In steady state unknown parameters are limited and this simplifies the calibration process i.e. to

obtain calibrated water levels only transmissivity (or hydraulic conductivity) and recharge values (from precipitation) are used and adjusted to obtain an acceptable fit.

- The water supply and conceptual scenarios are simulated in transient conditions. This state of groundwater flow modelling takes storage and time into account. The transient simulations were done to assess the impact due to proposed abstraction rates from drilled supply boreholes and also conceptual boreholes for water supply. The impact due to the simulated abstraction develops a radius of influence and quantifies any impact, if any, on neighbouring boreholes. The data and assumptions used in the model are listed in Table B3-1.

Table B3-1: Model context, data, boundary conditions and assumptions

Input parameter	Scale	Source, parameter or assumption description
Topography (DTM)	1:50 000	The topographic elevations were interpolated from the 1:50 000 scale 20 m contour intervals.
Rivers, streams, drainages	1:50 000	DWA shapefiles and data
Geology	1:250 000	Georeferenced electronic copy, digitized for the purpose of the model
Boreholes and pumping rates		Data sourced from SRK aquifer tests together with data from historical reports and projects. Water level data was available for 87 boreholes, of which 66 were used to calibrate the model to a 97% correlation (Table B3-2, Figure B3-3). Pump rates sourced from SRK report and estimated rates for conceptual boreholes
Rainfall (recharge)		Rainfall data was obtained from the WRYM data base for various stations within the model area
Steady State Modelling Parameters		
Boundary conditions		Rivers where modelled as constraint head boundaries
Recharge		Recharge was assumed to be in the order of 8.2% of MAP as indicated and used in the GYMR. The recharge values were calibrated to obtain acceptable flow equilibrium.
Transmissivity		Transmissivity parameters obtained from aquifer tests conducted on existing boreholes and educated assumptions through literature reviews and field experience was also made. Literature consulted was Kruseman et al. 1991.
Transient State Modelling Parameters		
Initial hydraulic heads		Calibrated water levels obtained from steady state model calibration scenario used as initial hydraulic heads
Specific storage		The volume of water that a unit volume of aquifer releases from or takes into storage per unit change in head.
Specific yield		The ratio of the volume of water that drains by gravity to that of the total volume of the saturated porous medium. Assumed at approximately 10 times the value of Storativity.
Storativity / storage coefficient		The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. Assumption of 0.001 to 0.005 for fractured aquifers and 0.01-0.05 for alluvial aquifer zones. No field test data were available for storativity values.
Effective porosity		Porosity is the ratio of the volume of void space to the total volume of the rock of earth material.

FINITE ELEMENT NETWORK

The groundwater flow model sub-catchment is contained within the catchments as set out in the greater project area (**Figure B3-2**). The model was constructed with one layer. The groundwater flow model was constructed with historical and newly obtained aquifer parameters.

The model domain was differentiated into a finite element network as shown in (**Figure B3-2**). The planned Lusikisiki project operations with regards to groundwater abstraction and sources are concentrated in, and consist of the area covered by modelled catchment.

SIMULATION OF SCENARIOS

Three scenarios were identified, as necessary, for simulation purposes in order to quantify the groundwater regime and associated impacts due to the proposed project operations. These simulation scenarios will aid in the decision making process regarding the sustainable management of the groundwater resource and potential impacts in this area.

Simulations varied with steady and transient state scenarios. Steady state refers to a scenario which does not have the influence of time and storage, and was implemented in the calibration phase of the model. The transient simulations take into account time, storativity and time dependent recharge. The steady state simulation provides the initial conditions for the transient model. Transient state scenarios were completed for a period of 25 years (9125 days) as steady state within the transient simulation is reached after 5 years.

The following three scenarios were simulated to determine the groundwater flow and impacts during project development and life of project:

1. **Scenario 1: Steady state present day water balance and flow conditions. This scenario was used to calibrate the flow model.**

2. **Scenario 2: Transient state to evaluate and simulate impacts of proposed water supply from existing boreholes drilled by SRK.**

3. **Scenario 3: Transient state to evaluate and simulate impacts of proposed water supply from both Scenario 2 boreholes and conceptual boreholes (Included a sensitivity analysis on recharge values i.e. recharge set as % of MAP and of lower 95th percentile).**

The transient construction water supply simulations in Scenario 2 and Scenario 3 provided an indication of the expected effect the abstraction will have on the regional groundwater system and neighbouring groundwater users if any. The transient simulations provided the simulated cumulative drawdown effect of the water supply.

MODEL CALIBRATION

The steady state flow model was calibrated based on the known geological, structural geological and piezometric head distribution data. Calibration was done by changing recharge and transmissivity values until an acceptable fit between the measured and simulated heads were obtained.

The head elevation data from 66 observation boreholes were used to calibrate the steady-state flow model (**Table B3-2**). The calibration was satisfactory when the correlation between the measured and simulated head data was $R^2 > 0.9$ (**Figure B3-4, Figure B3-5**).

B3.6.1 Hydraulic Zones

Six hydraulic zones were identified in the groundwater flow model, which influences the flow balance within the model boundary (**Table B3-3**). The hydraulic values marked in **Table B3-3** were obtained from existing groundwater data, field tests as well as the model calibration process. The values listed in the table were applied to the regional geological units, however various transmissivity in the range between 0.05 m^2/d and 8.98 m^2/d were applied to certain boreholes to enhance accuracy. For more detail on the hydraulic units entailed within the model boundary, please refer to the conceptual model in **Appendix C**.

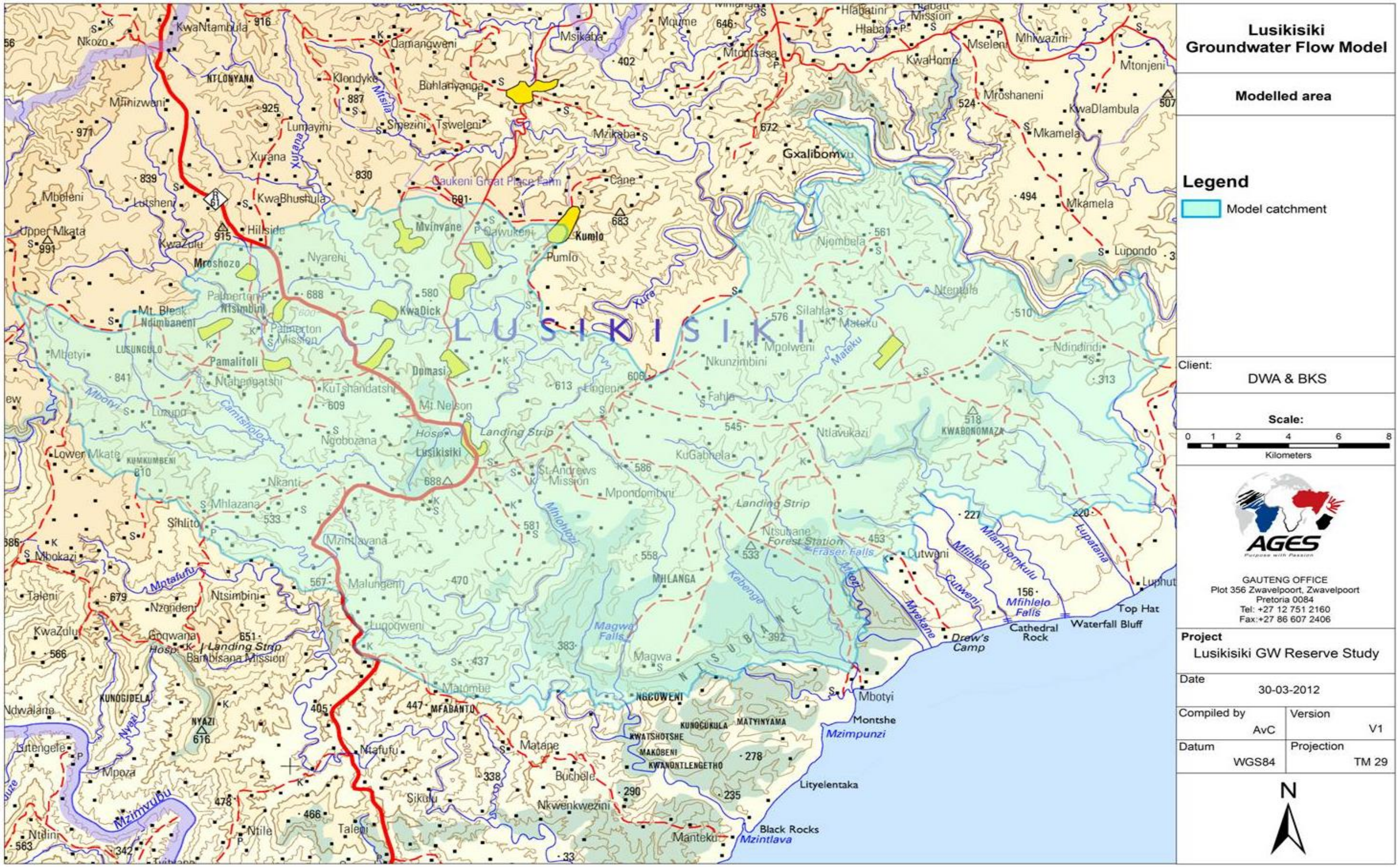

Figure B3-2: Model area and sub-catchment

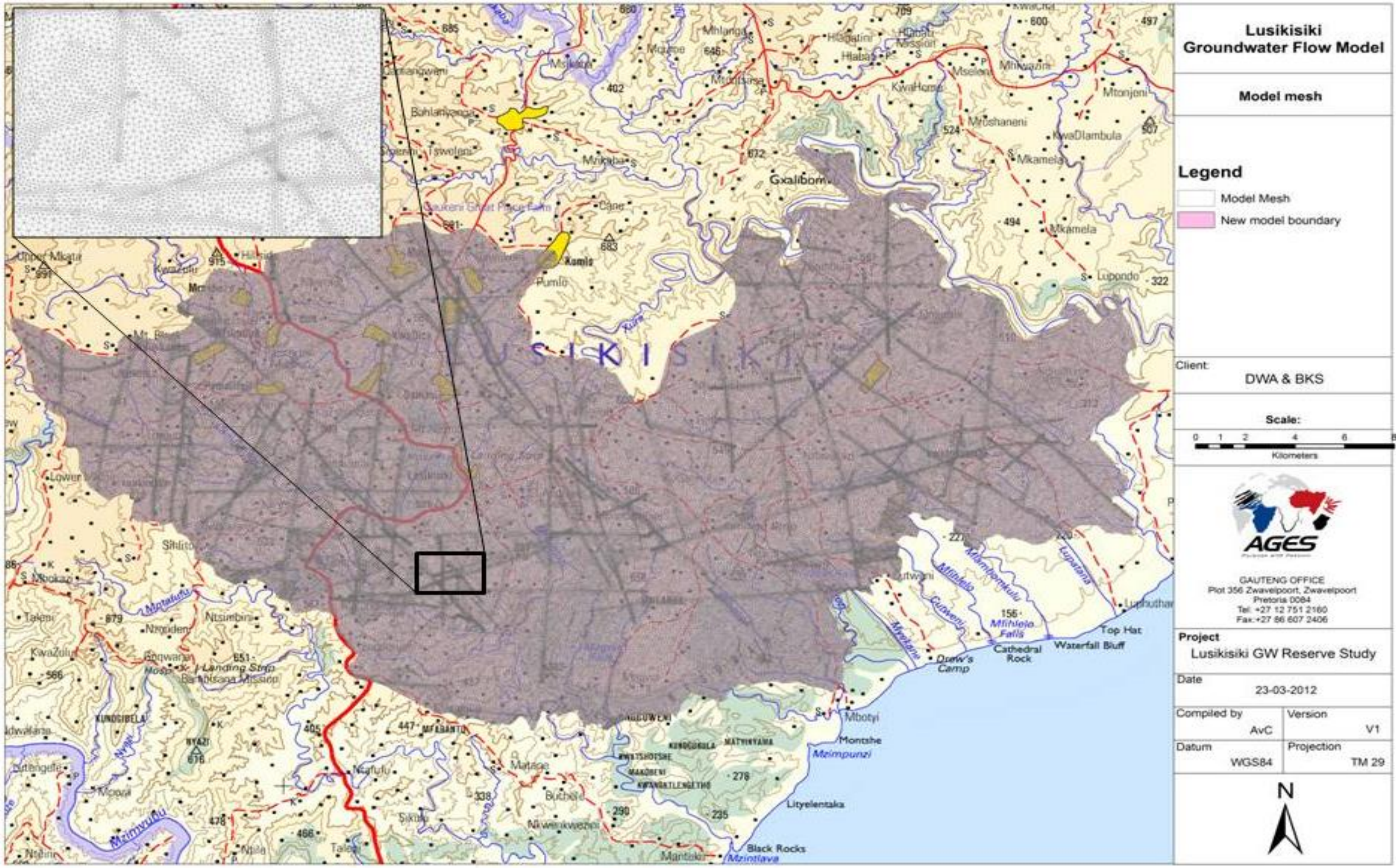

Figure B3-3: Generated model mesh

Table B3-2: Measured vs. simulated heads (Figure B3-5)

No.	Site ID	X	Y	Z (mamsl)	Measured WL (mbgl)	Measured heads (mamsl)	Simulated heads (mamsl)	Absolute error	Error (m)
1	3029DD00041	43112.9	-3469066.7	599.95	-9.00	590.95	600.65	9.70	-9.70
2	3129AD00001	44896.6	-3466209.0	642.48	-2.44	640.04	615.39	24.65	24.65
3	3129AD00011	45736.0	-3473665.6	530.30	-16.45	513.85	512.54	1.31	1.31
4	3129AD00012	45101.8	-3473600.8	535.81	-16.79	519.02	518.45	0.57	0.57
5	3129AD00013	45372.5	-3472154.9	533.86	-26.00	507.86	505.26	2.60	2.60
6	3129AD00126	46977.3	-3473765.8	512.00	-26.85	485.15	491.15	6.00	-6.00
7	3129BC00002	52586.8	-3461747.7	604.49	-1.83	602.66	599.72	2.94	2.94
8	3129BC00004	66541.1	-3476550.3	494.07	-3.66	490.41	456.02	34.39	34.39
9	3129BC00006	51474.9	-3467285.9	578.87	-17.07	561.80	551.15	10.65	10.65
10	3129BC00007	55285.9	-3461546.4	639.49	-10.97	628.52	627.49	1.03	1.03
11	3129BC00008	51157.4	-3461925.8	617.95	-4.00	613.95	605.97	7.98	7.98
12	3129BC00009	51533.9	-3466116.4	601.99	-7.10	594.89	640.64	45.75	-45.75
13	3129BC00011	51921.5	-3462638.0	644.84	-1.83	643.01	611.84	31.17	31.17
14	3129BC00014	68770.0	-3470957.5	527.36	-2.44	524.92	520.93	3.99	3.99
15	3129BC00015	48178.5	-3469395.7	560.96	-2.00	558.96	556.35	2.61	2.61
16	3129BC00024	69993.1	-3465915.2	457.54	-9.00	448.54	462.80	14.26	-14.26
17	3129BC00034	52423.6	-3473049.4	585.52	-0.21	585.31	585.54	0.23	-0.23
18	3129BC00037	54906.9	-3473339.4	617.00	-5.50	611.50	619.37	7.87	-7.87
19	EC-T60-051	72311.0	-3465491.8	446.87	-2.98	443.89	413.84	30.05	30.05
20	EC-T60-052	71671.0	-3464827.6	441.52	-2.15	439.37	440.16	0.79	-0.79
21	EC-T60-053	67457.2	-3469836.0	455.82	-13.72	442.10	457.45	15.35	-15.35

No.	Site ID	X	Y	Z (mamsl)	Measured WL (mbgl)	Measured heads (mamsl)	Simulated heads (mamsl)	Absolute error	Error (m)
22	EC-T60-054	63063.0	-3475151.0	470.81	0.00	470.81	469.94	0.87	0.87
23	EC-T60-057	46318.4	-3466173.1	587.55	-10.97	576.58	590.47	13.89	-13.89
24	EC-T60-058	44991.1	-3465590.8	593.89	-5.31	588.58	590.44	1.86	-1.86
25	EC-T60-061	49775.6	-3472613.4	475.80	-3.27	472.53	466.40	6.13	6.13
26	EC-T60-064	56373.2	-3468538.7	457.34	-3.41	453.93	458.60	4.67	-4.67
27	EC-T60-069	47622.0	-3469853.5	523.73	-4.56	519.17	521.66	2.49	-2.49
28	EC-T60-072	61894.3	-3474141.7	482.30	-2.91	479.39	476.44	2.95	2.95
29	EC-T60-074	62373.9	-3474582.5	473.54	-0.10	473.44	472.25	1.19	1.19
30	EC-T60-078	73370.6	-3466441.7	391.60	-0.06	391.54	384.82	6.72	6.72
31	Spr.010	52265.1	-3474920.7	522.52	0.00	522.52	505.13	17.39	17.39
32	Spr.012	61233.3	-3477217.0	489.52	0.00	489.52	484.36	5.16	5.16
33	Spr.013	60253.0	-3475204.3	531.80	0.00	531.80	531.59	0.21	0.21
34	Spr.014	59558.9	-3474506.2	573.67	0.00	573.67	564.20	9.47	9.47
35	Spr.015	59654.2	-3475137.7	542.59	0.00	542.59	537.63	4.96	4.96
36	Spr.017	71003.9	-3462803.9	528.65	0.00	528.65	520.99	7.66	7.66
37	Spr.020	66737.3	-3466168.9	549.40	0.00	549.40	542.20	7.20	7.20
38	Spr.021	71276.0	-3468874.4	499.70	0.00	499.70	497.04	2.66	2.66
39	Spr.024	74835.9	-3467350.2	470.53	0.00	470.53	434.70	35.83	35.83
40	Spr.025	55760.7	-3468289.2	539.34	0.00	539.34	522.22	17.12	17.12
41	Spr.026	46420.7	-3475083.9	496.80	0.00	496.80	489.88	6.92	6.92
42	Spr.031	45576.9	-3469012.8	637.15	0.00	637.15	641.14	3.99	-3.99
43	Spr.035	50690.8	-3479093.2	433.10	0.00	433.10	431.31	1.79	1.79

No.	Site ID	X	Y	Z (mamsl)	Measured WL (mbgl)	Measured heads (mamsl)	Simulated heads (mamsl)	Absolute error	Error (m)
44	Spr.037	66512.2	-3468038.1	528.20	0.00	528.20	535.37	7.17	-7.17
45	Spr.038	67789.8	-3463571.0	480.98	0.00	480.98	496.22	15.24	-15.24
46	Spr.039	69887.4	-3463588.1	544.24	0.00	544.24	540.83	3.41	3.41
47	Spr.040	72298.2	-3463480.2	499.84	0.00	499.84	521.02	21.18	-21.18
48	Spr.041	73212.6	-3462475.3	381.48	0.00	381.48	375.13	6.35	6.35
49	Spr.043	70663.4	-3460485.2	489.47	0.00	489.47	469.10	20.37	20.37
50	Spr.044	69770.1	-3461173.4	486.50	0.00	486.50	458.05	28.45	28.45
51	Spr.045	71973.4	-3461268.1	492.10	0.00	492.10	554.45	62.35	-62.35
52	Spr.053	54400.2	-3473678.7	641.24	0.00	641.24	639.10	2.14	2.14
53	Spr.067	57008.3	-3466548.4	498.03	0.00	498.03	498.23	0.20	-0.20
54	Spr.068	52133.8	-3471118.0	567.18	0.00	567.18	568.09	0.91	-0.91
55	Spr.069	51601.0	-3471703.0	560.90	0.00	560.90	567.32	6.42	-6.42
56	Spr.07	66512.1	-3475851.0	499.37	0.00	499.37	473.52	25.85	25.85
57	Spr.070	51770.3	-3473438.0	580.84	0.00	580.84	575.54	5.30	5.30
58	Spr.071	49224.7	-3471619.5	507.88	0.00	507.88	496.45	11.43	11.43
59	Spr.072	50002.8	-3468662.7	613.35	0.00	613.35	595.10	18.25	18.25
60	Spr.072	51440.1	-3462391.6	607.87	0.00	607.87	608.95	1.08	-1.08
61	Spr.074	50900.2	-3469059.5	586.25	0.00	586.25	578.50	7.75	7.75
62	Spr.075	51275.7	-3470121.4	537.14	0.00	537.14	530.32	6.82	6.82
63	Spr.08	65683.5	-3470573.2	510.15	0.00	510.15	512.40	2.25	-2.25
64	Spr.081	47461.9	-3464021.7	647.62	0.00	647.62	634.90	12.72	12.72
65	Spr.083	45955.6	-3467945.6	617.24	0.00	617.24	617.72	0.48	-0.48

No.	Site ID	X	Y	Z (mamsl)	Measured WL (mbgl)	Measured heads (mamsl)	Simulated heads (mamsl)	Absolute error	Error (m)
66	Spr.09	61002.0	-3471544.0	551.72	0.00	551.72	567.86	16.14	-16.14
			Minimum	**381.48**	**-26.85**	**381.48**	**75.13**	**0.20**	**-62.35**
			Maximum	**647.62**	**0.00**	**647.62**	**641.14**	**62.35**	**35.83**
			Average	**535.30**	**-3.22**	**532.08**	**529.40**	**10.56**	**2.68**
			Correlation	**99%**		**97%**	**97%**		

Table B3-3: Hydraulic zones and parameters – calibrated model (B3-4)

Lithologies	Source	T (m^2/d)	Recharge (% of MAP)
Alluvium	1:250 000	25	13%
Natal group sandstone	1:250 000	4	11%
Dolerite sills	1:250 000	0.02	3%
Adelaide predominantly mudstone	1:250 000	0.8	4%
Ecca shale	1:250 000	0.6	4%
Dwyka Tillite	1:250 000	0.6	8%

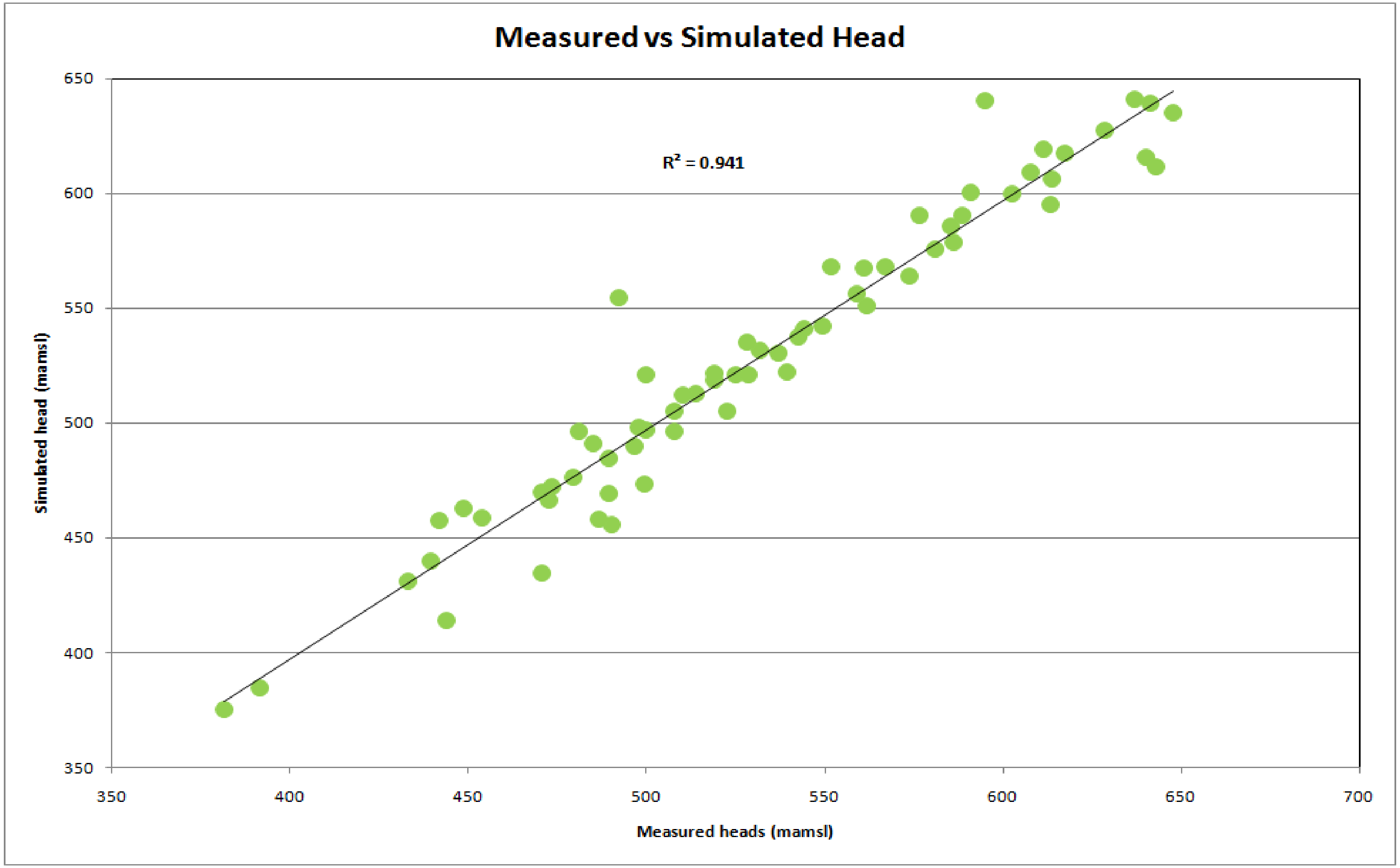

Figure B3-4: Graphic presentation of measured versus simulated heads

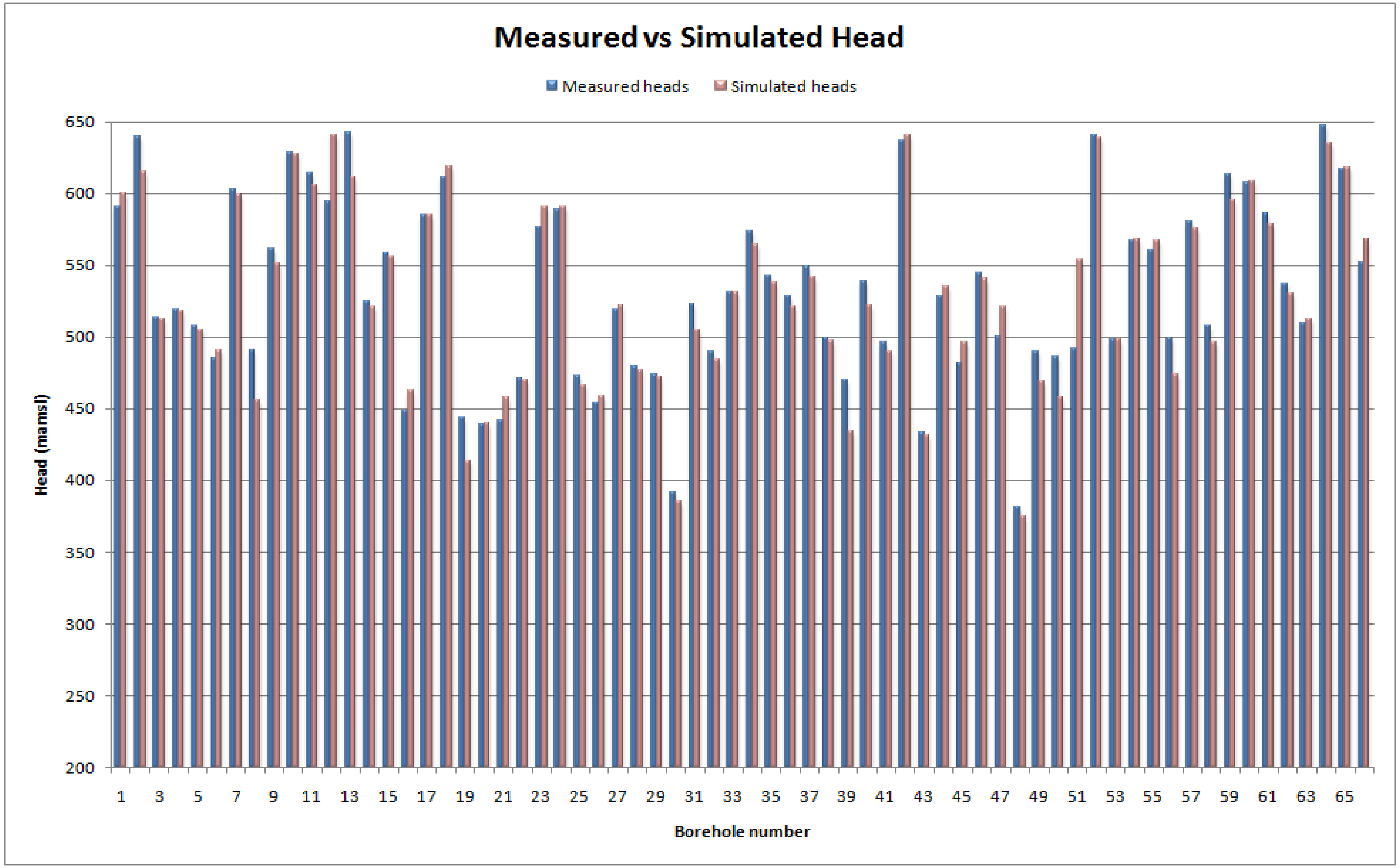

Figure B3-5: Bar chart comparison of measured vs. simulated heads

Scenario 1: Steady state pre-development, present day water balance and flow conditions – model calibration

The steady state simulation was calibrated using the recharge as a function of MAP i.e. 1 103 mm/a, and the calibrated water levels are shown in **Figure B3-6**. There is an average of 132 104 m^3/d flowing into the sub-catchment groundwater system from recharge. This resultant inflow is due to a combination of recharge and groundwater base flow. The groundwater balance represents inflows from recharge and outflows due to evapotranspiration.

The flow direction shows that the hydraulic gradient is from the topographical high in the north-west flowing south east along the surface water drainage pattern. This is confirmed by the good correlation between groundwater levels and topographical elevation reported earlier.

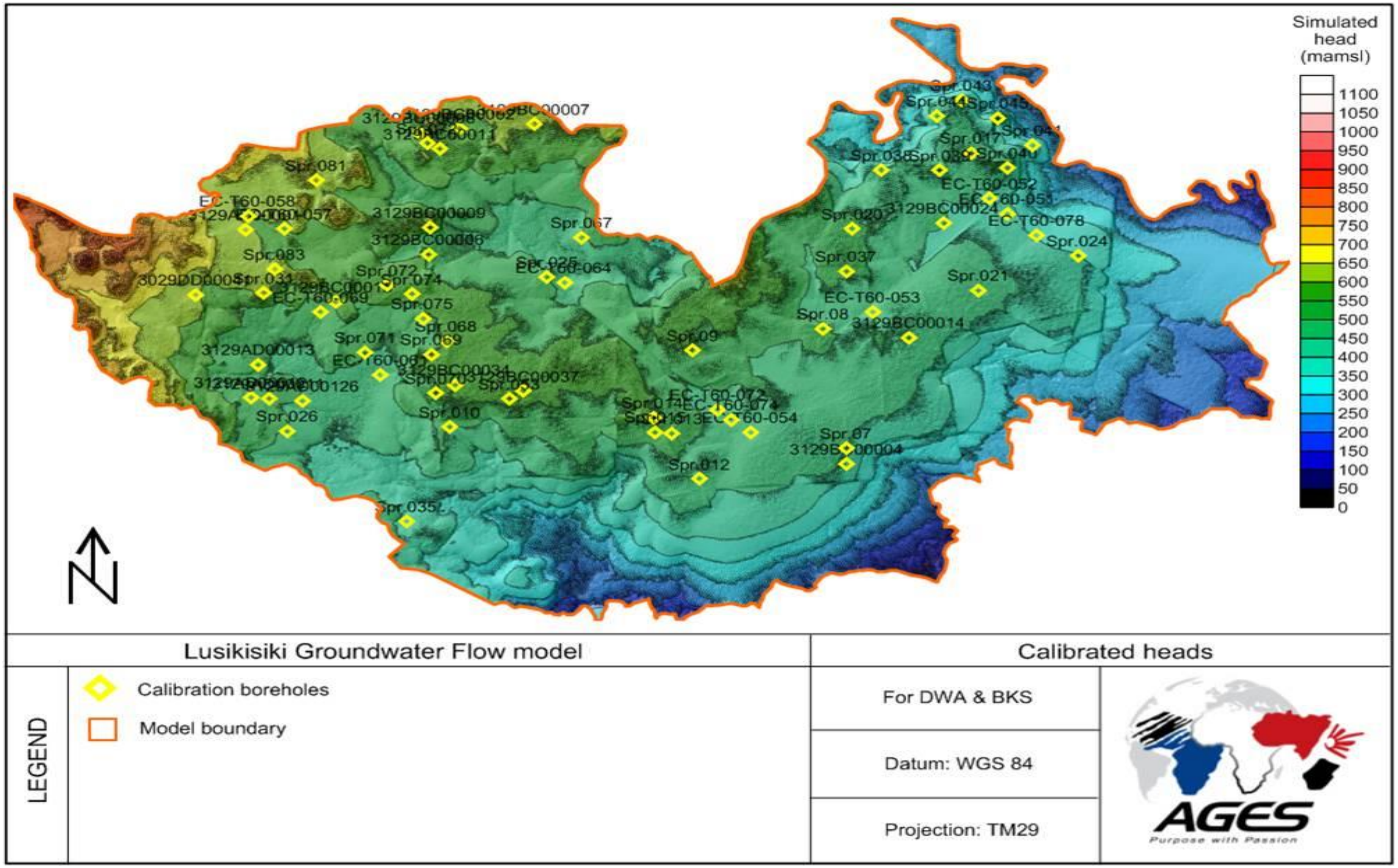

Figure B3-6: Steady State calibrated water levels

Scenario 2: Transient state water supply from SRK boreholes

The aim of the groundwater flow model is to simulate the potential impact of the abstraction of groundwater resources during the project operations on neighbouring groundwater users, if any. AGES received recommended abstraction yields from SRK and applied these yields to the groundwater flow model. Fourteen boreholes were assigned abstraction rates within the modelled catchment.

The total proposed abstraction volume used in scenario 2 is 1836.8 m^3/d. As shown in **Table B3-4**. Some of the boreholes are located within a close proximity of each other and abstraction from these will have a cumulative impact. Groundwater level monitoring is proposed to measure the effect and mitigate accordingly.

Table B3-4: Abstraction boreholes with associated volumes (Figure B3-7)

ID	BH no	Abstraction (m^3/d)	Initial head (mamsl)	Final head (mamsl)	Simulated drawdown (m)
a	EC-T60-057	29.4	588	574	14
b	EC-T60-069	11.2	521	501	20
c	EC-T60-064	51.8	457	448	9
d	EC-T60-055	64.8		457	NA
e	EC-T60-074	29.4	472	467	5
f	EC-T60-051	276.5	444	386	59
g	EC-T60-052	76.9	440	436	5
h	EC-T60-053	75.2	458	381	76
i	EC-T60-054	648.0	470	415	54
j	EC-T60-058	8.6	590	554	37
k	EC-T60-061	198.7	466	443	24
l	EC-T60-072	129.6	476	471	5
m	EC-T60-075	155.5		216	NA
n	EC-T60-078	81.2	405	380	25
	Minimum	**8.6**	**405**	**216**	**5**
	Maximum	**648.0**	**590**	**574**	**76**
	Average	**131.2**	**482**	**438**	**28**
Not available					

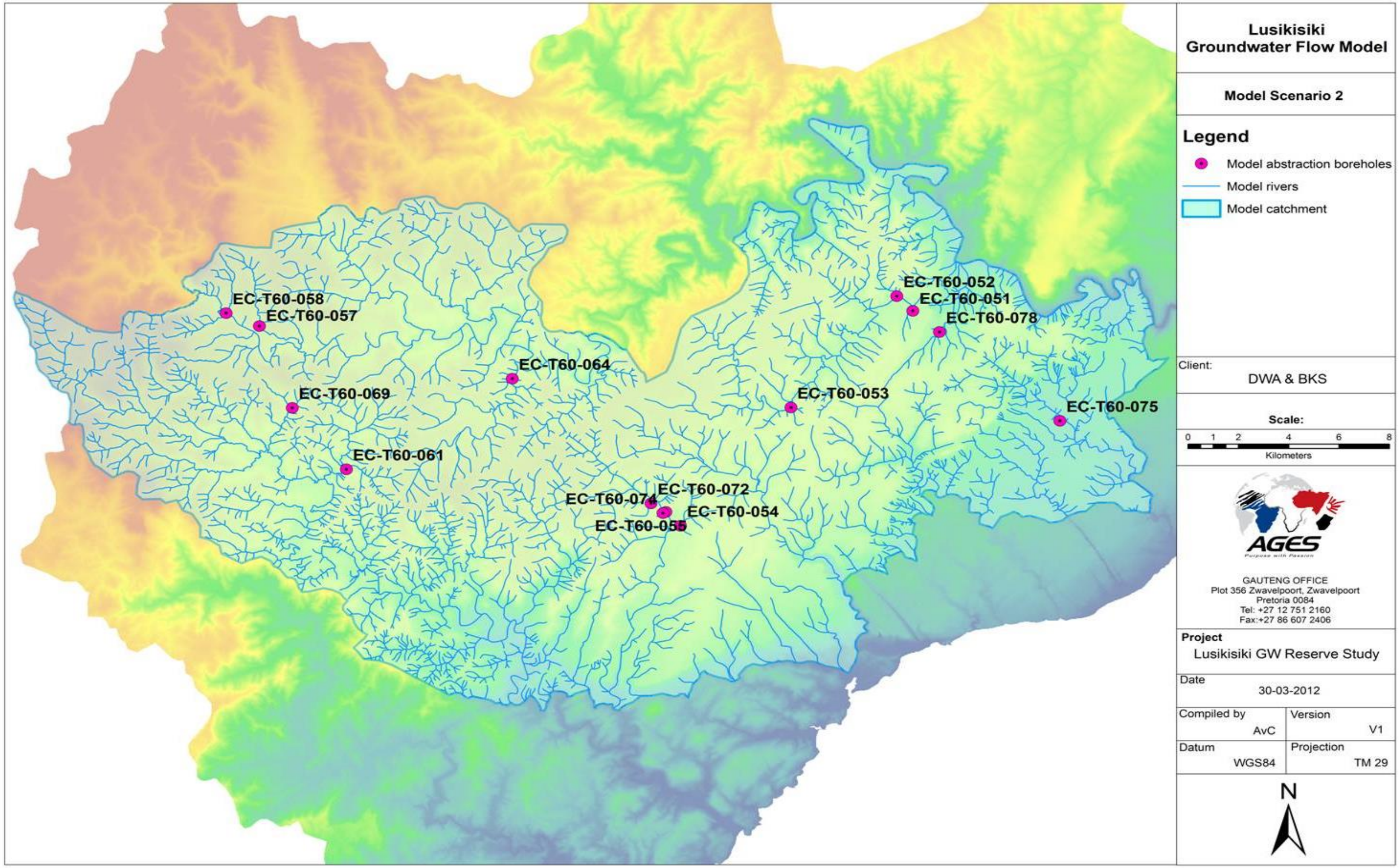

Figure B3-7: Proposed abstraction boreholes

The groundwater abstraction for water supply to a pipeline feeding the Lusikisiki water project will come from the modelled catchment for an extended period of time. The groundwater flow model was simulated for 25 years at proposed sustainable rates, where after recommended updated water balance should be done for the area once every 25 years.

The parameters used in the groundwater flow model were deduced from aquifer tests conducted on site and literature values for storage within the aquifer. Storage was assumed to be based on average calculations from the aquifer tests.

The groundwater flow balance indicate that 132 104 m³/d of water is flowing into the modelled catchment due to recharge from precipitation. Boreholes drilled throughout the modelled catchment accounts for 1 836.8 m³/d of abstraction. The balance of water is lost to evapotranspiration in the riparian zone along the drainage lines within the modelled catchment. Compared to the available groundwater from both the groundwater flow model and the GYMR there is enough groundwater available to sustain the required volume to be abstracted from the SRK boreholes.

Table B3-5: Groundwater flow balance for water supply during project operational phase

Scenario 2 Transient state water supply: Feflow model			
Component	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
Recharge from precipitation	132 104	0	132 104
Abstraction from current well field	0	-1 836	-1 836
Losses to evapotranspiration	0	-129 928	-129 928
Total	**132 104**	**-131 764**	**340**
		Balance error (%)	**0%**

The flow balance indicates sufficient recharge to the system is available to abstract the water necessary for supply over a period of 25 years in the modelled simulation. From the current GYMR calculations, however, ecological water requirements (EWR) through base flow in the region is a total of 282 184 m^3/d for the entire study area. The monitoring of water levels in the region is therefore recommended, as over abstraction could result in an imbalance in the water budget during climatic and seasonal changes.

The recommended sustainable rates for the abstraction boreholes are within the framework of the simulated 25 year period, and thus the aquifer tests were accurate. It should however be kept in mind that the model allows recharge at a daily volume into the system that allows for replenishment of resources, this is however not the case in reality. Seasonal recharge or recharge pulses are experienced in nature and allowing drawdown and subsequently recharge to be potentially more in some seasons than the figures simulated by the model. The recommendation for monitoring of water levels is stressed again.

The effect of the abstraction on the water level is not significant and the impact is minimal on neighbouring boreholes used as monitoring boreholes in the simulation. This is evidently displayed in **Figure B3-9** where the radius of influence caused by abstraction is shown.

A maximum drawdown level of 76 m was simulated at Borehole EC-T60-053 in the scenario at which storage were assigned a value of 5e-4. This drawdown value correlates well with the 66 m of drawdown achieved in the aquifer test on EC-T60-053. The drawdown of the various boreholes with water levels are shown in **Figure B3-8**, in some cases transmissivity was adjusted in the immediate catchment area of the boreholes in order to simulate a drawdown for each borehole that is realistic with reference to field experience and analogue data for the geology of the area. The drawdown levels could exceed this, and monitoring of these boreholes and associated water levels should be done during the 25 year period.

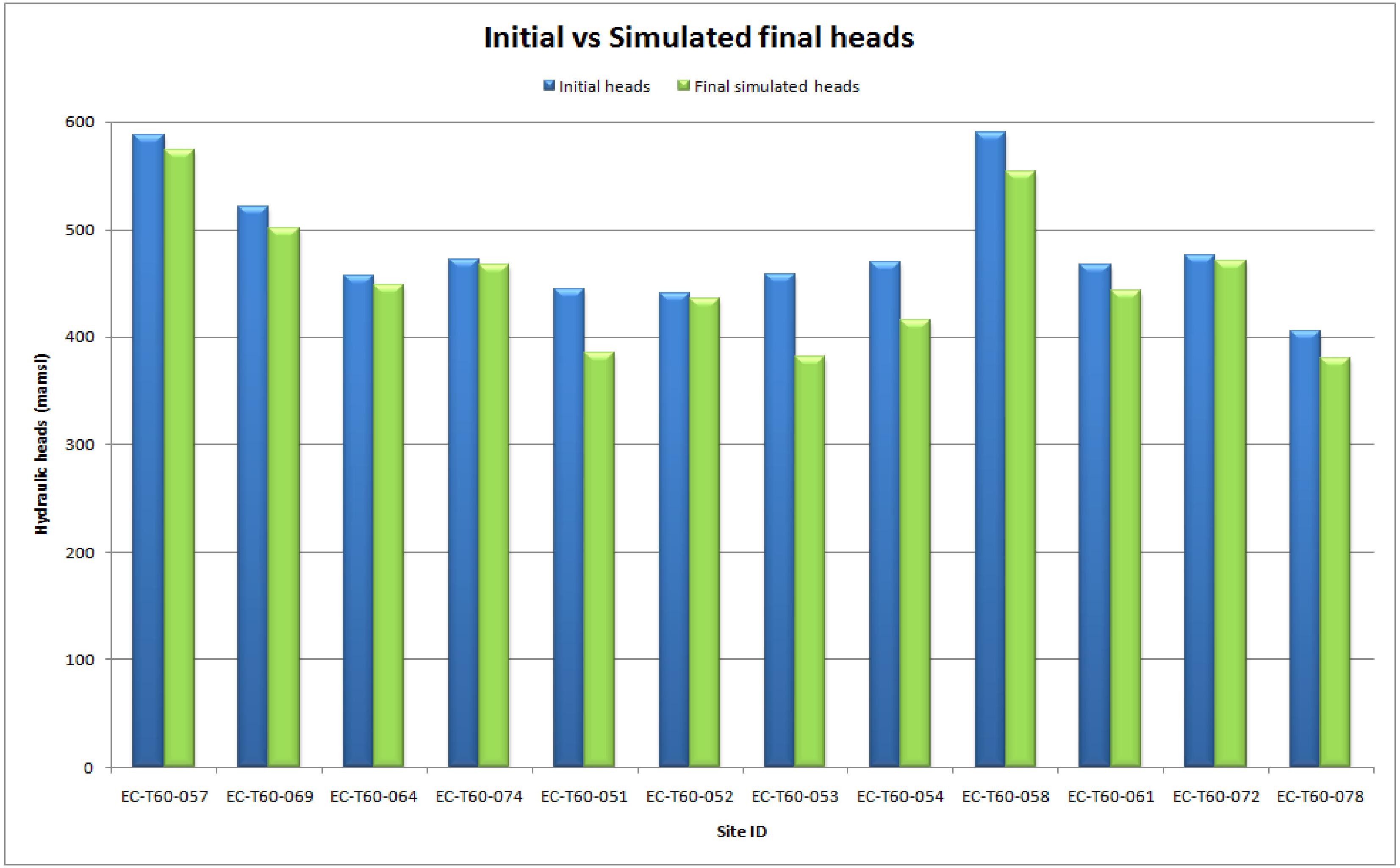

Figure B3-8: Initial heads as simulated in the model calibration against the final heads as simulated after 25 years of abstraction with storage assumed at 5e-4

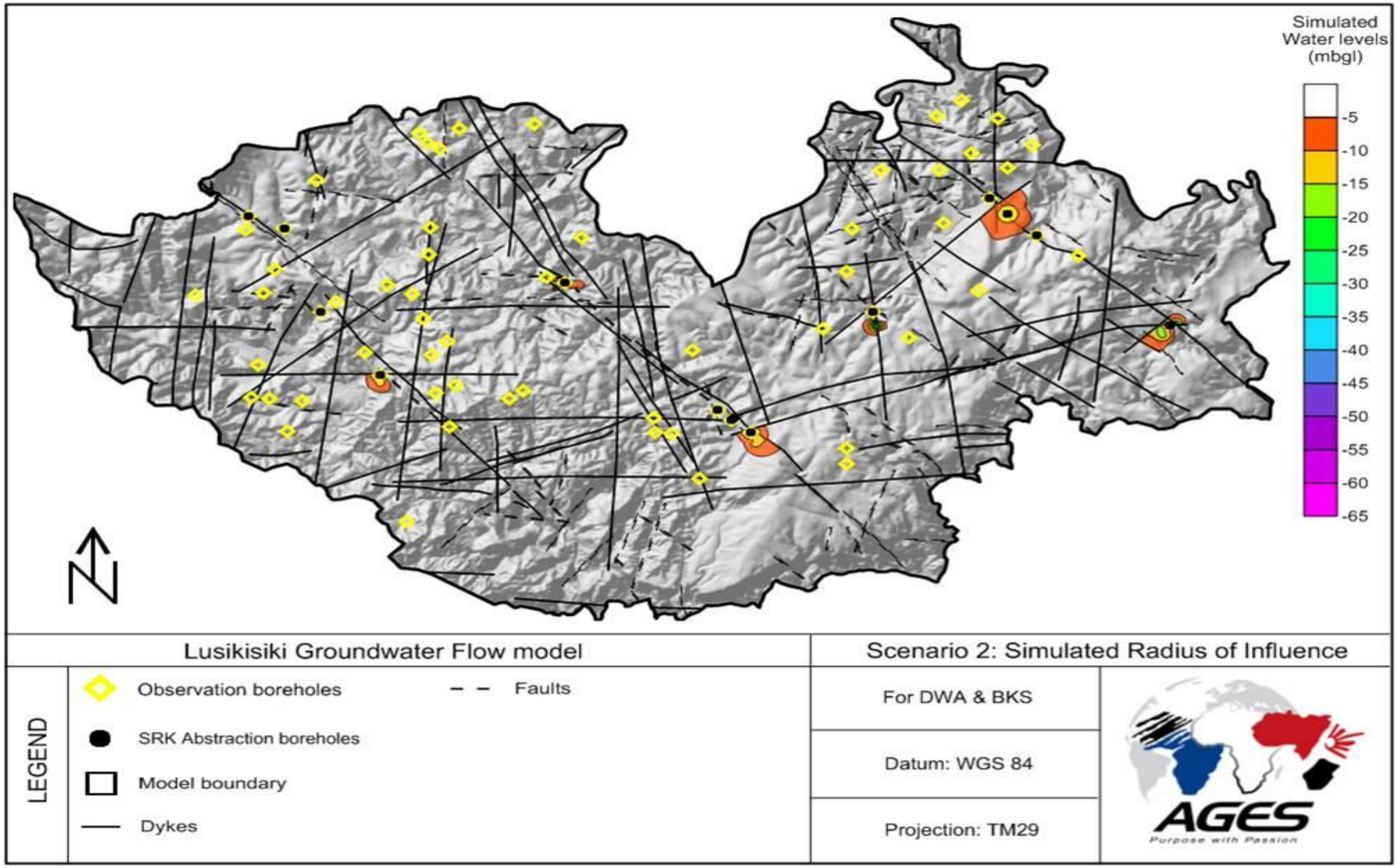

Figure B3-9: Map indicating the radius of influence of the abstraction boreholes as pumped with SRK recommended yields in Scenario 2

Scenario 3: Transient state water supply from SRK and Conceptual boreholes

Scenario 3 was divided into two simulations to serve as sensitivity analysis on recharge during years with normal rainfall and years with lower than normal rainfall or droughts. Scenario 3A was simulated with recharge based on MAP (1 103 mm/a); Scenario 3B was simulated with recharge set as a percentage of the lower 95th percentile of MAP to simulate a one in twenty year drought (814 mm/a). These rainfall averages is not the same as used in the GYMR simulations as it is data calculated for the modelled catchment.

The same transmissivity values and storage were used in the simulations of Scenario 3 as in Scenario 2. Conceptual boreholes where used to simulate probable future exploration drilling in areas where structures will be targeted. The abstraction from all 8 boreholes was simulated with a volume of 155.5 m^3/d, as well as the existing SRK borehole abstractions as used in Scenario 2. The simulation was done in transient state over a period of 25 years.

B3.6.1.3a Scenario 3A: Recharge based on map

Under average conditions an assumed recharge volume of 132 104 m^3/d replenishes the groundwater reserve within the model boundaries. The eight conceptual boreholes add stress to the groundwater reserve with an additional abstraction volume of 1 244 m^3/d (**Table B3-6**).

Table B3-6: Groundwater flow balance for water supply during Scenario 3A (MAP)

Scenario 3A transient state water supply: Feflow model			
Component	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
Recharge from precipitation	132 104	0	132 104
Abstraction from current well field	0	-3 081	-3 081
Losses to evapotranspiration	0	-129 023	-129 023
Total	**132 104**	**-132 104**	**0**
		Balance error (%)	**0%**

The EWR values will however be effected by the increased abstraction with less water available to feed base flow and the ecology, if assumed that the total volume of recharge is needed for EWR. The model simulates a scenario were all the inflows are available as groundwater, the GYMR however shows that only part of the inflow are available as groundwater and the rest is required by EWR.

The maximum drawdown during scenario 3A for the conceptual boreholes was achieved in CS2. The radius of influence of the conceptual boreholes under recharge as a percentage of MAP is shown in **Figure B3-10**.

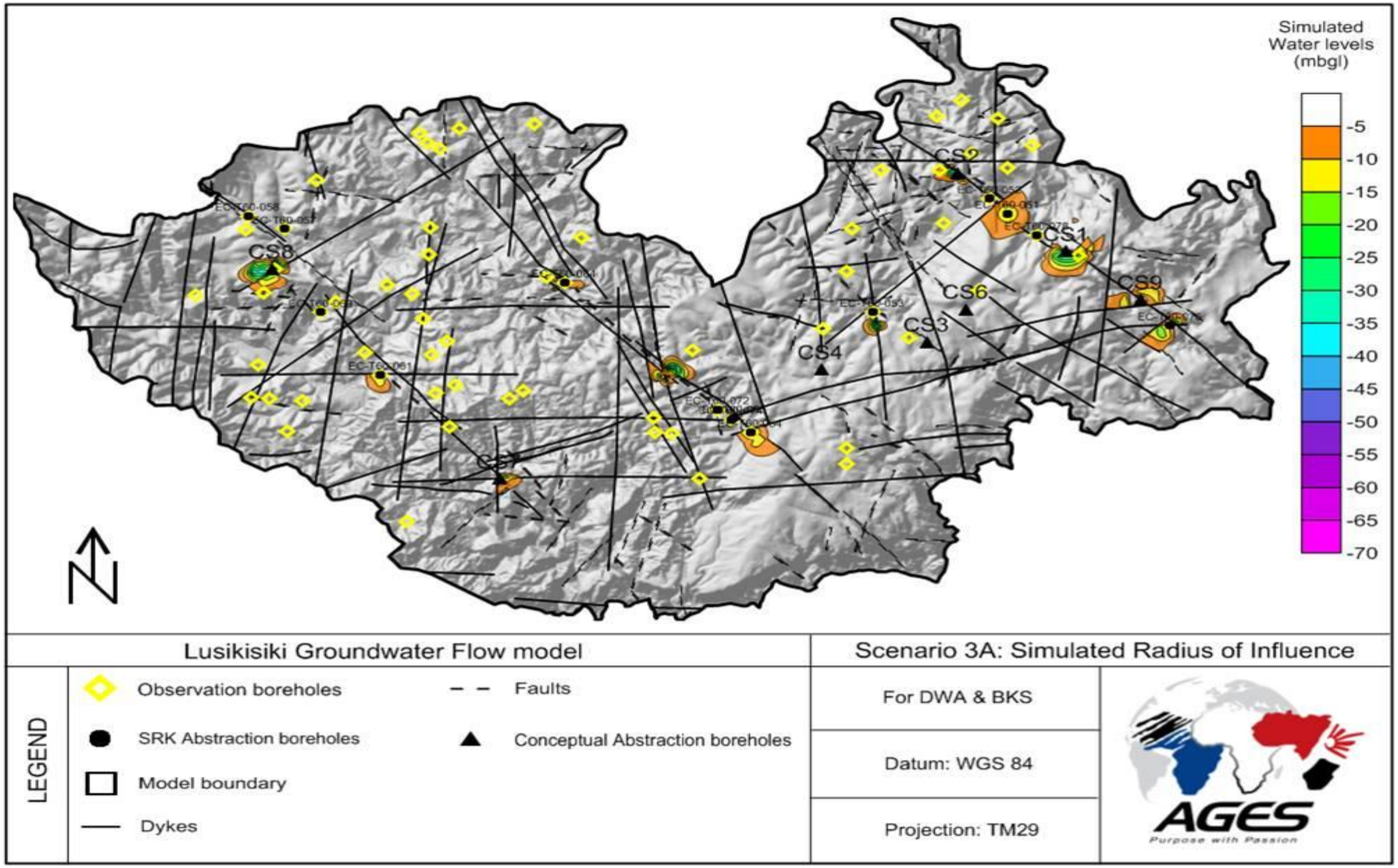

Figure B3-10: Map showing the radius of influence for SRK and Conceptual boreholes pumped under MAP recharge conditions

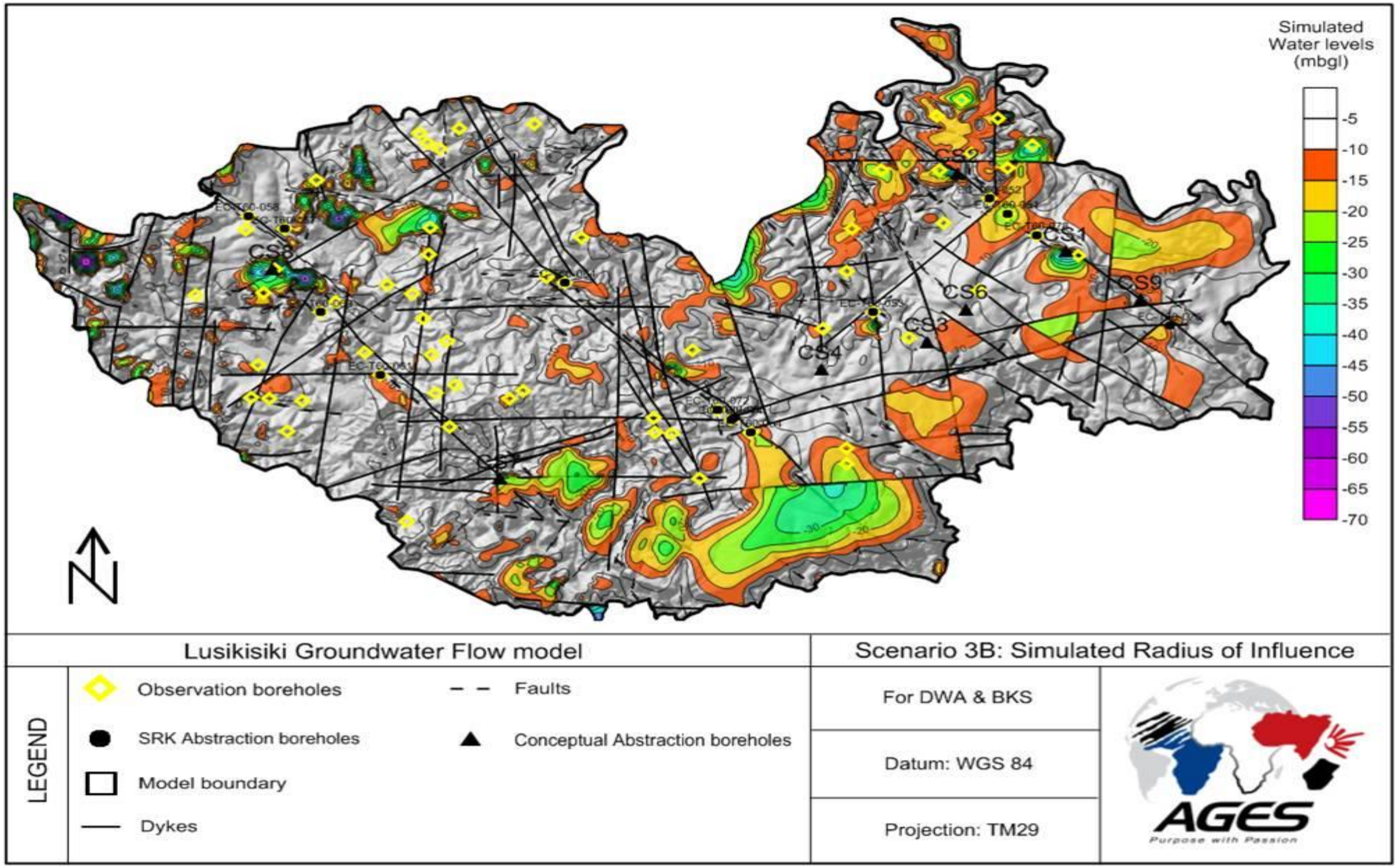

Figure B3-11: Map showing the radius of influence for SRK and Conceptual boreholes pumped under lower 95% assured recharge conditions

B3.6.1.3b Scenario 3B: Recharge based on Lower 95% assurance level of map

During years with lower than normal rainfall, recharge is also lower. To simulate the effect of lower recharge a sensitivity analysis was done on Scenario 3 to show the expected increase in drawdown of abstraction boreholes and also an increase in the radius of influence around these holes.

The lower 95% assurance level calculated on the regions rainfall indicates a one in twenty year drought. This value is 814 mm/a, for the modelled catchment decreasing the volume of water flowing into the system to 97 432 m^3/d. This affects the available water for EWR as abstraction will cause a greater radius of influence and also lower the regional water table. With a decrease in water level base flow also decreases and springs will start to run dry.

Table B3-7: Groundwater flow balance for water supply during Scenario 3A (Lower 95%)

Scenario 3B Transient State Water Supply: Feflow model			
Component	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
Recharge from precipitation	97 432	0	97 432
Abstraction from current well field	0	-3 081	-3 081
Losses to evapotranspiration	0	-94 351	-94 351
Total	**97 432**	**-97 432**	**0**
		Balance error (%)	**0%**

Table B3-7 shows the increased radius of influence caused through the lower recharge during periods of drought. A worst case scenario simulation shows that numerous springs dries up within the monitoring points and an average of 7.2 m of water is loosed throughout the study area due to lower than normal recharge.

The larger radius of influence indicated in **Figure B3-10** is supported by an overall increase in drawdown of the abstraction boreholes of 5 m. The monitoring boreholes show a minimum lowering in the water table of 0.1 m and a maximum drop of 44 m. The large topographical elevation differences in the area also cause a drought to affect the groundwater table more.

Based on the GYMR there is however still enough groundwater in reserve to carry the volumes abstracted from the SRK boreholes.

B4 CONCEPTUAL MODEL

No abstraction from boreholes was simulated during the steady state calibration.

The flow balance for the groundwater flow model showed that enough inflow occurs without losses being too high and thus correlates with the GYMR scenario under average rainfall with an assumed 57% availability factor leading to total recharge volume of 165 222 m^3/d as set out by the GYMR.

Table B4-1: Groundwater flow balance determined from the steady state flow model

Scenario 1 Present day steady sate: Feflow model			
Component	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
Recharge from precipitation	132 104	0	132 104
Abstraction from current well field	0	0	0
Losses to evapotranspiration	0	-132 104	-132 104
Total	**132 104**	**-132 104**	**0**
		Balance error (%)	**0%**

As previously mentioned, numerous springs occur in the study area. These springs were also used as calibration boreholes and observation points during further simulations. The water levels for the model calibration in steady state were 0 mbgl for the springs. Further scenarios simulating abstraction and drought events will show the effect of natural and sociological impacts on the groundwater systems through the evaluations of their effect on the regions springs.

B5 SUMMARY AND CONCLUSIONS

B5.1 MODEL SUMMARY

Conceptual model

- **Figure B2-1**: Conceptual Model depicts the current groundwater situation as shown in a conceptual model.
- The main aquifers in the region are fractured rock aquifers with dolerite sills and dykes acting as aquicludes and groundwater flow boundaries throughout the modelled catchment.
- Recharge mainly occurs through rainfall seeping into the groundwater system with a minor amount occurring from streams and rivers.
- MAP is 1103 mm/a, for the modelled catchment with recharge being 8.2% of MAP.
- Springs occur all over the modelled area at discharge points along elevated contacts.
- Abstraction from boreholes causes a radius of influence within the groundwater system which can affect neighbouring borehole abstraction volumes and sustainability.

B5.2 GROUNDWATER FLOW MODELLING

- The area delineated for the Lusikisiki groundwater flow model covers an area of 660.76 km^2.
- The simulation of a groundwater flow model is to help the user and involved parties to manage the water resources of the region and to aid in decision making.
- Objectives of the model were to:
    - **Evaluate the current state of the groundwater systems within the study area and to compare the steady state water balance to the GYMR model outcomes also done in this study.**
    - **Estimate and evaluating proposed pumping rates taking into account temporal and spatial factors as well as transient long term abstraction of groundwater from the proposed region.**
    - **Determine the radius of influence, and impacts, of well field pumping and dewatering on specified water users and the environment, and also to evaluate the impact of conceptual future groundwater abstraction points.**

- A finite element mesh was generated within the model boundaries and important modelling zones was chosen in the 2D framework.
- Conservative assumptions based on aquifer tests, hydrocensus and historical data as well as analogue values from literature were used in the model.

B5.3 SIMULATION OF SCENARIOS

The following three scenarios where simulated:

Scenario 1: Steady state presents day water balance and flow conditions, this scenario were used to calibrate the flow model.

Scenario 2: Transient state to evaluate and simulate impacts of proposed water supply from existing boreholes drilled by SRK.

Scenario 3: Transient state to evaluate and simulate impacts of proposed water supply from both Scenario 2 boreholes and conceptual boreholes (sensitivity analysis on recharge values).

Model calibration and hydraulic zones

- Recharge and transmissivity values where used and adjusted accordingly to calibrate the model to a suitable level of correlation within a steady state simulation.
- The correlation between simulated heads and measured heads in 66 observation boreholes where used to calibrate the model to a level above R2 of 0.90.
- After correlation boreholes with abstraction rates were added to simulate the transient state scenarios.

B5.4 MODEL CONCLUSIONS AND OUTCOMES

- From the three scenarios, and sensitivity analysis, it is evident that enough water is available for abstraction from the SRK boreholes to supply water to the LWRSS.
- During dry periods, or droughts, the available water will be significantly smaller and can affect base flow and spring flow if abstraction is continued at the same rate as during normal periods of rainfall.
- Scenario 1 indicates a steady state simulation where inflow equals outflows with no abstraction influencing the available water to the groundwater system or evapotranspiration.
- The volume through recharge available in the model is less than that in the GYMR scenario.
- Scenario 2 shows the abstraction of groundwater from the SRK boreholes at the recommended sustainable rates.

- These rates are proven to be sustainable in the modelled environment over a period of 25 years with storage and recharge balancing the extra loss through abstraction.
- Scenario 3A and 3B shows the sensitivity of the groundwater system to a change in recharge.
- An average drop of 7.2 m is observed in all observation borehole water levels when a one in twenty year draught is simulated.
- Drawdown in the SRK and Conceptual boreholes pumped during Scenario 3 increases with an average of 5 m.
- Throughout all scenarios EWR was not taken into account and thus as more water is abstracted the lower the available water for EWR and will negatively affect the natural environment along riparian zones.
- The volumes simulated by the model are however well below that of the available groundwater volumes as indicated by the GYMR scenarios.
- With abstraction from SRK boreholes and conceptual boreholes a total daily volume of 3 081 m^3/d is needed.
- If the lower 95% assurance level is used to simulate a drought the available groundwater from the GYMR is 232 356 m^3/d, calculating 57% of this volume equates to 132 443 m^3/d available in the modelled catchment.

B6 RECOMMENDATIONS

The following recommendations are proposed, based on the groundwater flow model:

- Groundwater level monitoring is proposed to measure the effect of abstraction in both the SRK and monitoring boreholes, and to mitigate accordingly.
- An updated reserve and groundwater flow model should be conducted to evaluate the effectiveness of sustainable abstraction rates and recommendations made in this study every 2 years.
- Abstraction rates of the water supply boreholes should be adjusted accordingly during dry periods.

B7 MODELLING METHODOLOGY

The purpose of using a model should be to turn data into information for decision making purposes. As shown earlier, the decision-making process requires data, expressed in terms of information until it is sufficient to make a decision. Models are used to elevate the level of information that can be extracted from the data (**Figure B7-1**).

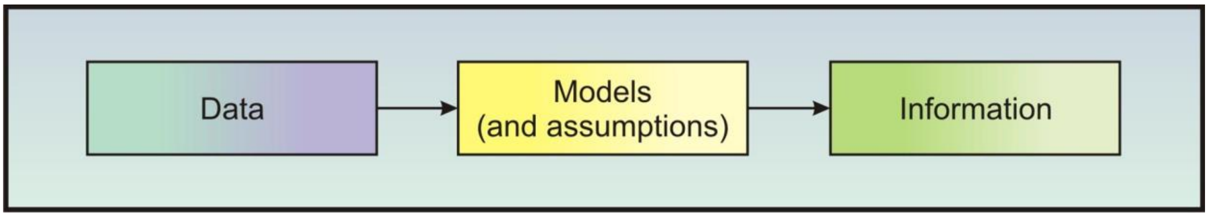

Figure B7-1 Schematic representation of the use of models to turn data into information information

One of the most common comments on modelling is that there are idealised underlying assumptions that may not represent the physical system accurately. The role of assumptions is to substitute information and without which no model would be possible. It would only be a perfect model (which does not exist) that would not be based on any assumptions. The purpose of the application of a model is to simulate the problem. The purpose is not to model the physical system with zero defects. The purpose of research is to develop models that describe the physical system (i.e. porous and fracture flow models in groundwater) with ever increasing accuracy. It must be accepted that there is no model that will ever be able to simulate the physical system with exact precision. Modelling for the purposes of decision-making is therefore not a purely scientific exercise, but also a management action that makes use of scientific tools to arrive at decision outputs.

To illustrate this point, a model can be equated to a map. A map is a model that represents an area in space. The purpose of a map is for the user to follow it to arrive at an unknown location. A simple line map that indicates the route/s between two points 1 and 2 is an example of a model, see **Figure B7-2** Schematic representation of a simple line map analogy for a model. The map is a simplified, two-dimensional representation of a three-dimensional terrain (i.e. it is a model) that does not represent the physical area accurately with all the trees and traffic lights and cars etc. It can be stated by anyone that the map is wrong. The map is not wrong because the purpose of the map is to solve the problem of finding one of the two locations and not to represent the physical area exactly. A detailed map that is more accurate would be scientifically more correct or acceptable, as it represents the physical area more accurately.

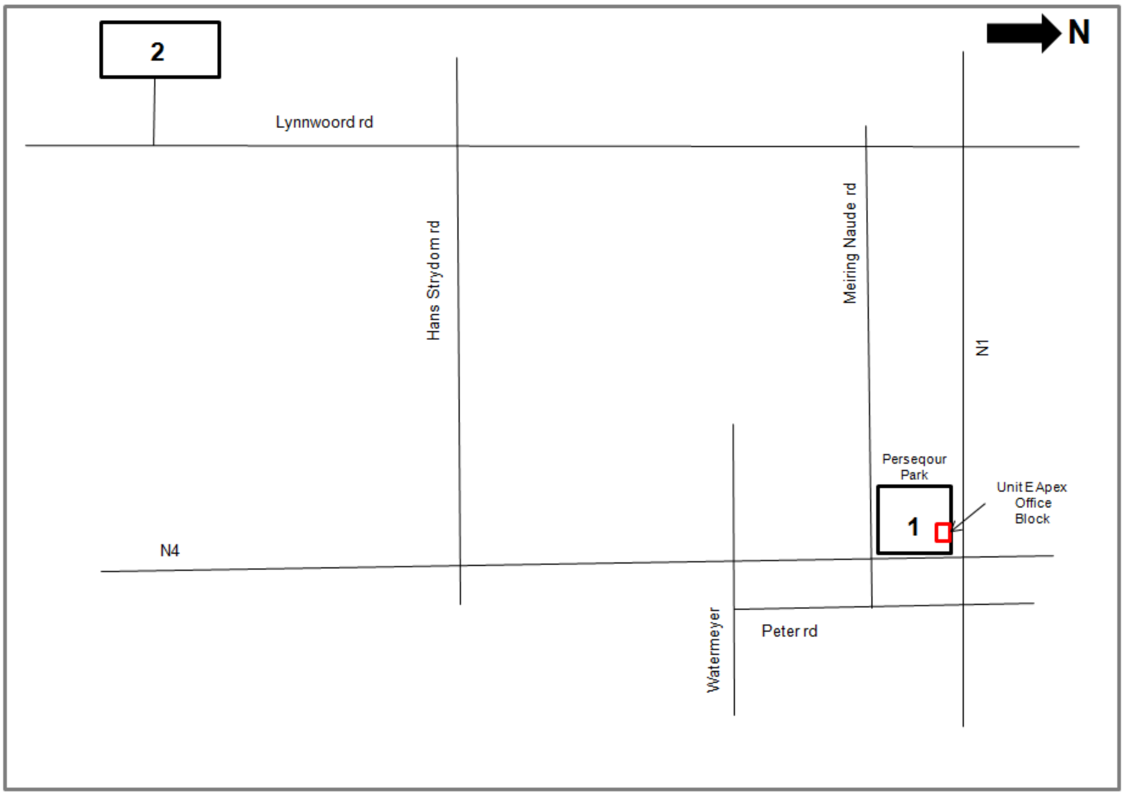

Figure B7-2 Schematic representation of a simple line map analogy for a model

For the purposes of decision-making, the more detailed map could be an "overkill" as it would take more time (and cost) to compile while serving the same purpose. If e.g. the detailed map, confuse the user because of too much data but not sufficient information, it would be a worse model than the simple line map. This is known as the less-is-more effect. The basis of this effect is that more information than is required could obstruct decision-making. It is not true that a model which describes the physical system most accurately is better, it is the one that is able to simulate the problem and provide the best answers for the purposes of decision-making, which is the better one. The complexity of the model is therefore not necessarily related to the complexity of the problem.

Information Box 7-A

To further illustrate the point of purpose, if one were to ask anyone whether a knife is a dangerous object or not? The answer could be that people get injured or even murdered by using knives and therefore all knives should be banned everywhere. If say an innocent person gets mugged and stabbed with a knife in the street, an ambulance takes that person to the trauma unit. The surgeon arrives and what does he use to open and cure the wound? A surgical "knife". It is therefore the purpose of the object that determines whether it is good or bad and not the object itself. It is the same with modelling. Everything has a use that can be abused if applied outside its purpose.

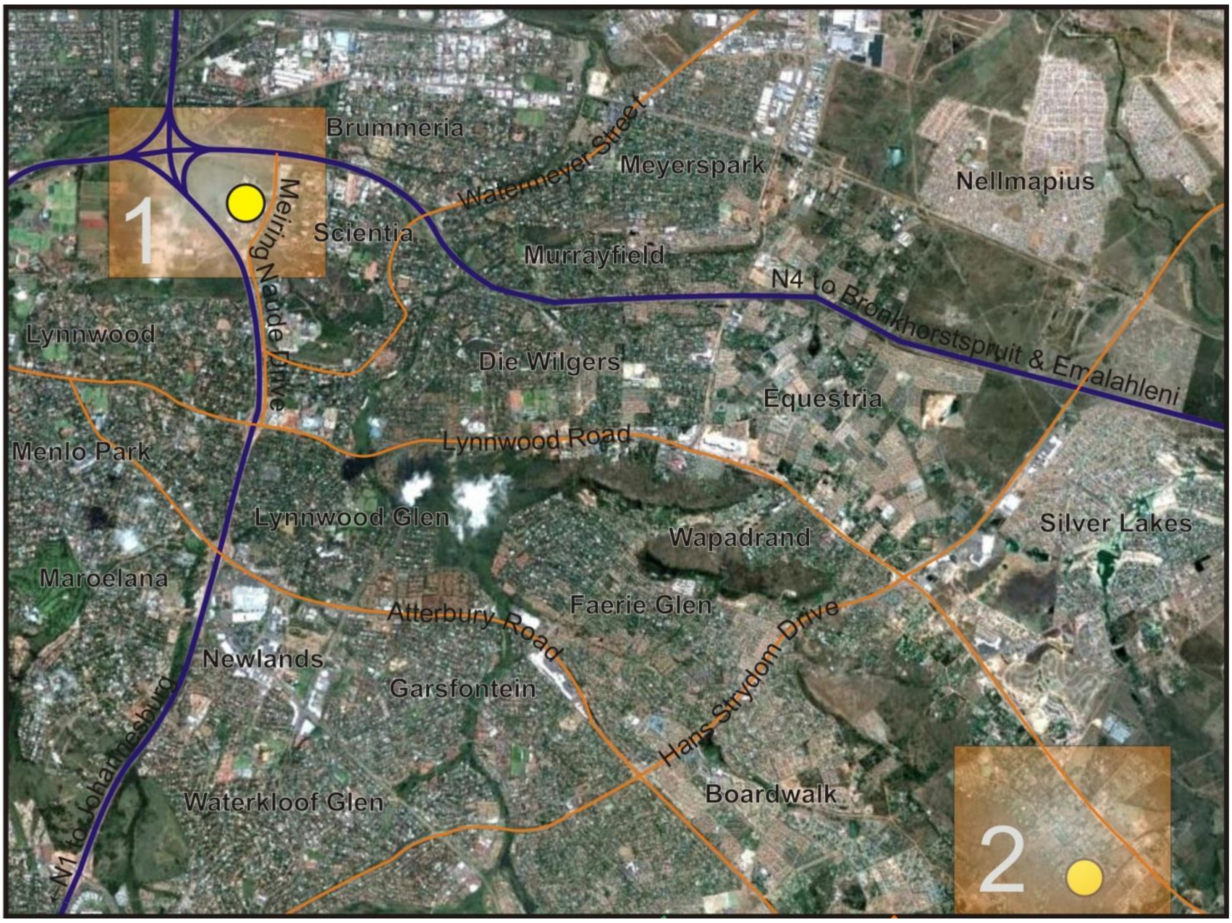

Figure B7-3: Schematic representation of a detailed map analogy of a model

Appendix C

Groundwater Community Compatibility Study

GROUNDWATER-COMMUNITY COMPATIBILITY STUDY

Feasibility Study for the Augmentation of the Lusikisiki Regional Water Supply Scheme MODULE 3—Groundwater Augmentation

15 April 2011

Conducted on behalf of:

BKS (PTY) LTD

Compiled by:

Project team:

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C1 INTRODUCTION

AGES' Social Unit sought to explore the knowledge, attitudes and perceptions of community members, whom reside within the Lusikisiki Regional Water Supply project area, concerning surface and groundwater as a domestic water source. This was undertaken with the aim to discover which factors might impinge on the sustainability of the Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme.

South Africa is a semi-arid country, plagued by ever-recurring droughts that are sometimes punctuated by extreme floods (Perkins). The country's annual rainfall is 475 mm, compared with a world average of 860 mm (Perkins). Coupled with the fact that 80 percent of our rainfall occurs during summer months and is spatially poorly distributed, it is clear that we have a water availability problem and a resource management challenge (Perkins).

To address this water availability problem, the National Water Act (36 of 1998) proposes that water consultants adopt an approach that is strategic, deliberate and dictated by socio-political reforms and socio-economic development needs on a programmatic basis for long-term sustainability. AGES conducted a ground- and surface water compatibility assessment of key areas in the larger project area to ensure that the development of water resources and systems be managed to achieve optimum long-term social and economic benefit for society from their use. The purpose of this report is to present the findings of this assessment and recommend future groundwater awareness enterprises.

The main objective of the groundwater—community interdependency study is to proactively determine the attitude of communities and their knowledge regarding surface and groundwater. Both these variables are of the essence towards ensuring the sustainability of the larger regional water supply project. Understanding those factors has implications for the development of sustainable ground- and surface water sources.

This study was important, because there has been a considerable high level of project letdown (Hemson, 2002). Whilst there are many discussions about the cause of these project failures, the foremost cause determined by researchers in rationalization of the occurrence is meagre institutional and social development (ISD).

C2 CONTEXT: FEASIBILITY STUDY FOR AUGMENTATION OF THE LUSIKISIKI REGIONAL WATER SUPPLY SCHEME

BACKGROUND OF FEASIBILITY STUDY

On the 1st of September 2010 the Department of Water Affairs appointed BKS and four sub-consultants (Africa Geo-Environmental Services, KARIWA Project Engineers & Associates, Scherman Colloty & Associates, and Urban-Econ) to embark on the Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme (BKS (Pty) Ltd, 2011).

After the first democratic elections, the Transkei as an entity fell away, and the region became part of the vast and diverse Eastern Cape Provence. Following the land reincorporation, the Department of Water Affairs and Forestry (DWAF) took on the task of developing the region (BKS (Pty) Ltd, 2011). Consequently the Eastern Pondoland Basin Study (EPBS) was commissioned in 1999, by The Directorate: National Water Resource Planning, to further investigate the water supply situation in the area. Special emphasis was placed on the Lusikisiki Regional Water Supply Scheme (LRWSS) area for further development (BKS (Pty) Ltd, 2011). Recommendations from the study suggested:

- The construction of the Zalu Dam in the Xura River, and/or,
- The development of groundwater sources, as the best augmentation options (BKS (Pty) Ltd, 2011; DWAF, 2005).

In 2007, SRK Consulting completed the Lusikisiki Groundwater Feasibility Study. The project considered the groundwater potential and compared new information with information sourced by former studies (BKS (Pty) Ltd, 2011). Findings indicated a strong probability of discovering high yielding boreholes, and that the conjunctive use of surface water (Zalu Dam) and groundwater may be the best solution for the LRWSS.

OBJECTIVES OF THE FEASIBILITY STUDY

BKS reports that:

"The objective of this study is to complete a comprehensive engineering investigation at the feasibility level for the proposed Lusikisiki Regional Water Supply Scheme, including the proposed Zalu Dam in the Xura River, and to define the most attractive composition and size of the water supply components, taking augmentation from groundwater resources into account (BKS (Pty) Ltd, 2011)."

Scope of the Feasibility Study

The extent of the feasibility study includes the determination of the achievability of the project. This was done by investigating which factors influences the success of conjunctive surface water and groundwater use so that the existing water supply infrastructure can be upgraded and expanded. The upgraded and expanded scheme should be able to provide all water users with the minimum water supply requirements (BKS (Pty) Ltd, 2011).

Organisation of the Project

In order to achieve the objective of the feasibility study, various activities were identified that need to be investigated. The required activities were grouped into 14 modules as shown in the table below. These modules were sub-divided between the main consultant, BKS, and the four sub consultants (Africa Geo-Environmental Services (AGES), KARIWA Project Engineers & Associates, Scherman Colloty & Associates, and Urban-Econ). AGES was mandated to complete Module 3 as highlighted in yellow in **Table C2-1** below. This study forms part of activities completed as a subsection of Module 3 and entails a groundwater–community interdependency survey.

Table C2-1: Study structure

New modules	Modules from ToR	Module leader	Company	Deliverable
1. PROJECT MANAGEMENT 1.1 Study initiation and inception 1.2 Project management and administration	Project management (incl. study initiation and inception)	JD Rossouw	BKS	**Inception Report**
2. WATER RESOURCES	***Module 2***: Yield analysis	JD Rossouw	BKS	**Water Resources Report**
2.1 Hydrology	***Module 1***: Hydrology	E van Niekerk	BKS	♦ Hydrology chapter in Water Resources Report
2.2 Yield analysis	2.1 Water resources	JD Rossouw		♦ Yield Analysis chapter in Water Resources Report
2.3 Reservoir sedimentation	2.3 Reservoir sedimentation	Dr A le Grange	BKS	♦ Sedimentation chapter in Water Resources Report
3. GROUNDWATER AUGMENTATION	***Module 5***: Groundwater augmentation	JA Myburgh	AGES	**Assessment of Augmentation from Groundwater Report**
4. RESERVE - ECOLOGICAL WATER REQUIREMENTS	2.2 Ecological water requirements	Dr P Scherman	SC&A	**Intermediate Reserve Determination Report** ♦ Reserve Template
5. WATER REQUIREMENTS	***Module 3***: Water requirements	HS Pieterse	BKS	
5.1 Domestic water requirements	3.1 Domestic water requirements	T Feigenbaum	Urban-Econ	**Domestic Water Requirements Report**

New modules	Modules from ToR	Module leader	Company	Deliverable
5.2 Agriculture / Irrigation potential	3.2 Irrigation potential	G Bloem	Kariwa	**Irrigation Development Report**
6. WATER SERVICE INFRASTRUCTURE		Dr GH de Villiers	BKS	**Water Distribution Infrastructure Report**
6.1 Distribution infrastructure	3.3 Distribution infrastructure	JPC van Heerden	BKS	♦ Chapter in Water Distribution Infrastructure Report
6.2 Water quality	***Module 4*** Water quality	Dr GH de Villiers	BKS	♦ Chapter in Water Distribution Infrastructure Report
7. PROPOSED ZALU DAM		W van Wyk	BKS	
7.1 Site investigations	***Module 6*** Site investigations	M van Schalkwyk	BKS	**Materials & Geotechnical Investigations Report**
7.2 Dam technical details	***Module 7*** Dam technical details	W van Wyk	BKS	**Dam Preliminary Design Report, including design criteria, dam type selection, dam sizing**
8. COST ESTIMATE AND COMPARISON	***Module 8*** Cost estimate and comparison	HS Pieterse	BKS	♦ Project cost chapter included Main Study Report
9. REGIONAL ECONOMICS	***Module 10*** Regional economics	BJ van der Merwe	Urban-Econ	**Regional Economics Report**
10. ENVIRONMENTAL SCREENING	***Module 9*** Environmental screening	N Liversage	BKS	**Environmental Screening Report** ♦ Scope of works for EIA
11. PUBLIC PARTICIPATION	***Module 13*** Public participation	EM Mashau	BKS	♦ Included in Environmental Screening Report
12. LEGAL, INSTITUTIONAL & FINANCIAL ARRANGEMENTS	***Module 12*** Legal, institutional and financial arrangements	RA Pullen	BKS	♦ **Legal, institutional & financing arrangements chapter in Main Study Report**
13. RECORD OF IMPLEMENTATION OF DECISIONS (RID)	***Module 11*** Record of implementation of decisions (RID)	HS Pieterse	BKS	**RID**
14. MAIN REPORT AND REVIEWS	***Module 14*** Task reviews, recommendations and Main Report	JD Rossouw	BKS	**Main Study Report**

LOCATION OF PROJECT AREA

The study area consists of the region between Lusikisiki and the coast, expanding from the Mzimvubu River in the south west to the Msikaba River in the north-east

During the Inception Phase the study area was extended in the vicinity of the Zalu Dam and to the north of Lusikisiki (BKS (Pty) Ltd, 2011).

Photo C2-1: Mzimvubu River

In the south-eastern part of the study area the main focus was on water supply from groundwater, due to the distance from the surface water source, Zalu Dam, as well as the topography.

Photo C2-2: Mzimvubu estuary

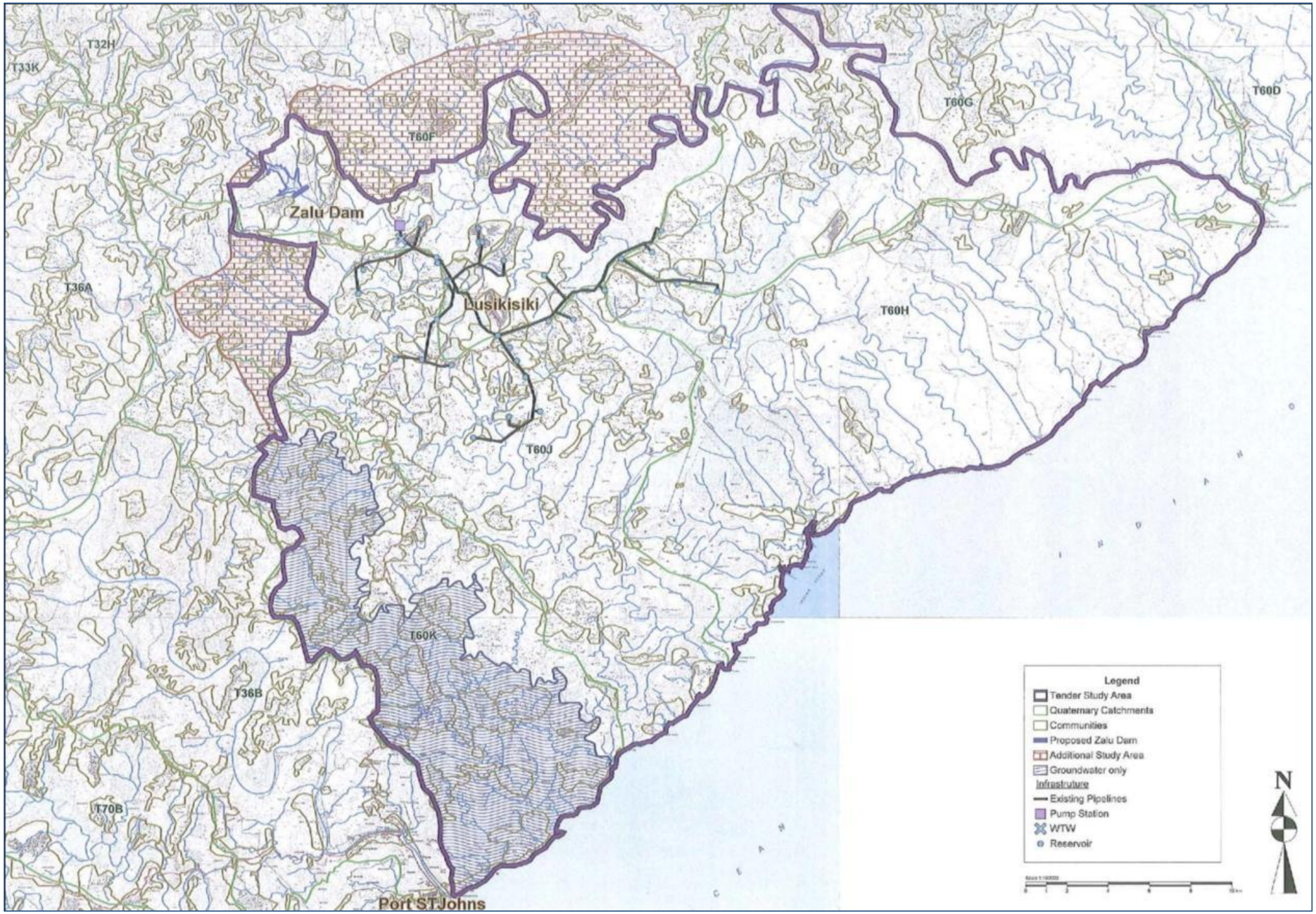

Figure C2-1: Project Area

C3 OBJECTIVES FOR THIS STUDY: GROUNDWATER COMMUNITY INTERDEPENDENCY SURVEY

As part of the AGES' mandate to perform an assessment of augmentation from the groundwater report (as highlighted in yellow in **Table C2-1**), AGES' Social Unit engaged in a sub-assessment of community dependencies and attitudes towards groundwater. An assessment of community dependencies and attitudes towards surface- and groundwater as a domestic water source is essential, as project failure is often attributed to poor community "buy-ins" into larger projects.

The groundwater—community interdependency study included:

(i) **An assessment of community dependencies and attitudes towards groundwater:**

(ii) **An assessment of regional groundwater use and infrastructure statistics, and**

(iii) **Attitude analyses – groundwater versus surface water.**

The findings of these assessments are discussed in this report.

C4 BACKGROUND OF PONDOLAND

On 26 October 1976 Transkei (meaning the area beyond the river Kei), officially the Republic of Transkei (Xhosa: iRiphabliki yeTranskei), became the first independent homeland. The Transkei had an area covering a total of 45,000 km^2 (17,000 sq mi), and was bordered by the Umtamvuna River in the north and the Great Kei River in the south, while the Indian Ocean and the Drakensberg mountain range of the landlocked kingdom of Lesotho served as the Transkei's respective eastern and western frontiers. Its southern border was the Great Kei River, with the Indian Ocean to the east, KwaZulu Natal to the north and Lesotho to the northwest (see **Figure C4-2**). The capital and main city was Umtata.

Transkei represented a significant precedent and historic turning point in South Africa's policy of apartheid and "separate development" in that it was the first of four territories to be declared independent. Throughout its existence, it remained an internationally unrecognised, diplomatically isolated, a politically unstable de facto one-party state, which at one point even broke relations with South Africa, the only country that acknowledged it as a legal entity.

In 1994, it was reintegrated into South Africa and became part of the Eastern Cape Province. The Pondoland region lies on the Transkei coast between the Mtamvuma and Umtata rivers, bordering on Kwazulu Natal in the north and divided by Umzimvubu River into East and West Pondoland, each with its own chief (UWP Engineers, 2001).

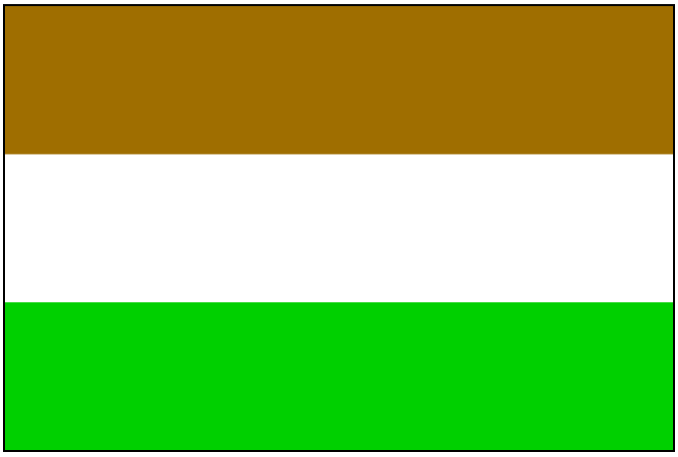

Figure C4-1: Transkei flag

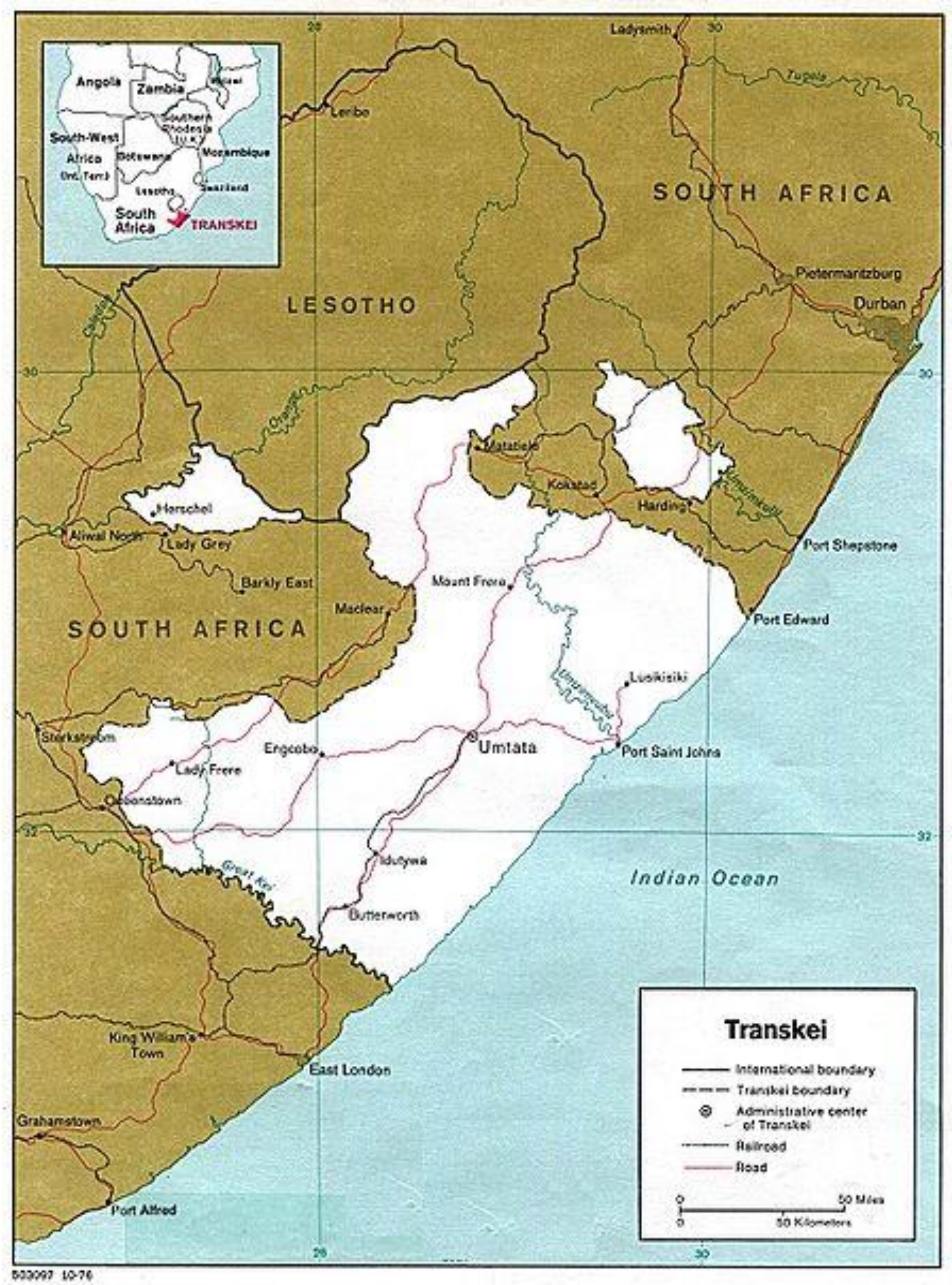

Figure C4-2: Former Transkei

In East Pondoland the towns and districts are Lusikisiki, Flagstaff, Bizana and Tabankulu; and in West Pondoland the towns are Port ST John's, Libode and Ngqeleni. Qaukeni Great Place in Lusikisiki is the home of the Pondoland King Xolilizwe Sigcau, descendant of the great King Faku (UWP Engineers, 2001). The Pondoland region is the richest cattle region in the Transkei, and also the most fertile, although farming methods are very primitive (UWP Engineers, 2001). The agricultural potential is greater than that of any other part in the Transkei (UWP Engineers, 2001). The principal agricultural products are maize and dagga, the latter being cultivated and smuggled out (UWP Engineers, 2001).

The first president of an independent Transkei Botha Sigcau was the King of East Pondoland (UWP Engineers, 2001). Oliver Reginald Tambo the then president of the ANC was also born in Pondoland, the district of Bizana (UWP Engineers, 2001).

C5 REGIONAL GROUNDWATER USE AND INFRASTRUCTURE STATISTICS

C5.1 BACKGROUND

The existing general infrastructure within the region is under developed is generally in a poor state (UWP Engineers, 2001). In general, the level of hardship for the local population concerning water and sanitation services is high (UWP Engineers, 2001). Only the towns of Lusikisiki and Flagstaff have water born sanitation facilities (UWP Engineers, 2001). At present approximately 100 000 (20%) of the population within the study area is supplied with water from nine schemes, but often at levels of service below RDP standard (UWP Engineers, 2001). The remaining 80% of the population does not have access to water services.

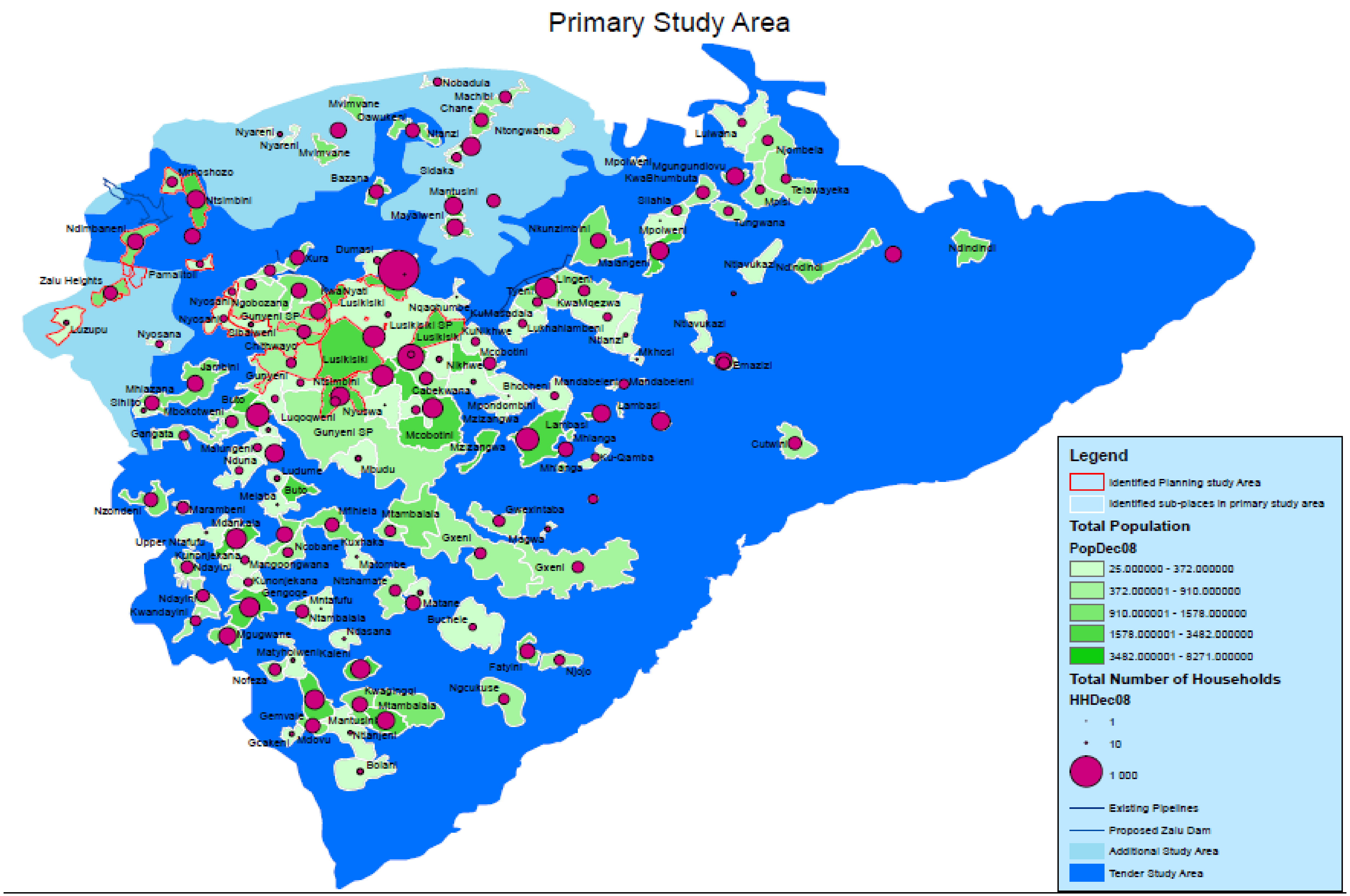

Figure C5-1: Population (Urban Econ)

C5.2 GROUNDWATER USAGE

According to AGES database, there are 221 boreholes, 170 springs, 13 pans/dams, and 3 rivers/streams within the Lusikisiki groundwater feasibility study area. Refer to **Figure C5.2** for a visual representation of existing boreholes and springs in the study area.

Table C5-1: Groundwater usage

Data Sources	Boreholes	Springs	Pan or dam	River or stream	Total
GRIP	24	91	3	3	**121**
NGDB	197	79	10	0	**286**
TOTAL	**221**	**170**	**13**	**3**	

Boreholes

Of the 221 boreholes, 60 are in use, 37 are unused, 9 are destroyed and 115 are unknown.

Table C5-2: Boreholes

	Boreholes				
	In use	Unused	Destroyed	Unknown	Total
GRIP	7	8	9		24
NGDB	53	29	0	115	197
TOTAL	**60**	**37**	**9**	**115**	

Boreholes in use

Of the boreholes in use, 17 operates with a hand pump, 5 monos, one has no equipment, three are submersible, 24 operate with a wind pump, and the statuses of 10 are unknown.

Table C5-3: Boreholes in use

Boreholes - in use							
	Handpump	Mono	No equipment	Submersible	Windpump	Unknown	Total
GRIP	3	2	1	1			7
NGDB	14	3		2	24	10	53
TOTAL	**17**	**5**	**1**	**3**	**24**	**10**	

Boreholes unutilised

Three of the unutilised boreholes have hand pumps, one is mono, 12 have no equipment, one is submersible, two are wind pumps, and the statuses of 18 are unknown.

Table C5-4: Boreholes unutilised

BOREHOLES - UNUSED							
	Handpump	Mono	No equipment	Submersible	Windpump	Unknown	Total
GRIP	1	1	3	1	2		8
NGDB	2		9			18	29
TOTAL	**3**	**1**	**12**	**1**	**2**	**18**	

Boreholes destroyed

Of the boreholes destroyed, four have hand pumps, 3 no equipment, and two have wind pumps.

Table C5-5: Boreholes destroyed

Boreholes - destroyed							
	Hand pump	Mono	No equipment	Submersible	Wind pump	Other	Total
GRIP	4		3		2		9
NGDB							0
TOTAL	**4**	**0**	**3**	**0**	**2**	**0**	

Boreholes unknown

The following statistics are available of the boreholes unknown. Two have hand pumps, and one has a turbine.

Table C5-6: Boreholes unknown

Boreholes - unknown							
	Hand pump	Turbine	No equipment	Submersible	Wind pump	Unknown	Total
GRIP							0
NGDB	2	1				192	195
TOTAL	**2**	**1**	**0**	**0**	**0**	**192**	

Springs

One hundred springs are in use and 70 statuses are unknown.

Table C5-7: Springs

Springs					
	In Use	Unused	Destroyed	Unknown	Total
GRIP	91				91
NGDB	9			70	79
TOTAL	**100**	**0**	**0**	**70**	

Springs in use

None of the springs in use has equipment. Statistics however indicated that 10 spring's abstract water from other measures unknown.

Table C5-8: Springs in use

Springs - in use							
	Hand pump	Mono	No equipment	Submersible	Wind pump	Other	Total
GRIP			90			1	91
NGDB						9	9
TOTAL	**0**	**0**	**90**	**0**	**0**	**10**	

Springs unutilised

All springs are used.

Table C5-9: Springs unutilised

Springs - unused							
	Hand pump	Mono	No equipment	Submersible	Wind pump	Other	Total
GRIP							0
NGDB							0
TOTAL	**0**	**0**	**0**	**0**	**0**	**0**	

Pan or dam

One pan/dam is in use; two unused and 10 are unknown. None of the dams has pumps or equipment.

Table C5-10: Pan or dam

Pan or dam					
	In use	Unused	Destroyed	Unknown	Total
GRIP	1	2			3
NGDB				10	10
TOTAL	**1**	**2**	**0**	**10**	

River or stream

Data indicates that there are three rivers/streams in use but there are no pumps or equipment to extract water from the rivers/streams.

Table C5-11: Rivers or streams

River or stream					
	In use	Unused	Destroyed	Unknown	Total
GRIP	3				3
NGDB					0
TOTAL	**3**	**0**	**0**	**0**	

Figure C5-2 is a visual representation of all the boreholes and springs in the area.

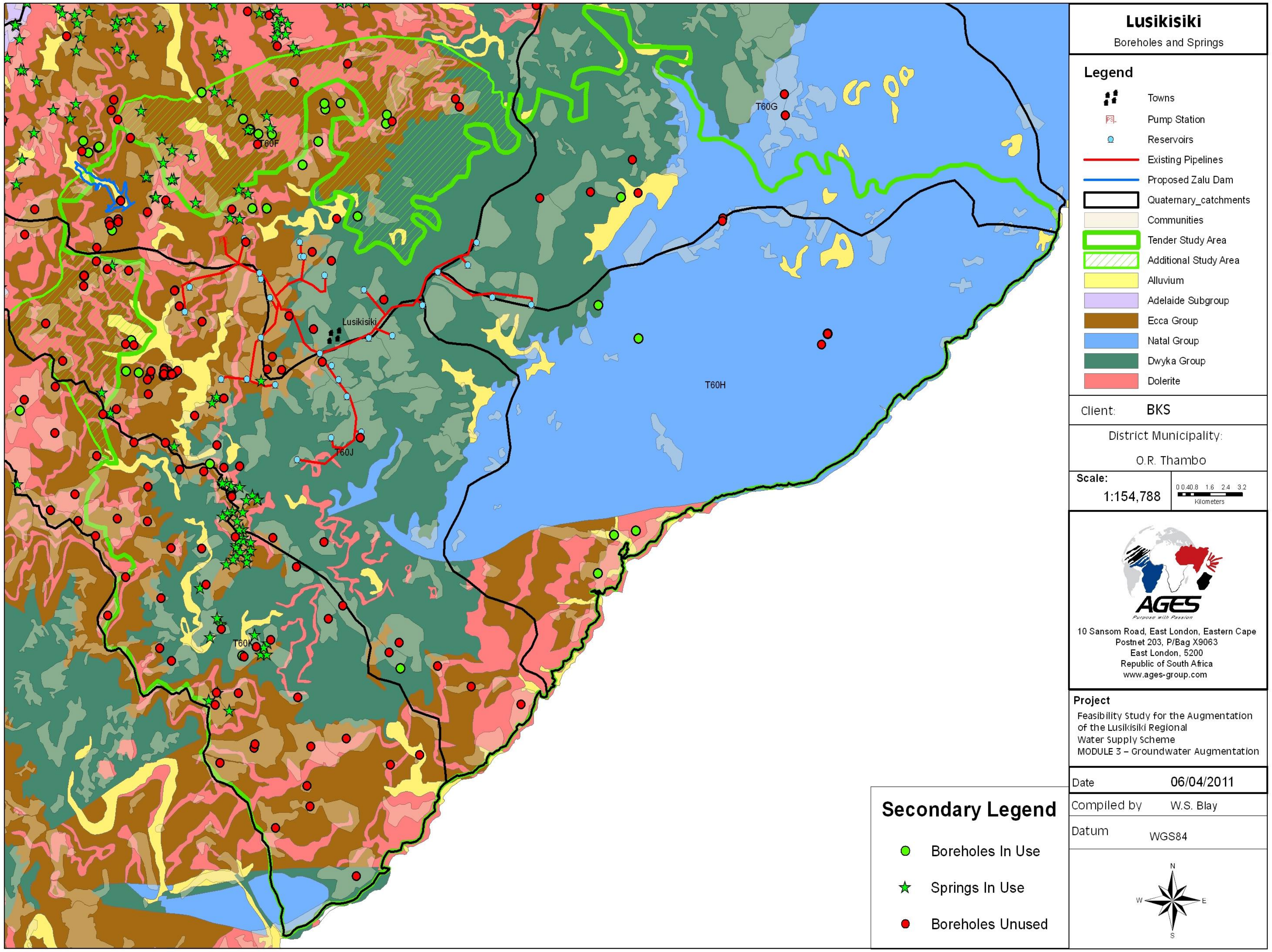

Figure C5-2: Lusikisiki boreholes and springs

C6 COMMUNITY DEPENDENCY AND GROUNDWATER ATTITUDES

METHODOLOGY

A survey that measured groundwater community compatibility levels was conducted at key vicinities in the study area. The purpose of the survey is to identify social factors that may influence the sustainability of the larger water supply project. In this sense, AGES assessed the knowledge communities carried concerning groundwater as well as their general attitude towards the use of groundwater as a water source. If a community has limited knowledge concerning groundwater and if their attitudes towards groundwater is negative it may result in higher levels of vandalism, they may be less likely to share water with neighbouring villages, or engage in general behaviour that do not promote the conservation of water, for example leaving taps to run unchecked.

SAMPLING

This survey formed part of the larger socio-economic survey conducted by Urban-Econ. Urban-Econ is one of the sub-consultants for the Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme. The socio-economic survey formed part of Urban-Econ's deliverables as stated in the Module 9 study structure (refer to the Organisation of the Study section in the beginning of the report). The socio-economic assessment created an opportunity for AGES to incorporate a subset of questions that would provide us with the data we required for this research.

The socio-economic survey recruited a small number (sample) of participants from the population (360). Participants were grouped in terms of their location within a predetermined area. With reference to the **Figure C6-1** on the following page, six areas were delineated. These six areas formed the focus of the community interdependency survey and are referred to as Zalu Dam, Lusikisiki, Network East, Network South, Remote South, and Remote West.

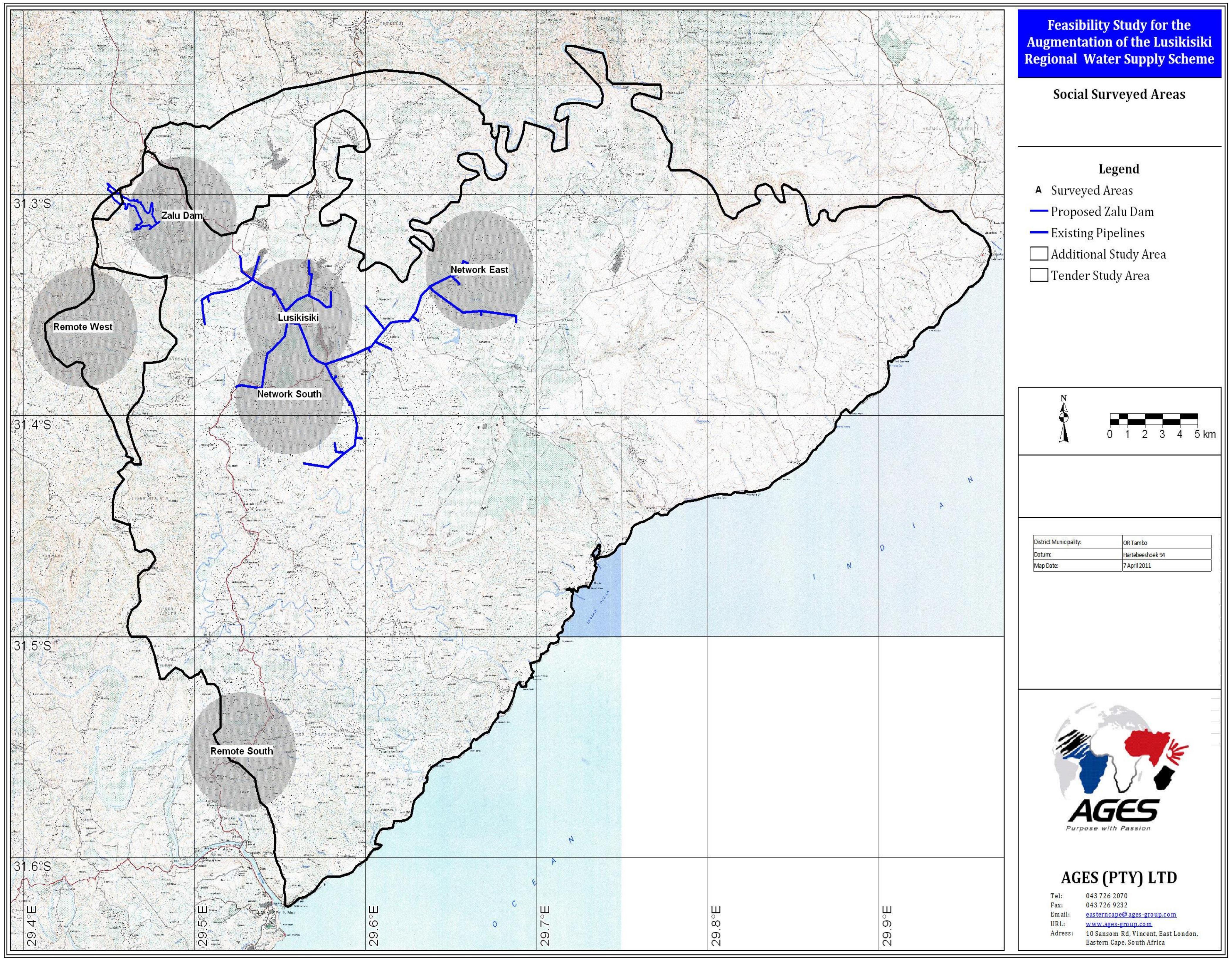

Figure C6-1: Surveyed areas

PROCEDURE

AGES collected data by means of the following methods:

At ground level survey per target area questionnaires were used in this study, as it was the most practical vehicle for collecting information (refer to **Table C6-1** below for an example of the survey sheet). The surveyors were trained in isiXhosa and each question was revised in order to minimise incorrect interpretation of the questions. Despite this training it was obvious that some of the questions were not clearly understood. In such cases data had to be adjusted for interpretation purposes.

Table C6-1: Social survey questions

Local groundwater knowledge			
Have they drilled boreholes in your area in the past?	YES/NO		
Is there enough groundwater in your area to serve everybody?	YES/NO		
Are people drinking groundwater from boreholes in your area?	YES/NO		
What does groundwater in your area taste like?	GOOD/BAD		
Attitude towards groundwater			
How does the community feel about having groundwater as a water source?	POS/NEG		
Do you think groundwater is safe to drink?	YES/NO		
Can groundwater be polluted?	YES/NO		
Do some of the people become sick from groundwater?	YES/NO		
Is the borehole pump house or windmill a safe area for children?	YES/NO		
Source preference based on Perceptions			
Please rate the following table using either a 1, 2 or 3.			
1 indicates the highest and 2 indicates medium and 3 indicates low:			
1 = Best/highest			
2 = Medium			
3 = Worst/Lowest			
QUANTITY			
QUALITY			
COST TO DEVELOP			
COST TO MAINTAIN			
SUSTAINABILITY			
MY PREFERENCE			

METHOD OF DATA COLLECTION

The focus of the survey was to determine the following about the community members:

(iv) Knowledge about the local groundwater conditions;

(v) Attitude towards groundwater, and

(vi) Source preference based on perceptions.

These variables are of the essence towards ensuring the sustainability of a groundwater project. If the attitudes of the community are negative towards groundwater, for example, their experiences of groundwater is that it has a salty or bitter taste and that the boreholes run dry, their motivation to protect their water sources would be minimal. In addition, if the community has limited knowledge about groundwater, for example, the water cycle, or the quantity of groundwater in comparison to surface water, it may lead to behaviour that does not promote the conservation of their water sources.

SURVEY FACILITATION

Six people from the project area, which are fluent in isiXhosa, assisted to record answers onto the questionnaire sheets. These people were trained to complete the survey in isiXhosa. Each question was revised to clarify any uncertainty that may result from incorrect interpretation. This was done to try to enhance the validity of the questionnaires.

DATA ANALYSIS

Stage 1: Data captured

Once the relevant variables were measured, the data was captured into excel worksheets. The scores on these variables (data) were transformed statistically in order to describe the data more succinctly and inferences were made about the target areas in general based on the data from the samples.

Stage 2: Identification of themes

We identified and labelled themes that characterised various sections of the data. Three (3) theme titles were conceptualised and they elicited the essence of the data (Willig, 2001).

Stage 3: Clustering of themes

A Structure was introduced into the analysis. The themes identified in the previous stage were listed and thought about in relation to one another. Some of the themes formed clusters of concepts that share similar notions. Headings were provided to clusters of themes that elicited their essence. Care was taken that the link between themes identified resonated with the participant's responses.

Stage 4: Production of a summary table

During this stage, summary charts of the structured themes were produced for each individual target area surveyed. The summary charts consisted of the cluster labels collectively with their subordinate theme labels.

C7 RESULTS AND ANALYSIS

C7.1 LOCAL GROUNDWATER KNOWLEDGE

One of the focus areas of the study was to determine the community members' attitude and their knowledge regarding groundwater. Both these variables are of the essence towards ensuring the sustainability of a project if groundwater is going to be a potential water source. Understanding those factors has implications for future use and development of sustainable groundwater sources. This research is important, because there has been a considerable high level of project letdown (Hemson, 2002). Whilst there are many discussions about the cause of these project failures, the foremost cause determined by researchers in rationalization of the occurrence is meagre institutional and social development (ISD). Studies such as these have implications for future use and development of sustainable groundwater source development strategies.

If ISD were envisioned as a primary strategy to make groundwater source development projects more sustainable, with the underlying assumption that information and skill will lead to an increase in sustainable practices, one would assume that it becomes imperative to determine the community members' attitude and their knowledge regarding groundwater.

In order to investigate this, twenty-seven (27) questions were asked to the participants. Nine of these questions dealt with knowledge and attitude towards groundwater. The remaining questions dealt with source preference based on perceptions.

The first nine questions were designed to explore how the knowledge and attitudes of the community members may mediate their ability to negotiate sustainable groundwater practices.

In the analysis of the surveys, the following three salient themes were identified.

(i) Knowledge about the local groundwater conditions;

(ii) Attitude towards groundwater, and

(iii) Source preference based on perceptions.

Each theme with its constituent sub-themes is presented and discussed.

Three sub-themes constitute the main theme "Knowledge-Local Groundwater Conditions". This theme represents the specific knowledge participants have about groundwater in their area. The specific local groundwater knowledge participants have are of importance to this study as it may indicate useful information to the geohydrological studies in terms of indicating in which areas groundwater was previously found. It also gives an indication how much certain communities have been exposed to ideas and knowledge concerning groundwater. The less knowledge one gets about a certain issue the more misconceptions may be present. In light of this, it will give an indication of which communities need to be exposed more to knowledge concerning groundwater. Many health belief modules state that knowledge influences a person's attitude, which in turn affects one's behaviour. Establishing the amount of knowledge a community has about previous groundwater projects therefore becomes important.

C7.1.1 Have they drilled boreholes in your area in the past?

Zalu Dam

In the area labelled Zalu Dam, as shown on **Figure C6-1**, 77% of respondents indicated that boreholes have been drilled in their area in the past. Results from the groundwater use and infrastructure study agree with the finding and indicate that there are two (2) unused boreholes in the direct vicinity. 33% of respondents indicated that there has not been any drilling in their area in the past (Refer to **Figure C7-1**). This indicates that they are unaware of the two unused boreholes.

Remote West

In the area labelled Remote West, as shown on **Figure C6-1**, 59% of respondents indicated that there have not been drilling in their area in the past (Refer to **Figure C7-1**). Results from the groundwater use and infrastructure study (refer to **Figure C7-1**) indicated that there is indeed a borehole in the area but the borehole is unused.

Network South

In the area labelled Network South, as shown on **Figure C6-1**, 96% of respondents indicated that there have not been any drilling of boreholes in their area in the past. Results from the groundwater use and infrastructure study (Refer to **Figure C7-1**), however indicate that there is a borehole in close proximity of the area. This borehole is however not in use.

Lusikisiki

In the area labelled Lusikisiki, as can be viewed on **Figure C6-1**, 91% of respondents indicated that there have not been any drilling of boreholes in their area in the past. 5% of respondents indicated that they did not know if there was any drilling in the past. Results from the groundwater use and infrastructure study (**Figure C7-1**) however indicate that there is a borehole in close proximity of the area. This borehole is however not in use.

Network East

In the area labelled Network East, as can be viewed on **Figure C6-1**, 10% of respondents had no knowledge about whether there had been drilling in their areas in the past. 80% of respondents indicated that there have not been any drilling and 10% said that there had been (Refer to **Figure C7-1**). Results from the groundwater use and infrastructure study (refer to **Figure C5-2**) correlated with the 80% who said they have not drilled boreholes in their area in the past, and indicated that there are not boreholes in the direct vicinity.

Remote South

In the area labelled Remote South, as shown on **Figure C6-1**, 56% of respondents indicated that there had not been any drilling of boreholes in their area in the past (Refer to **Figure C7-1**). Results from the groundwater use and infrastructure study (**Figure C5-2**) however indicate that there is a borehole in close proximity of the area. This borehole is however not in use.

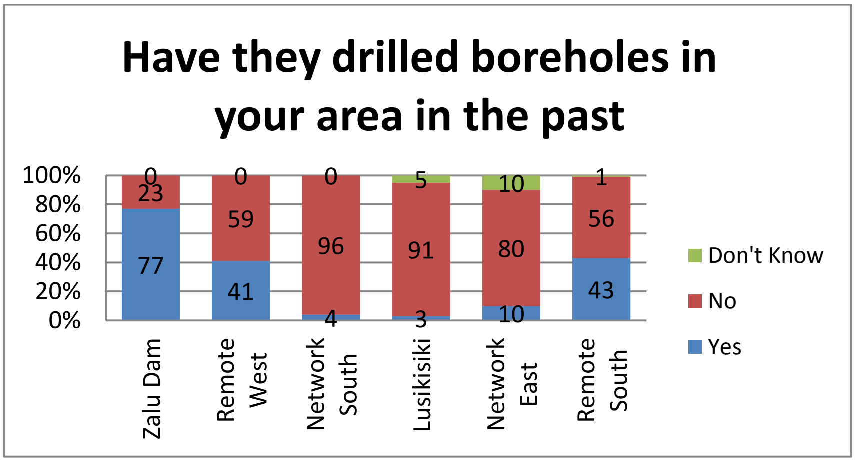

Figure C7-1: Have they drilled boreholes in your area in the past?

In summary, Zalu Dam and Network East were the most accurate in their knowledge concerning boreholes drilled in their areas in the past. All the other areas have inactive boreholes. However in Lusikisiki and Network South an overwhelming majority of community members were unaware of the boreholes and was therefore the least accurate in their estimations. This may possibly indicate that there have not been extensive awareness creations around the boreholes in the past.

C7.1.2 Is there enough groundwater in your area to serve everybody?

Zalu Dam

In the Zalu Dam area, 69% of the respondents think that there is enough groundwater in their area to serve everybody (refer to **Figure C7-2**). This is the only area where the majority feels that there is enough groundwater in their area to serve everybody. In all other areas, the majority of respondents believe there is not enough groundwater to serve everybody. This is significant because it indicates that people in the other areas have incorrect knowledge concerning the amount of groundwater available.

Remote West

In the Remote West Area, 55% of the respondents indicated that there is not enough groundwater available in their area to serve everybody. In addition 11% of the respondents indicated that they did not know if there is enough groundwater (refer to **Figure C7-2**).

Network South

In the Network South Area, 88% of the respondents indicated that there is not enough groundwater available in their area to serve everybody (refer **Figure C7-2**).

Lusikisiki

In the Lusikisiki Area, 40% of the respondents indicated that there is not enough groundwater available in their area to serve everybody. In addition 20% of the respondents indicated that they did not know if there is enough groundwater (refer to **Figure C7-2**).

Network East

In the Network East Area, 62% of the respondents indicated that there is not enough groundwater available in their area to serve everybody. In addition 24% of the respondents indicated that they did not know if there is enough groundwater (refer to **Figure C7-2**).

Remote South

In the Remote South Area, 71% of the respondents the respondents indicated that there is not enough groundwater available in their area to serve everybody. In addition 11% of the respondents indicated that they did not know if there is enough groundwater (refer to **Figure C7-2**).

Zalu Dam

77% of the respondents in the Zalu Dam area reported they were drinking groundwater from boreholes in their area. This is the only area where the respondents overwhelmingly indicated that they are drinking groundwater (refer to **Figure C7-3**). This may explain why these respondents believe that there is enough water for everyone in their community and why they also know that there are boreholes in the area. According to the infrastructure statistics the Zalu Dam area does not have an active borehole. The question therefore is raised do the community members actually have groundwater or do they merely think it is groundwater.

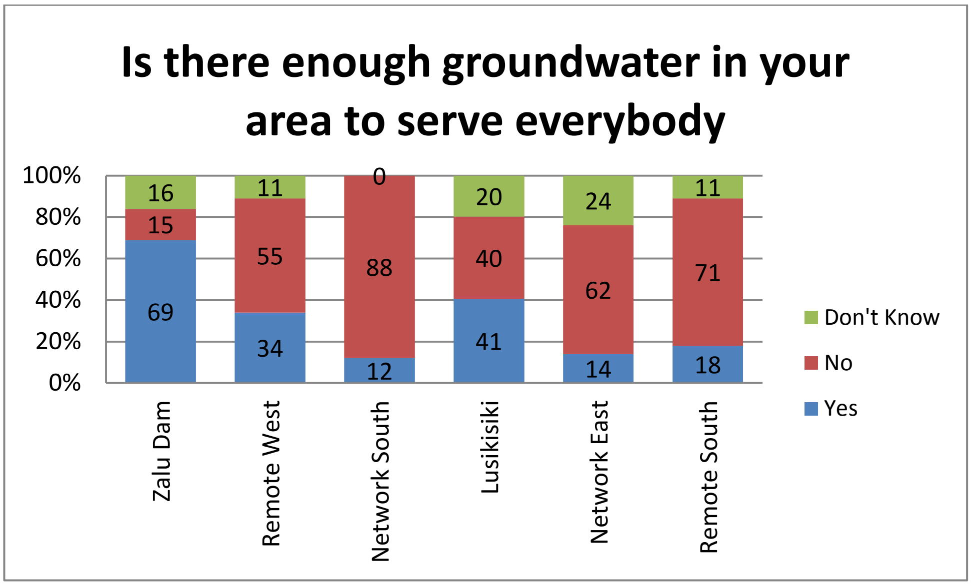

Figure C7-2: Is there enough groundwater in your area to serve everybody?

Remote West

38% of the respondents from the Remote West Area indicated that they drink water from boreholes. 17% of the respondents is uncertain if they are drinking borehole water (refer to **Figure C7-3**). Data from the infrastructure study indicate that there is only an inactive borehole in the area.

Network South

81% of respondents in the Network South area stated that they are drinking groundwater. 8% of the respondents was unsure and 12% of the respondents indicated that they are drinking groundwater (refer to **Figure C7-3**). Infrastructure data does not indicate any active boreholes in the area.

Lusikisiki

In the Lusikisiki area 70% of the respondents indicated that they are drinking groundwater. 18% were unsure and 12% of the respondents said that they are drinking groundwater (refer to **Figure C7-3**). Infrastructure data does not indicate any active boreholes in the area.

Network East

68% of the respondents said that they are not drinking groundwater from their area. A high percentage of individuals (25%) indicated that they did not know what water they are (refer to **Figure C7-3**). Infrastructure data does only indicate an active borehole in the far vicinity.

Remote South

This area is the area who mostly (84%) indicated that they do not drink groundwater from this area (refer to **Figure C7-3**). Infrastructure data correlates with this and does not indicate any active boreholes in the area.

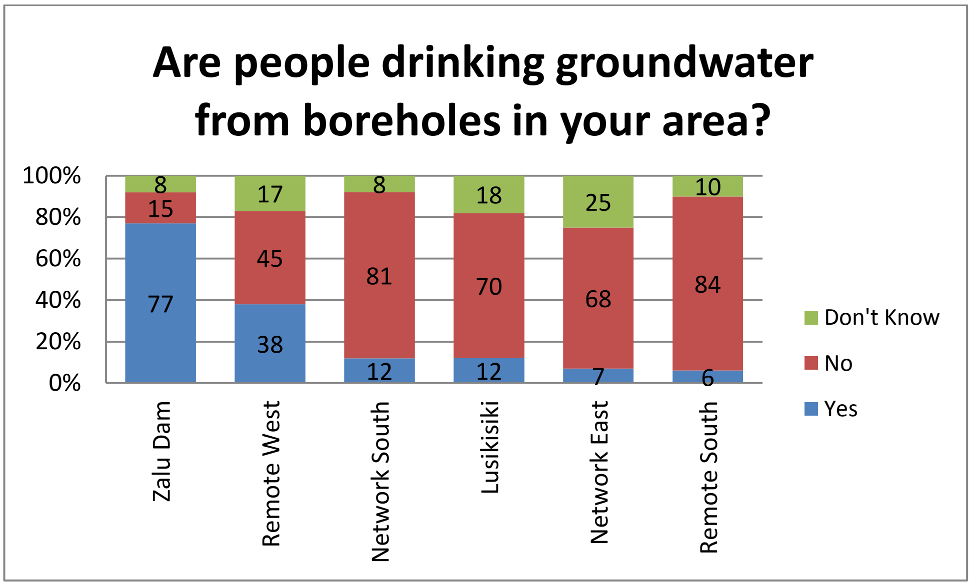

Figure C7-3: Are people drinking groundwater from boreholes in your area?

Figure C7-4 below indicates the average percentage of specific knowledge participants carry about groundwater in their area.

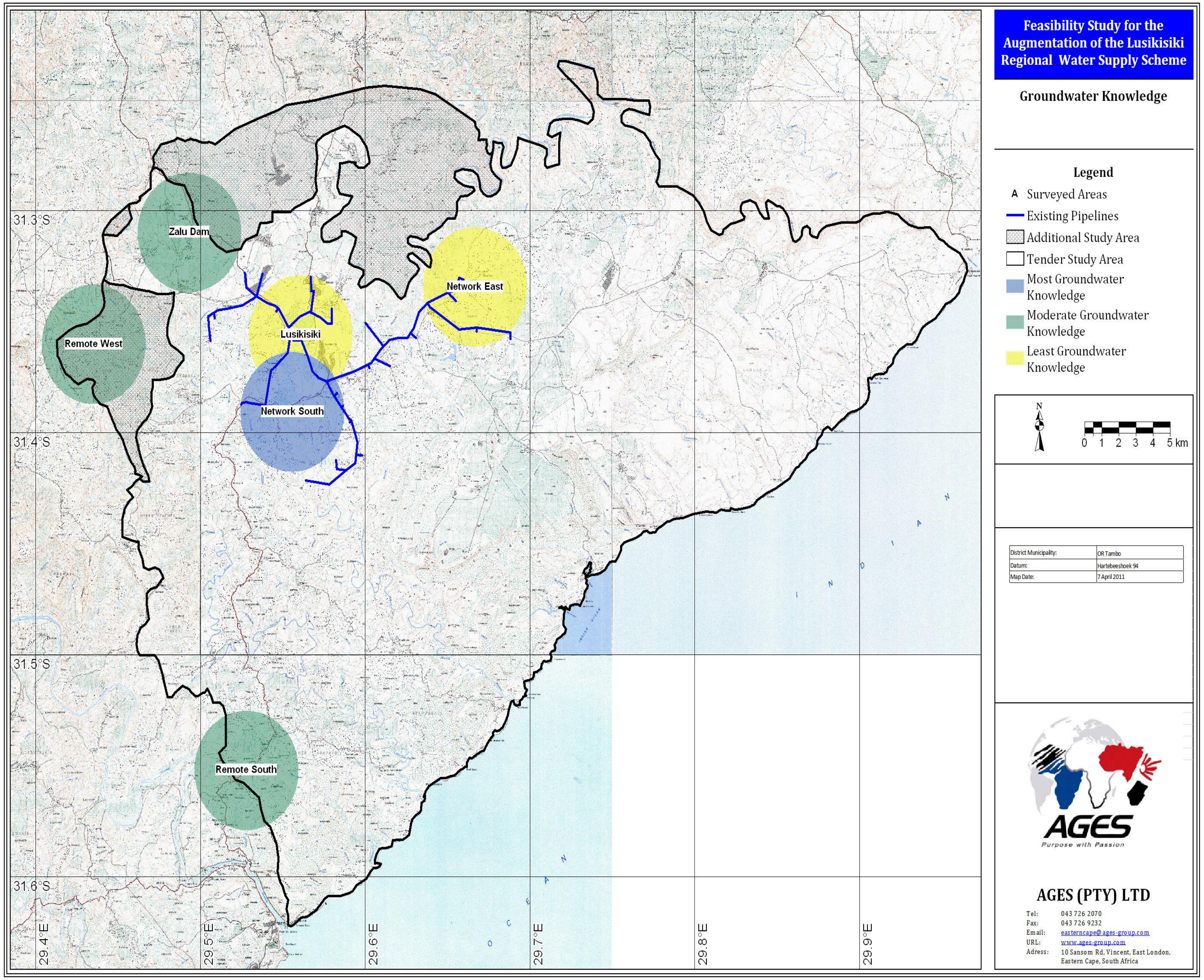

Figure C7-4: Local groundwater knowledge

C7.2 ATTITUDE TOWARDS GROUNDWATER

In traditional psychology, it is assumed that an individual's beliefs provide the impetus for behaviour. The theme "Attitude Towards Groundwater" represents the specific attitudes participants have about groundwater in their area. The specific attitudes the residents of the villages in question are of importance to this study as sustainable groundwater source development strategies are determined not only by individual's knowledge and understanding of groundwater, but also on their attitudes towards groundwater. If the community members have a negative attitude towards groundwater, it could be assumed that they would not act in manner that would support the sustainability of the water supply project.

C7.2.1 What does groundwater in your area taste like?

Zalu Dam

77% of respondents indicated that the groundwater in their area tastes good (see **Figure C7-5**). 8% of respondents were unsure.

Remote West

66% of respondents indicated that the water tasted good in their area (see **Figure C7-5**).

Network South

42% of respondents indicated that the water in there is does not taste good (refer to **Figure C7-5**).

Lusikisiki

In Lusikisiki 52% of respondents believe that the water tastes good in their area. 14% of respondents had no opinion (refer to **Figure C7-5**).

Network East

In the Network East area 82% of respondents did not favour the taste of groundwater (refer to **Figure C7-5**). 15% of respondents were unsure of the taste.

Remote South

In the Remote South area 84% of respondents did not favour the taste of groundwater (refer to **Figure C7-5**).

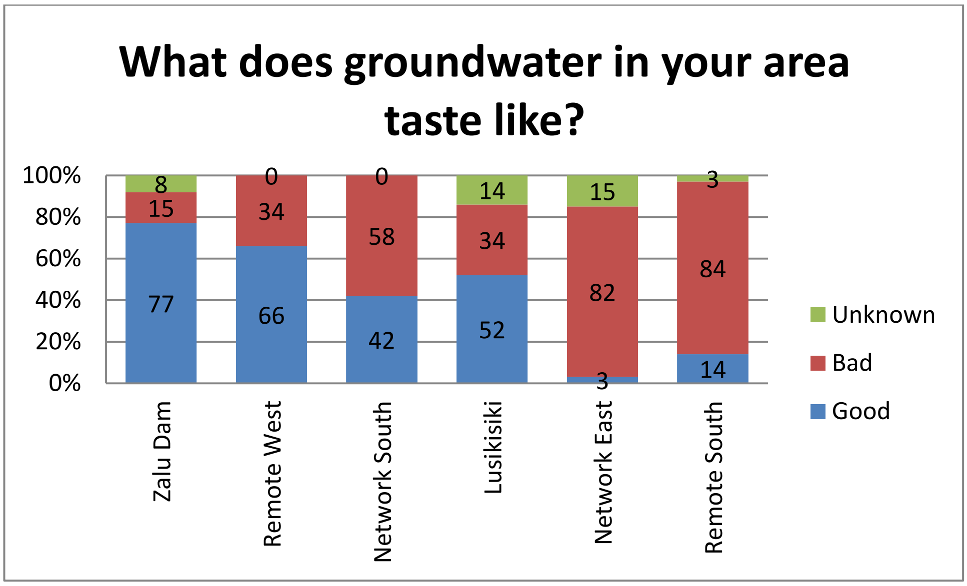

Figure C7-5: What does groundwater in your area taste like?

C7.2.2 How does the community feel about having groundwater as a water source?

Zalu Dam

84% of respondents were positive towards groundwater as a water source in the Zalu Dam area (refer to **Figure C7-6**).

Remote West

59% of the respondents in the Remote West area are positive towards groundwater as a water source (refer to **Figure C7-6**).

Network South

Only 35% of the respondents in the Networks South Area are in favour of groundwater (refer to **Figure C7-6**).

Lusikisiki

21% of the respondents in Lusikisiki are unsure whether they are in favour, or against, the idea of having groundwater as a water source. 48% of respondents are positive towards the idea of groundwater as a water source (refer to **Figure C7-6**).

Network East

A wopping 89% of respondents in the Network East area has a negative attitude towards groundwater as a water source (refer to **Figure C7-6**).

Remote South

79% of the respondents in the Remote South area are against groundwater as a water source. 10% are indecisive and 11% of the respondents are in favour of groundwater as a water source (refer to **Figure C7-6**).

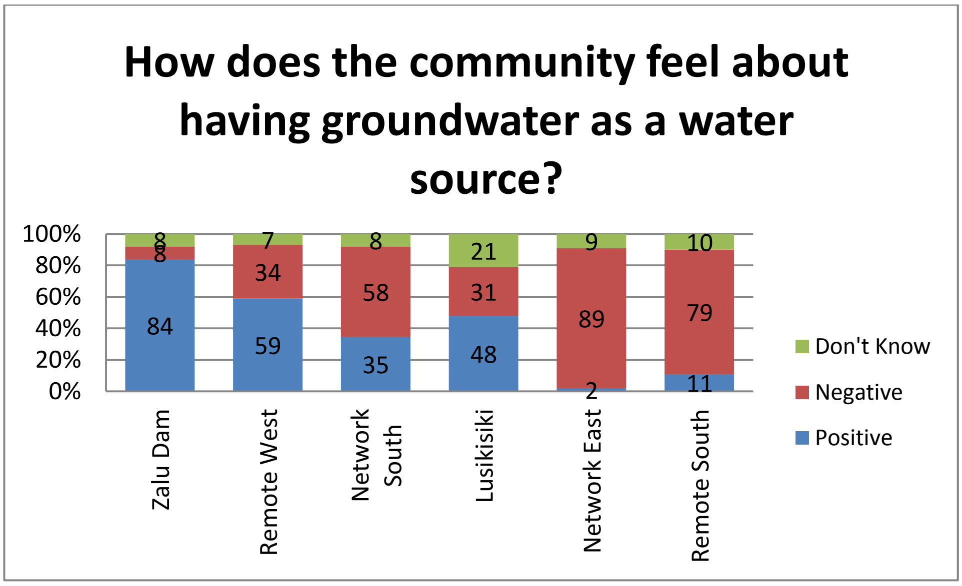

Figure C7-6: How does the community feel about having groundwater as a water source?

C7.2.3 Do you think groundwater is safe to drink?

Zalu Dam

62% of the respondents in the Zalu Dam think that it is safe to drink groundwater (refer to **Figure C7-7**). 30% of the respondents were unsure and only 8% did not think it was safe.

Remote West

45% of respondents thought it was unsafe to drink groundwater in the Remote West area. 14% of respondents were unsure (refer to **Figure C7-7**).

Network South

In network South 65% of respondents do not think it is safe to drink ground (refer to **Figure C7-7**).

Lusikisiki

In the Lusikisiki area 21% of respondents did not know if the groundwater is safe to drink. 26% of respondents said it is not safe to drink the groundwater. 53% of respondents said it is safe to drink the groundwater (refer to **Figure C7-7**).

Network East

In Network East 76% of the respondents said that it is not safe to drink groundwater. 16% of respondents do not know if it is safe and 8% of the respondents indicated that it is safe to drink groundwater (refer to **Figure C7-7**).

Remote South

75% of the respondents in the Remote South area think groundwater to be unsafe to drink. 16% of the respondents do not know if groundwater is safe or unsafe and 18% of the respondents believe groundwater to be safe (refer to **Figure C7-7**).

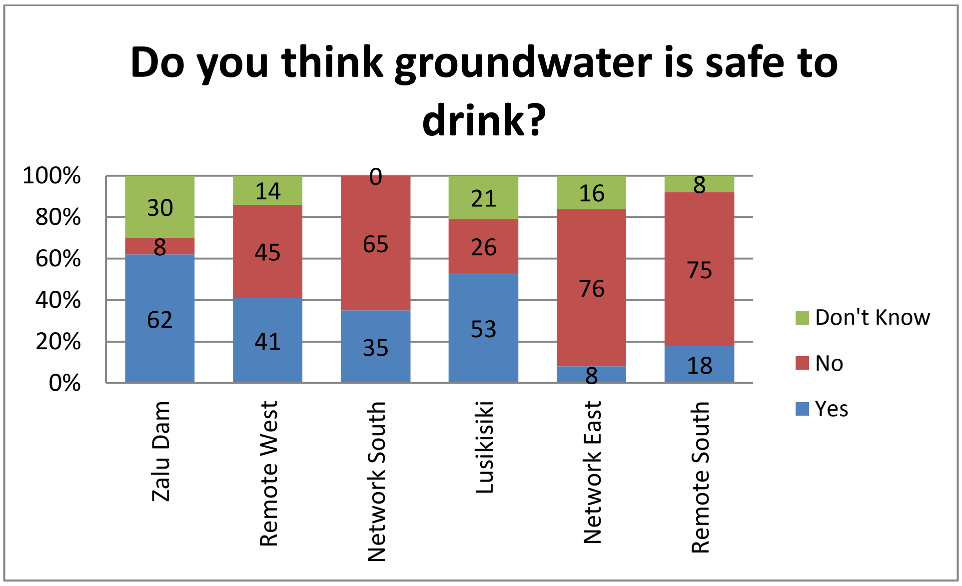

Figure C7-7: Do you think groundwater is safe to drink?

C7.2.4 Can groundwater be polluted?

Zalu Dam

47% of the respondents in the Zalu Dam area said that they do not know if groundwater can be polluted. 38% of the respondents said that it cannot be polluted and 15% indicated that it can be polluted (refer to **Figure C7-8**).

Remote West

In the Remote West area 48% of respondents said that groundwater cannot be polluted. 45% of the respondents said that groundwater can be polluted and 7% is not sure that groundwater can be polluted (refer to **Figure C7-8**).

Network South

In Network South 42% of respondents said that groundwater cannot be polluted. 58% of the respondents said it can become polluted (refer to **Figure C7-8**).

Lusikisiki

38% of the respondents in the Lusikisiki area said that groundwater cannot be polluted. 42% of the respondents said that it can be polluted and 20% said it cannot be polluted (refer to **Figure C7-8**).

Network East

75% of the respondents in area Network East said that groundwater cannot be polluted as opposed to 10% who said it could be polluted. 15% of the respondents was indecisive (refer to **Figure C7-8**).

Remote South

86% of the respondents said that groundwater cannot be polluted. 4% of the respondents said it could be polluted and 10% did not know (refer to **Figure C7-8**).

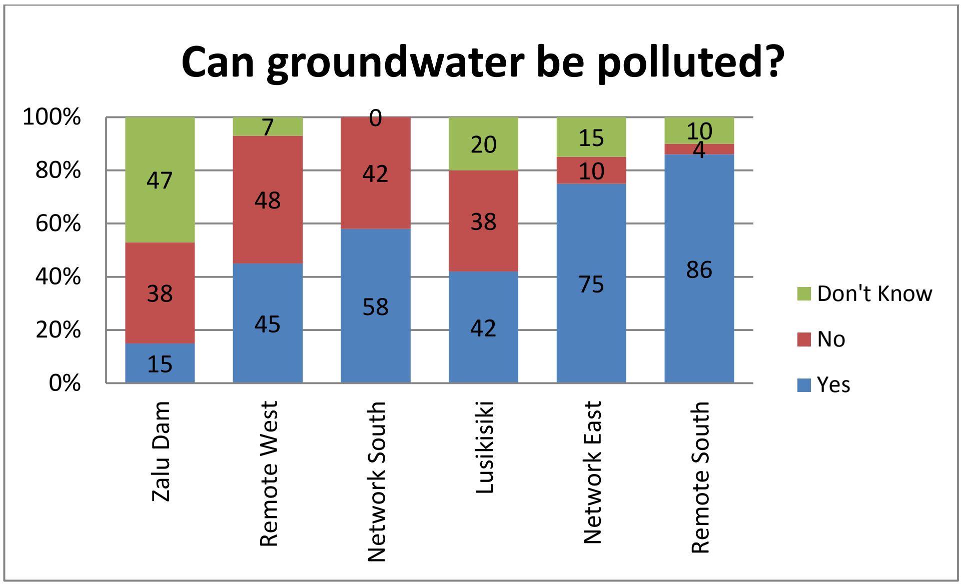

Figure C7-8 Can groundwater be polluted?

C7.2.5 Do some of the people become sick from groundwater?

Zalu Dam

77% of the respondents in the Zalu Dam area say people do not become sick from groundwater. 23% of the respondents say that some of the people do become sick from groundwater (refer to **Figure C7-9**).

Remote West

In the Remote West area 38% of the respondents say that some people become sick from groundwater. 55% of the respondents say that some of the people do becomes sick from groundwater. 7% of the respondents indicated that they do not know if people become sick form the water (refer to **Figure C7-9**).

Network South

42% of the respondents in the Network South area say people do not become sick from groundwater. 50% of the respondents say that some of the people do becomes sick from groundwater. 8% of the respondents indicated that they do not know if people become sick form the groundwater (refer to **Figure C7-9**).

Lusikisiki

62% of the respondents in the Lusikisiki area say people do not become sick from groundwater. 12% of the respondents say that some of the people do becomes sick from groundwater. 26% of the respondents indicated that they do not know if people become sick form the groundwater (refer to **Figure C7-9**).

Network East

55% of the respondents in the Network East area say people do not become sick from groundwater. 24% of the respondents say that some of the people do becomes sick from groundwater. 21% of the respondents indicated that they do not know if people become sick form the groundwater (refer to **Figure C7-9**).

Remote South

58% of the respondents in the Remote South area say people do not become sick from groundwater. 33% of the respondents say that some of the people do becomes sick from groundwater. 10% of the respondents indicated that they do not know if people become sick form the groundwater (refer to **Figure C7-9**).

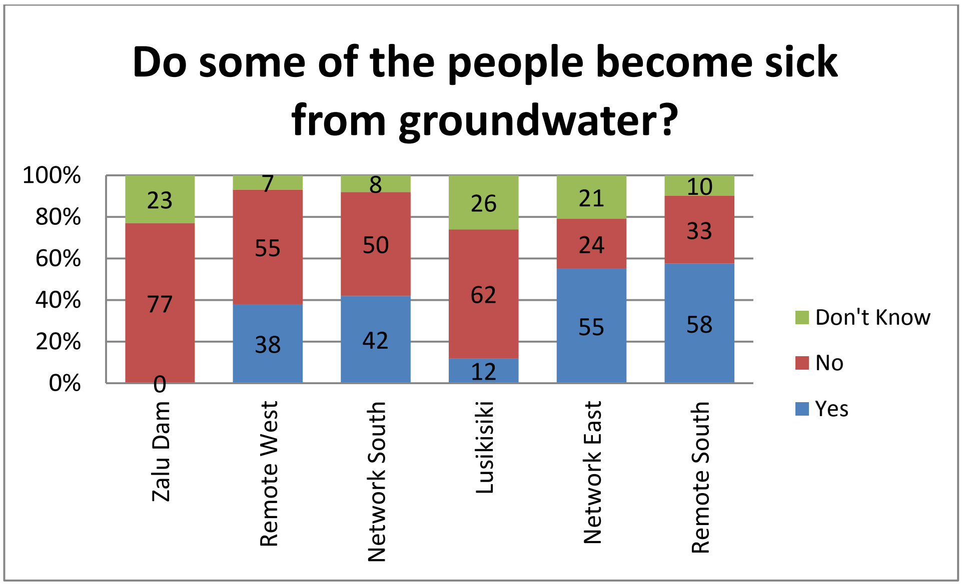

Figure C7-9: Do some of the people become sick from groundwater?

C7.2.6 Is the borehole pump house or windmill a safe area for children?

Zalu Dam

15% of the respondents in this area think the borehole pump house or windmill is a safe area for children. 62% of the respondents feel that it is not a safe area for children. 23% of the respondents do not know if it is safe or not (refer to **Figure C7-10**).

Remote West

38% of the respondents in this area think the borehole pump house or windmill is a safe area for children. 62% of the respondents feel that it is not a safe area for children. 23% of the respondents do not know if it is safe or not (refer to **Figure C7-10**).

Network South

42% of the respondents in this area think the borehole pump house or windmill is a safe area for children. 34% of the respondents feel that it is not a safe area for children. 28% of the respondents do not know if it is safe or not (refer to **Figure C7-10**).

Lusikisiki

16% of the respondents in this area think the borehole pump house or windmill is a safe area for children. 19% of the respondents feel that it is not a safe area for children. 65% of the respondents do not know if it is safe or not (refer to **Figure C7-10**).

Network East

8% of the respondents in this area think the borehole pump house or windmill is a safe area for children. 16% of the respondents feel that it is not a safe area for children. 76% of the respondents do not know if it is safe or not (refer to **Figure C7-10**).

Remote South

8% of the respondents in this area think the borehole pump house or windmill is a safe area for children. 13% of the respondents feel that it is not a safe area for children. 80% of the respondents do not know if it is safe or not (refer to **Figure C7-10**).

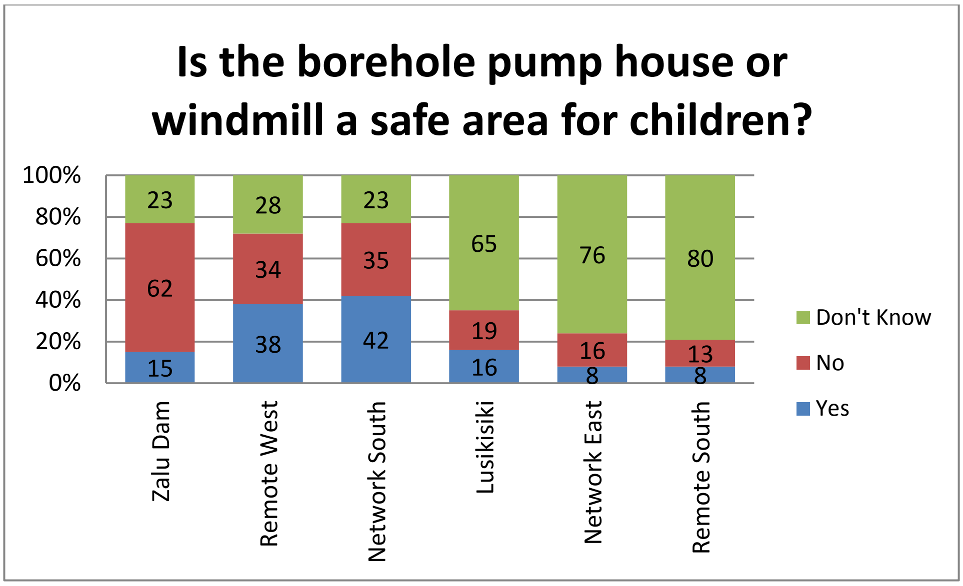

Figure C7-10: Is the borehole pump house or windmill a safe area for children?

Figure C7-11 below indicates the average percentage of how different village members feel about having groundwater as a water source in their area.

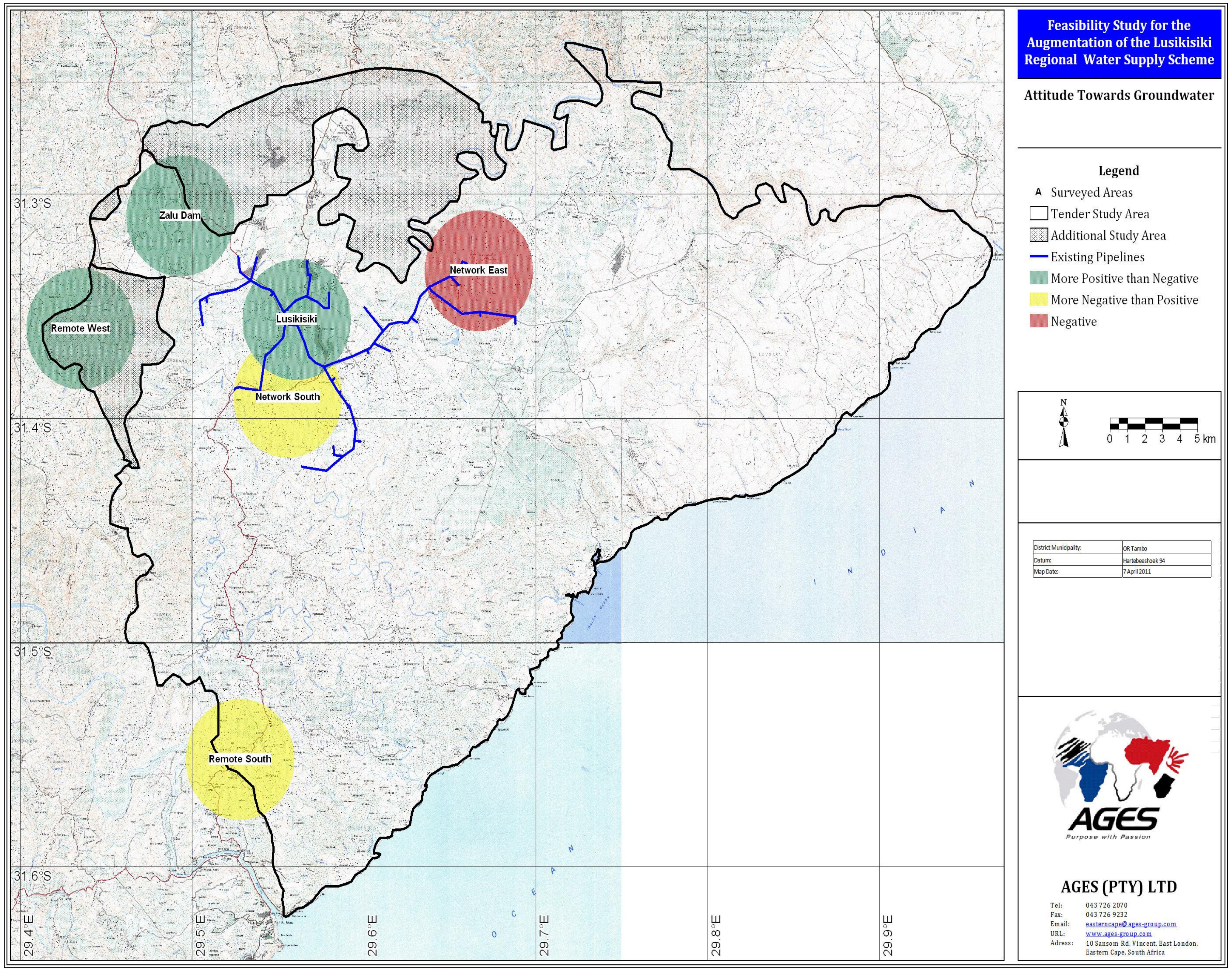

Figure C7-11: Attitude towards groundwater

C8 ATTITUDE ANALYSES – GROUNDWATER VS SURFACE WATER

Six sub-themes constitute the main theme "Source preference based on perceptions". This theme represents the respondents' perceptions regarding various water sources. The six sub-themes covered quantity, quality, cost to develop, cost to maintain, sustainability and my preference. Respondents had three options to rate namely, groundwater, springs or surface water. Each option had to be rated as Best/Highest, Medium and Worst/Lowest.

Figure C8-1 indicates in summary format, the mean source preference based on perceptions, per area.

Zalu Dam

Results indicate that 45% of respondents in the Zalu Dam area prefer borehole water. 39% prefer surface water and 16% of the respondents are more in favour of spring water as a water source.

Remote West

The results indicated that 39% of respondents in the Remote West area prefer borehole water. 32% of respondents prefers surface water and 30% of respondents are more in favour of spring water as a water source.

Network South

The results indicated that 64% of respondents in the Network South area prefer borehole water. 20% of respondents prefer surface water and 15% of respondents are more in favour of spring water as a water source.

Lusikisiki

The results indicated that 42% of respondents in the Lusikisiki area prefer borehole water. 24% of respondents of respondents prefer surface water and 34% of respondents are more in favour of spring water as a water source.

Network East

The results indicated that 40% of respondents in the Network East area prefer borehole water. 30% of the respondents prefer surface water and 30% of the respondents are more in favour of spring water as a water source.

Remote South

The results indicated that 46% of the respondents in the Remote West area prefer borehole water. 22% of the respondents prefer surface water and 33% of respondents are more in favour of spring water as a water source.

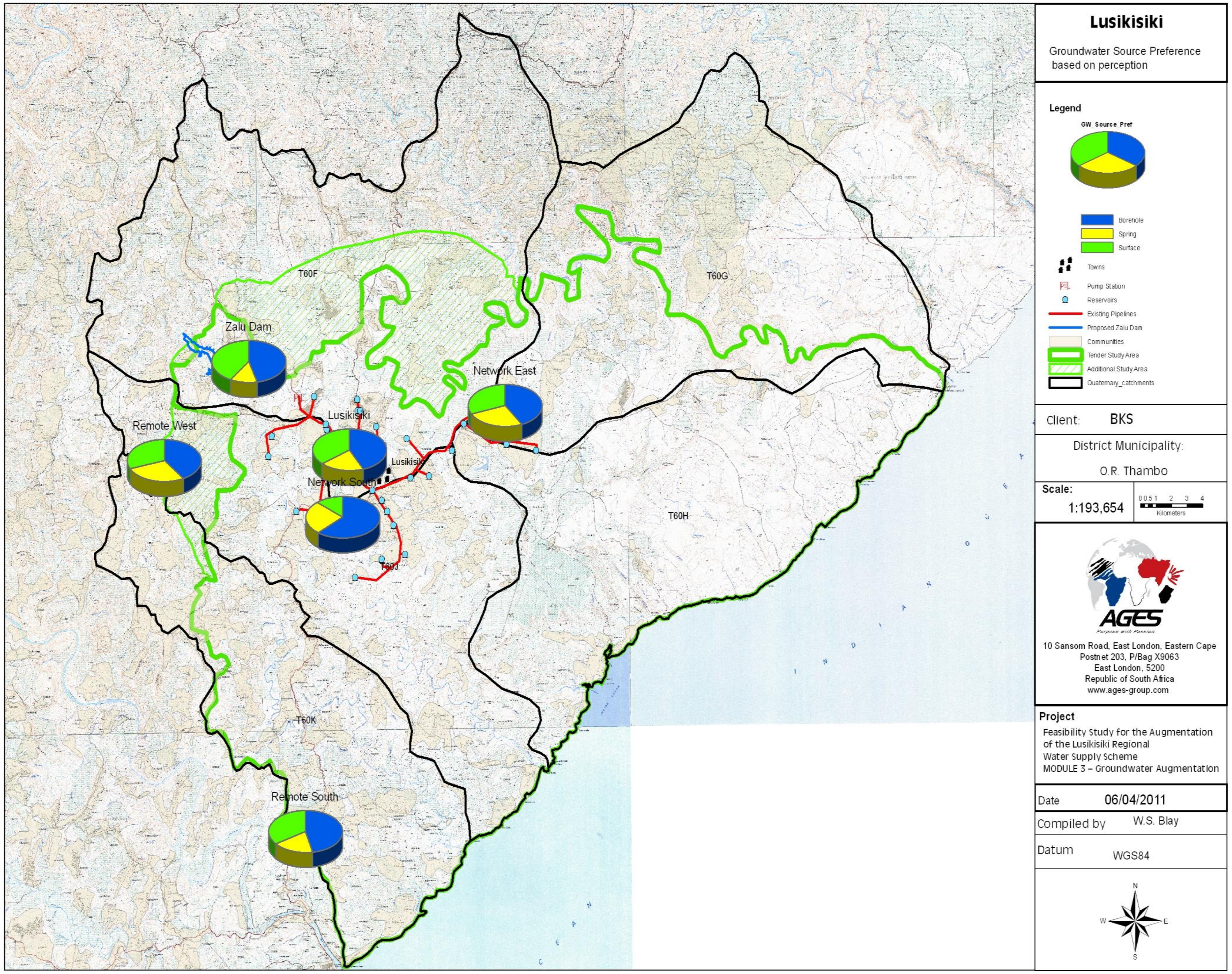

Figure C8-1: Source preference based on perceptions

C9 SUMMARY

The objectives of this study were to:

- identify community dependencies and attitudes towards groundwater;
- assess regional groundwater use and infrastructure statistic; and
- determine water source preference based on perceptions.

These factors aim to support the geohydrological study. In order to investigate these objectives, a desktop study was initiated and the questionnaire sheets of 360 participants in the Lusikisiki project area were analysed using statistical methods of analysis.

In the survey analysis, the following three salient themes were identified namely:

- local groundwater knowledge;
- attitude towards groundwater; and
- source preference based on perceptions.

The desktop study sourced and plotted regional groundwater use and infrastructure statistics.

The results indicated that Lusikisiki and Network East area have the least groundwater knowledge. The Network South area has the most groundwater knowledge. Lusikisiki, Zalu Dam and Remote West Areas have a more positive attitude than negative attitude. Network East area has a negative attitude towards groundwater.

C10 RECOMMENDATIONS

Based on the results of the groundwater community interdependency survey, the following recommendations are made to the technical team for incorporation during the implementation phase of the project:

1. **The groundwater compatibility assessment team must be given the opportunity to present their findings to ensure that the engineering team incorporate social trends that might influence the final design approach and layout.**

2. **Focussed groundwater awareness programmes must be carried out in five distinct zones in the study area.**

3. **With reference to Figure C8-1, these two zones are defined by clustering certain target areas defined during the social survey:**

   a) Target areas Lusikisiki and Network South to be referenced as Awareness Zone 1 (AZ1)

   b) Target areas Remote West and Zalu Dam to be referenced as Awareness Zone 2 (AZ2)

   c) Target area Remote South to be referenced as Network East Awareness Zone 3 (AZ3)

   d) Target area Network East to be referenced as Network East Awareness Zone 4 (AZ4)

4. **The awareness programme in AZ1 should be extended to include the communities located directly east of the production boreholes drilled near the river. It is proposed to use the community and commercial centre in Lusikisiki as a central point for such an awareness workshop. This proposal should however first be discussed with local authorities and community leaders.**

5. **The awareness programme in AZ2 should be carried out in the direct vicinity of Zalu Dam.**

6. **Awareness creation workshops should have the following basic approach:**

   a) Two hour workshop per zone;

   b) The focus will be on community leaders and role players that will be involved during the implementation phase as well as the O&M phase of the project, and

   c) Emphasis will be placed on perceptions that were mapped out during the compatibility study which can negatively impact long term sustainable groundwater use.

7. **Additional technical workshops should be scheduled during the implementation phase to address technical components in terms of long term pump operation and maintenance as well as the groundwater management and monitoring plan that have been planned for the**

project. This should be done with inputs from the engineering project management team.

8. **Cost estimates for the proposed meetings and workshops must be defined and finalised with inputs from the project management team to form part of the implementation stage of the project as soon as possible.**

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Appendix D

Community Groundwater Awareness Creation

Awareness Creation Enterprise for Ground- and Surface Water of the Lusikisiki Regional Water Supply Scheme

MODULE 3—Groundwater Augmentation

12 August 2011

Conducted on behalf of:

BKS (PTY) LTD

Compiled by:

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D1 INTRODUCTION

Africa Geo-Environmental Services' (AGES) social unit engaged in a water awareness initiative that supported and enhanced the larger Lusikisiki Regional Water Supply Scheme project.

The purpose of the water awareness initiative was to increase project sustainability through creating awareness around ground- and surface water and stimulate sensitivity within participants concerning the importance of conserving water.

The water awareness initiatives were conducted in four (4) wards (wards 20, 21, 22, and 23), which had previously been identified as having:

a) the least groundwater knowledge, and

b) high negative perceptions and attitudes towards the use of groundwater as a water source, in a social survey conducted during phase 1 of the project (for more information refer to AGES social report with reference no. 2011/03/14/SCL).

As part of the awareness initiative:

a) two (2) awareness workshops were conducted to relevant prominent community members,

b) three (3) local schools were targeted (Mxhume High School; Maqulu Junior Secondary School; and Miqikela Senior Secondary School), and

c) the local radio station, Nkonjane Community Radio, gave AGES a slot to broadcast knowledge on ground-and surface water.

D2 RATIONALISATION

The government has endeavoured to alleviate poverty by aiming to provide all South Africans with at least a basic level of service by 2013 (Department of Provincial and Local Government (DLPG), 2004). This is quite a challenge as there are presently over 6 million individuals in South Africa without access to a basic level of water supply service (Cullis, 2005). What strains the endeavour further is that South Africa is not abundantly endowed with surplus supplies of fresh water and financial resources for the provision of basic infrastructure services are restricted (Cullis, 2005).

Regardless of this drive to endow water to rural communities, there exists a high level of project letdown (Hemson, 2002). Whilst there are many discussions about the cause of these project failures, the foremost cause determined by researchers in rationalization of the occurrence is meagre institutional and social development (ISD).

AGES aimed to improve the Lusikisiki project's sustainability through strengthening the institutional and social development already taking place.

D3 ASSUMPTIONS

AGES' main suppositions, with regard to creating a sufficient ground- and surface water knowledge base and motivation to take all possible measures to sustain the groundwater resources within the communities, was based on the following premises:

Whether the community members were presented:

a) appropriate information regarding how ground- and surface water is formed;

d) come to the understanding that ground- and surface water is a restricted resource and can be depleted;

e) discover how it becomes polluted;

f) understood this information thoroughly; and

g) were sufficiently motivated to act on this information to protect their water, the premise was, that it would lead to greater project sustainability.

In order to ensure, as far as possible, that each of these premises were met the intervention was meticulously planned using well practised psychological principals to develop and implement the intervention.

Due to time and financial restraints, it was both impossible and impractical to present each and every individual within the project area with information regarding ground- and surface water. Some methods to supply large numbers of individuals with information in an easy and understandable manner, and create motivation included presenting water awareness workshops to schools and prominent community members and broadcasting educational information on the local radio station. It was assumed that if such awareness initiatives were presented in the correct manner it may well lead to community members taking up ownership of the water supply systems that would be endowed to them from the project.

D4 METHODOLOGY

D4.1 WHY RUN WORKSHOPS?

Workshops are some of the most effective methods to promote change in individuals. Individuals do much of their learning by interacting with, observing and listening to peers.

D4.2 WHAT TYPE OF WORKSHOP SHOULD BE RUN?

D4.2.1 Theoretical approach for producing change: post modernism

In order to maximise facilitating change in individuals, a clear understanding needs to exist of the theoretical approach that will guide the workshop. For the purposes of the water awareness workshop, AGES approached the group from a post-modern paradigm. Central to a post-modern paradigm, people form constructs which encapsulate their concepts about the world. In terms of this understanding, community members for instance may previously have formed constructs around groundwater in accordance to the views and opinions expressed and taught by their local communities. These constructs may lack some of the more scientific, westernised explanations of how groundwater is formed, becomes polluted, and runs dry. For example, some of the Project steering Committee (PSC) members at the groundwater awareness workshop that was held in Bengu believed that groundwater comes from salt under the ground that dissolves and turns into water. These constructs are in contradiction to the Western and more scientific explanations around the origin of groundwater. The constructs people hold according to post modernistic views are not fixed, but are revised and replaced as new information becomes available to the individual concerned. Seeing that AGES' main purpose for conducting the workshop was to create awareness around groundwater, it became vital for new information to be introduced to those attending the workshop to revise and replace any insufficient constructs around groundwater. From a post modernistic perspective therefore each person behaves like a scientist, formulating hypotheses to explain life's experiences and in this case knowledge around how ground- and surface water works. These hypotheses are then tested and revised as new experiences are encountered.

D4.2.2 Type of group: Psycho educational

The ground- and surface water awareness workshop was psycho-educational in nature. It aimed at changing behavioural responses by exploring values and beliefs and teaching new ways of thinking and behaving. It was primarily prevention oriented, helping the communities to avoid future water problems. It is normal for people to actively develop ideas and concepts to help them make sense of their world. In other words, they form constructs to describe their environment. As their experiences widen, their original constructs may no longer make sense, so they will replace some of these constructs with new ones. During this process, it is useful for them to have information from both professionals and from peers. Psycho-educational workshops provide an opportunity for helping individuals learn and develop healthy constructs, and consequently to change their attitudes and behaviours so that they may avoid the continuation and/or development of unnecessary problems.

Because psycho-educational workshops focus on the acquisition of information and knowledge, these workshops are generally more structured than other types of workshops. They may deliver content in accordance with a structured curriculum. They usually have specifically defined goals, and explicit expectations of group members. Although the focus is on learning, the process usually involves group interaction with members of the group sharing and discussing thoughts, feelings, experiences, attitudes, beliefs and values, particularly as these relate to relevant topics. Thus, in a psycho-educational group, group members gain particular knowledge and learn specific skills while participating in a process, which includes group interaction and support. Psycho-educational workshops rely on strategies and techniques from an educational and a cognitive-behavioural approach. The leader is challenging, directive and didactic.

Psycho-educational workshops attempt to change attitudes and behaviours by providing new information and teaching new ways of thinking and behaving.

D4.3 Planning the Workshop Programme

D4.3.1 Identifying the needs of the target group

The communities that fall within the project area are in the process of being endowed with water supply systems. In order for those water supply systems to be maintained properly it is assumed that it would be necessary that the people living in the areas, where the water supply systems are implemented obtain the following information:

- What groundwater is;
- How the water cycle works;
- How groundwater is pumped up with a well;
- How groundwater becomes polluted or contaminated;
- What an aquifer is, and how pumping cause a decline in the water table;
- What the amount and distribution of water is in the earth’s oceans, rivers, lakes, groundwater, ice caps, and atmosphere;
- Whose responsibility the planet is;
- What pollution solutions are available.

D4.3.2 Designing the workshop

The listing and accumulating of the assumptions listed above opened opportunities to identify topics to be used in the awareness initiatives. These topics were arranged into a sequence so that each topic was appropriately placed at the correct stage during the workshop. For example the first part of the workshop is significant on joining and group cohesion. Similarly, the last part of the workshop emphasised individuality and how people could individually contribute to the sustainability of groundwater rather than promoting group cohesion. A workshop, which includes a variety of activities, each lasting for about ten to fifteen minutes, will usually keep individuals involved, connected and focused. The workshop was designed so that each topic flowed smoothly from one activity to another to maintain interest and energy while continuing to address the relevant theme or topic. Clear goal were set for each topic so that the workshop did not deteriorate into a purposeless workshop and so that the outcomes could be evaluated with regard to these goals. The topics that were identified for the workshop were used to help decide on goals for the workshop. The goals to be achieved in the workshop included:

- Encourage participants to share their views on what is groundwater;
- Discover and identify how the water cycle works using visual aids;
- Explore with the group what an aquifer looks like and which factors contribute to water being pumped up with a well;
- Discover and identify how groundwater can become polluted or contaminated;
- Encourage participants to share their views on the amount and distribution of water in the earth's oceans, rivers, lakes, groundwater, ice caps, and atmosphere;
- Encourage discussions around pollution solutions.

D4.3.3 Choosing media and activities

Activities are very important tools for working with groups. Activities promote a sense of competence and a sense of belonging. Activities also provide the opportunity for self-growth and learning. When designing the workshop, the programme was varied in the use of method and activity while maintaining a focus likely to result in the achievement of the goals. For example, the workshop started with a joining session. A snack time was also included into the programme. Including a snack time can be particularly useful for groups of long duration as it provides a break and enables participants to relax together in an unstructured way.

(See **Section D9** for the Water Awareness Workshop Programme that was utilised)

D4.4 WHOM TO INCLUDE

Because of time and financial constraints, it was not possible to conduct workshops with all the community members, although this would have been the preferred and most effective method. It was decided that the next best option would be to conduct a workshop with key community members such as with the Ward Councillors and local Project Steering Committee (PSC). The premise was that if the councillors and PSC were kept informed it would also lead to the diffusion of information to grass-root levels and lead to greater awareness by the local communities.

To enhance this diffusion of information to grass-root levels the Project Steering Committee (PSC) members were equipped to do the following during the workshop:

- The PSCs received material to recap the presentation and explain any questions that may have arisen;
- The material was visual and informative to allow people who cannot read to follow the material;
- They were provided with informative material to leave with community members. Thus they were equipped to answer the questions in the community.

AGES used material that was easy to understand by all members of the community and that was culturally sensitive. The material was easy to teach for the trainer and can also be easily understood by the members of the community. All the material was visual with pictures and illustrations and in the local language. The material was written in isiXhosa.

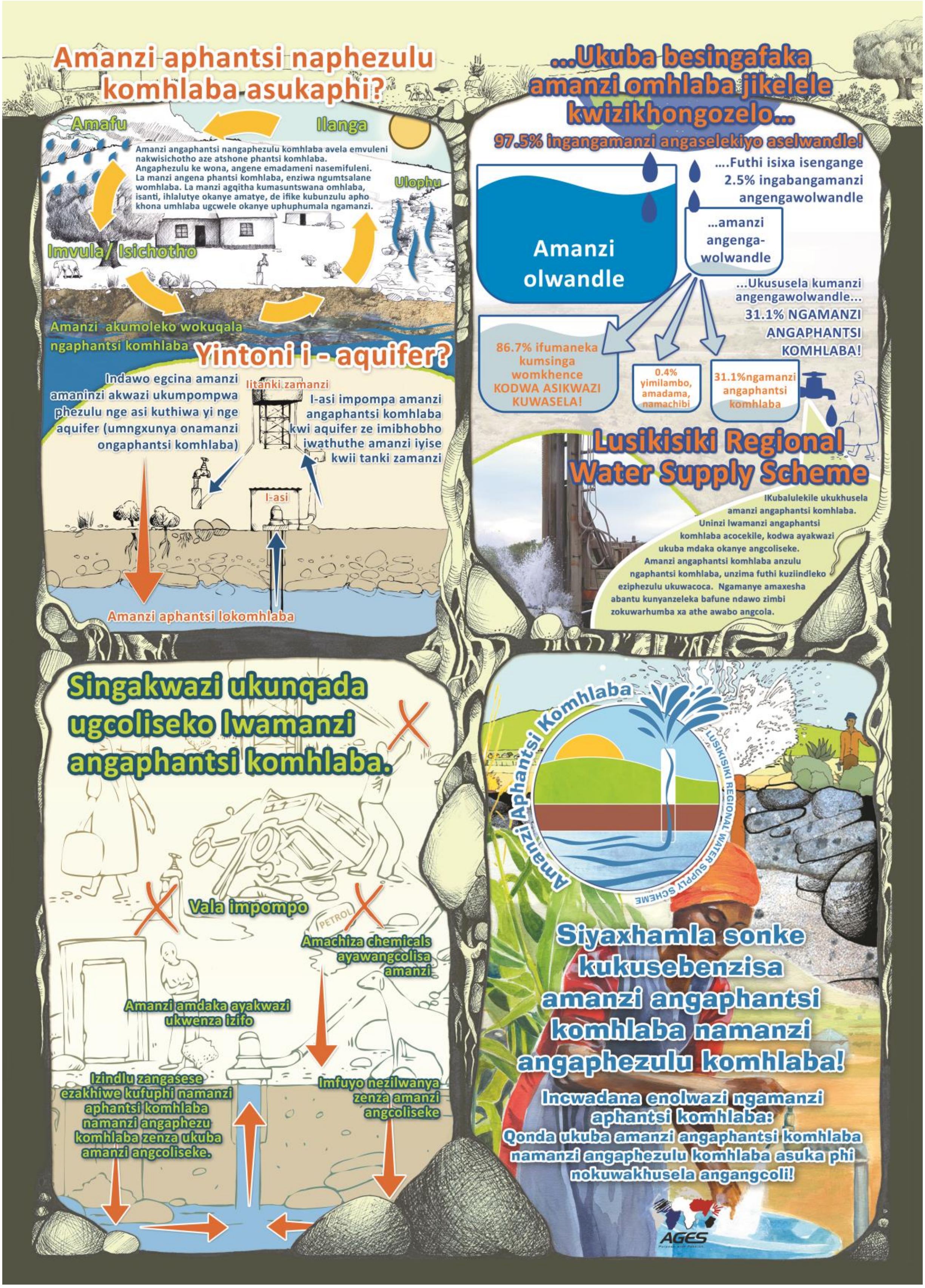


Figure D4-1: Awareness Pamphlet

D5 IMPLEMENTATION OF THE GROUND AND SURFACE WATER ENTERPRISE

The AGES team followed the following implementation route:

D5.1 GROUNDWATER AND FRESHWATER AWARENESS WORKSHOPS

- Four wards which had previously been identified as having the least groundwater knowledge and high negative perceptions of groundwater in the social survey conducted as part of Phase 1 of the project, were targeted as priority groups to receive the workshop. The selection criteria for participants were individuals who were socially active in their communities whether in sports initiatives, political activity or developmental projects. Basically, people who were highly likely to spread the new information they receive at the end of the workshop. The newly elected ward counsellors from Lusikisiki assisted greatly in this regard, also securing venues and local labour which was going to be used as a catering group.

- The workshops were well attended and delivery well received by the participants. The largest group was recorded at 50 participants from one ward only.

- The workshops themselves were divided into two workshops and or/days because of locality logistics of the participants. Therefore, wards 20, 21, and 22 were combined into one workshop. Ward 23 comprising of 8 large villages and the most isolated of the three wards, was given its own workshop day.

D5.2 GROUNDWATER AND FRESHWATER AWARENESS WORKSHOPS

Three local schools were visited at Lusikisiki and these were: Mxhume High School; Maqulu JSS and Mqikela Senior Secondary School. In each school, only the highest grade pupils in the school were prioritized to participate in the workshops. The total number of pupils interacted with in Lusikisiki is 148 pupils. This selection criterion was preferable because ideal workshop participants would be ones that share the knowledge they receive with others at large in their communities.

Fruit was distributed to all students in all the schools visited who had attended the workshop as a token of good faith.

D5.3 GROUNDWATER AND FRESH WATER AWARENESS IN LUSIKISIKI LOCAL RADIO STATION

The local radio station, Nkonjane Community Radio, was approached and notified of the awareness effort that the AGES office was driving at in the local area. A slot to have the workshop broadcasted on air was secured for the 22/07/2011. The slot that the workshop was aired was at 11:30 am and the response from the listeners was equally positive and engaging.

D6 ETHICAL CONSIDERATIONS

A number of ethical issues were raised by this ground- and surface water awareness initiative and were addressed as follows: participation was voluntary; information was given about the project with no distortion of detail. No harm, embarrassment, or offence was foreseen for the ground- and surface water awareness initiative although some of the discussions may have heightened participants' hopes of receiving piped water. Care was however taken to explain to participants that this was only a ground- and surface water awareness initiative.

D7 EVALUATING THE OUTCOME OF THE WORKSHOP

Research studies relating to the outcomes of workshops suggest that individuals can derive considerable psycho-educational benefit and demonstrate improved psychosocial functioning as a result of the workshop. However this does not mean that all workshops will necessarily be able to achieve their defined objectives. In order to be accountable, therefore, it is desirable to take specific action to evaluate the outcome of the workshop.

Continuous assessment techniques were employed to evaluate the water awareness workshop presented by AGES. Continuous assessment relies predominantly on informal data gathering. Data collected reflected on participant's individual behaviour, cognition and emotions, and the influence of the group experience on the individual.

Participants seemed to find a lot of enjoyment out of the activities that were used to bring across points during the workshop. Participants seemed excited and laughed a lot during the workshop. Participants also seemed interested in what was being said and from their questions they posed it became quite evident that the content of the workshop was relevant.

At the end of each workshop, participants were given a sheet of paper in which they were asked to anonymously rate the workshop. 100% of attendees rated the workshop positively (Addendum B).

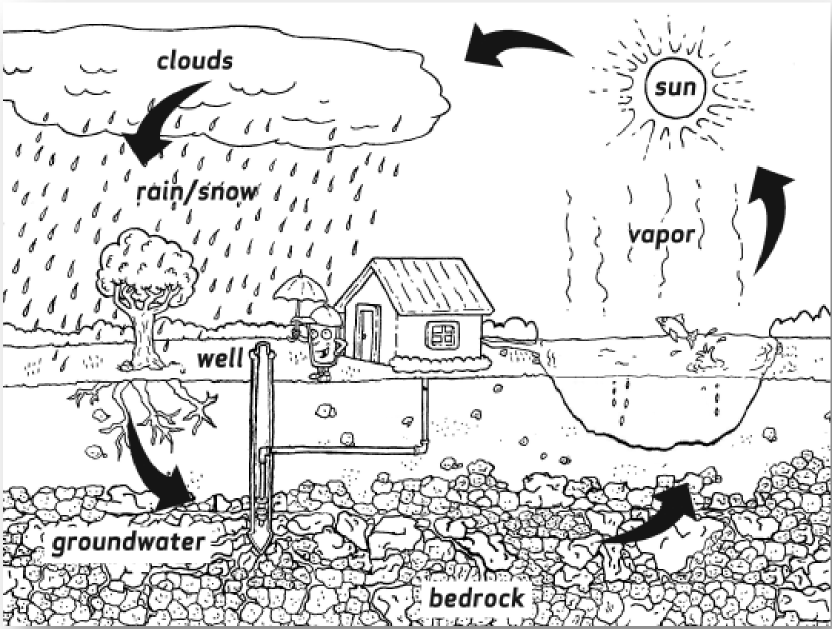
D8 CONCLUSION

Africa Geo-Environmental Services' (AGES) social unit presented a water awareness workshop that supported and enhanced the Lusikisiki project's institutional and social development. The purpose of the workshop was to increase project sustainability through creating awareness around ground- and surface water and stimulate sensitivity within participants concerning the importance of conserving water.

Continuous assessment techniques were employed to evaluate the water awareness workshops. Participants seemed to find a lot of enjoyment out of the activities that were used to bring across points during the workshop and the goals set for the programme were reached.

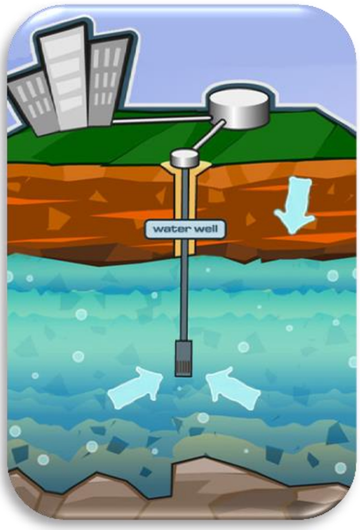
D9 THE PROGRAMME

11:00am Use the joining activity 'balloon game'.



11:15am Invite the group to discuss the question 'what is groundwater'. Write ideas about groundwater on poster paper. Include the following ideas:

Groundwater comes from rain, snow, sleet, and hail that soak into the ground. The water moves down into the ground because of gravity, passing between particles of soil, sand, gravel, or rock until it reaches a depth where the ground is filled, or saturated, with water. Explain the water cycle using a poster.



Next, invite the group to discuss the factors that contribute to water being pumped up with a well. Include the following ideas: An area that holds a lot of water, which can be pumped up with a well, is called an aquifer. Wells pump groundwater from the aquifer and then pipes deliver the water to the water tank. Use visual aids.

Most groundwater is clean, but groundwater can become polluted, or contaminated. Discuss how is can become polluted. Emphasise that because it is deep in the ground, groundwater pollution is generally difficult and expensive to clean up. Sometimes people have to find new places to dig a well because their own became contaminated.

11:35am Use the 'Edible Earth Parfaits' activity to teach about the geological formation in an aquifer, how pollution can get into groundwater and how pumping can cause a decline in the water table.

11:45am Snack-enjoy ice cream soda

12:00am Use the activity 'How Wet is Our Planet' to describe the amount and distribution of water in the earth's oceans, rivers, lakes, groundwater, ice caps, and atmosphere.

12:10am Use the activity 'The Disposable Plate' to introduce the theme of our responsibility to the planet, looking at what cannot be fixed once broken.

12:20am Ask the group to discuss pollution solutions. Question them about how they can keep their water safe.

12:30am Close

Materials Needed

Sticky labels, felt pens, balloons, poster paper, water cycle and groundwater pollution posters, a child's jigsaw, a Lego set, paper and Sellotape, a plate, glue, a mallet, a cloth, blue food colouring, vanilla ice cream, Sprite, small gummy bears, chocolate chips, crushed cookies, variety of coloured cake decoration sprinkles and sugars, drinking straws, clear plastic cups, ice cream scoop, spoons, large map of the world or diameter globe, five-gallon container (translucent), three clear containers (cups or jar). Label on "freshwater", the second "groundwater", and the third "rivers and lakes". Tablespoon, eye dropper, blue food colouring.

Activities and Games

Balloon Game: Ask each participant to:

1. **Write his or her name on a sticky label which still has the backing on it.**
2. **Without removing the backing fold the label and insert it into a balloon.**
3. **Blow up the balloon and tie it up.**

Next, invite the participants to form a large group. Tell them they are to hit the balloons so that they move around the room. When I signal they should allow the balloons to fall to the ground. Tell the group to pick up the balloon nearest them and burst it. When the balloons are burst, each person is to take the name tag from their balloon and search for the person whose name tag they have. When they find the person, they introduce that person to the group and share one thing about that person that that person would not mind the others to know (for example their favourite food).

Edible Earth Parfaits:

1. **Review what groundwater is.**
2. **Begin to construct your edible aquifer by filling a clear plastic cup 1/3 full with gummy bears, chocolate chips (represents gravel and soils).**
3. **Add enough soda to just cover the candy.**
4. **Add a layer of ice cream to serve as a "confining layer" over the water-filled aquifer. Discuss what a confining layer is/does.**
5. **Then add more "sand/gravel" on the top of the "confining layer".**
6. **Coloured sugars and sprinkles represent soils and should be sprinkled over the top to create the porous top layer (top soil).**
7. **Now add the food colouring to the soda. The food colouring represents contamination.**

Watch what happens when it is poured on the top of the "aquifer". Point out that the same thing happens when contaminants are spilled on the earth's surface.

8. **Using a drinking straw, drill a well into the centre of your aquifer.**

9. **Slowly begin to pump the well by sucking on the straw. Watch the decline in the water table.**

10. **Notice how the contaminants can get sucked in to the well area and end up in the groundwater by leaking through the confining layer.**

11. **Now recharge your aquifer by adding more soda which represents a rain shower.**

12. **Review what you have learned as you enjoy eating your edible aquifer.**

How wet is our Planet?

13. **Fill in the empty bucket with five gallons of water, and ask the students to imagine that this is all the water on earth including the water that is contained in the atmosphere, glaciers, ice caps, lakes, rivers, oceans and streams.**

14. **Next, have a volunteer take out 25 tablespoons of water from the bucket and place it in the large, clear jar labelled "freshwater". This represents all the freshwater on earth (water contained in the atmosphere, icecaps, rivers, ponds, lakes, and groundwater). Now all the water in the bucket represents all the salt water on earth. Ask the group what the difference between salt and fresh water is (saltwater is not drinkable, fresh water is).**

15. **Next, have another volunteer take out 8 tablespoons from the freshwater supply and place it in the measuring cup labelled "groundwater". This represents all the groundwater on earth. Discuss that groundwater is water that is located underground in the cracks and spaces between sand and gravel. Ask them if they have ever dug a hole in earth and discovered water in the sand; tell them that this is groundwater.**

16. **Finally, have a third volunteer take out one tenth of a tablespoon (or about 25 drop with an eye dropper) and pour it in a small glass labelled "rivers and lakes". This water represents all the water in rivers and lakes on earth. Now we have removed the water contained in groundwater, rivers and lakes from the world's "freshwater" container, the "freshwater" container now represents all the water contained in the atmosphere (clouds, rain, snow and all the water on the planet that is frozen (polar ice caps and glaciers). Ask the steering committee if it is easy to make a trip to Antarctica to chip away a chunk of ice, then melt it in order to get a drink. Ask the group to compare the amount of drinkable water (the "groundwater" and "rivers and lakes" container) to the amount of undrinkable water (the bucket of salt water and the "freshwater" container).**

17. **Discuss with the group that we all have a responsibility to protect water in all its forms on earth. Of immediate concern is the protection of our drinking water sources. The amount of freshwater on earth represents a small percentage of the total water available. The**

freshwater in groundwater, rivers, and lakes is our primary source of drinking water. You may have been surprised to learn that groundwater and surface water make up such a small percentage of the earth's total water supply. It becomes very apparent then how important it is to protect these water sources since they are available in limited quantity and since our existence depends on them.

The Disposable Plate:

1. **Call up three of four volunteers to help with a challenge to fix something that you break.**
2. **Get an easy child's jigsaw, break it up and set the volunteer the task of piecing it back together.**
3. **Now get a Lego model and break that up for the second volunteer to rebuild.**
4. **Get a picture, tear it up and give it to the next volunteer with a roll of Sellotape.**
5. **For a grand finale, get a plate, wrap it in a cloth, and with a huge mallet smash it to smithereens. Tip out the pieces for the fourth volunteer and set them to work with a tube of glue.**
6. **Let this run for a couple of minutes, checking on the progress, and then judge the results. The point is that all are at least basically fixable except the plate. Encourage some applause as the volunteers sit back down.**
7. **Now link the illustration to our responsibilities to the environment and our natural resources. As we dispose of things, creating waste and causing harmful emissions, we are causing a strain on the environment, particularly the much spoke of groundwater. We can be naïve, saying it'll all be fine, but some things, like the plate in our illustration, cannot be fixed.**

Appendix E

Optimisation of Groundwater Abstraction Network

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E1 BACKGROUND

As part of the Module 3 scope of work, AGES has done an intermediate groundwater reserve determination on the quaternary catchments covering the extended project area as indicated in **Figure E1-1**. Details and results of this component of the study is reported in **Appendix A** of the Groundwater Report. Usable groundwater volumes were accurately defined per quaternary catchment from this study, based on high assurance levels.

A detailed groundwater flow model was then compiled for a delineated part of the project area, which evaluated the optimum number and localities of production boreholes within this regional well-field area (RWA). For this purpose, the use of Feasibility Study boreholes as well as several additional Conceptual Boreholes was simulated to evaluate the impacts of long term abstraction. The location and distribution of these boreholes were defined within the regional hydrogeological model area (RWA) that was delineated based on an amended combination of Groundwater Resource Units identified during the initially conducted feasibility study of SRK.

It is therefore the purpose of this component of the study to report yields and positions of future production boreholes within the RWA. This will comprise conceptual boreholes as well as existing boreholes already drilled by SRK during previous feasibility studies. Final amended recommendations for abstraction rates of SRK boreholes are given since the model has indicated that some of these boreholes are too close to each other, and will have to be utilised at reduced rates to minimise the influence between neighbouring boreholes.

Based on groundwater quality, specifically elevated iron concentrations, it will be important for groundwater from the regional well field to be blended with surface water as far as possible. The engineering team also need to look at optimum pipeline routes and lengths to decide which feasibility study and conceptual boreholes will be used in the end. Surface water quality need to be evaluated against groundwater quality to determine if suitable blending ratios can be achieved while still meeting the water demand. Treatment options must be found for the possible oxidation and precipitation of high-iron content water.

Communities that fall outside the RWA need to be served by stand-alone schemes. These schemes will either serve single communities or small clusters of communities depending on local groundwater conditions. Water sources will involve springs as well as new boreholes that need to be developed. Detail regarding the clustering of these stand-alone communities as well as a table summarising costs to develop groundwater sources for all these clusters and communities are given.

The engineering team will have to look at areas that cannot practically and affordably be reached by bulk pipeline infrastructure (from blended surface + groundwater), and should this implicate that there are additional communities that need to be served by stand-alone schemes than the ones listed in the table mentioned above, AGES should look at development potential and costs for this to be included in the cost tables for stand-alone schemes.

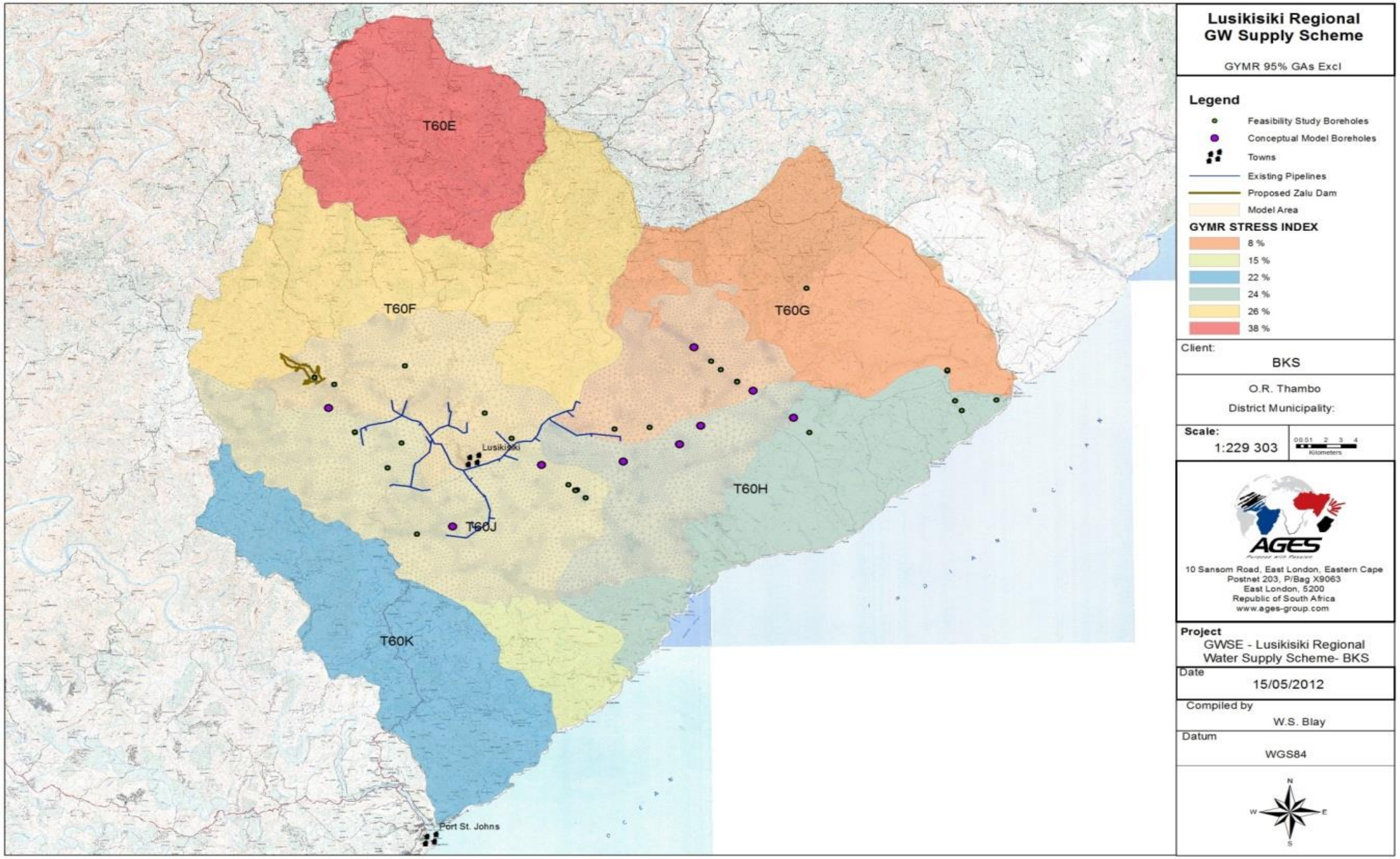

Figure E1-1: Quaternary catchments for which groundwater reserve determination was carried out

E2 GROUNDWATER RESERVE DETERMINATION (GYMR)

Four scenarios were modelled in the GYMR namely:

- Present Day conditions based on a 95% assurance of rainfall excluding general authorisations;
- Present Day scenario based on a 95% assurance of rainfall (includes drought cycles) including General authorisation volumes;
- Present Day Scenario based on Mean Annual Precipitation (MAP) excluding General Authorisation volumes across catchment. In the study area the 95% assured rainfall is approximately 80% of the MAP, and
- Future 2020 scenario based on 95% assurance of rainfall excluding general authorisations

Table E2-1 summarises the three main scenarios that were evaluated where it can be seen that most catchments are only Moderately to Slightly stressed. The more stressed catchment – T60E – falls outside the main project area and no additional abstraction is required or recommended in this catchment. (See **Figure E1-1**).

Table E2-1: Groundwater Reserve determination results per quaternary catchment

Present Day - 95% Assurance - GA's Included														
Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)	Usable GW (l/s) Assuming 40% EWR	Usable GW (m3/d) Assuming 40% EWR	Usable GW (m3/d) Assuming 80% EWR	Proposed additional m3/d abstraction
T60E	198	885	709	6.03%	8.47	8.47	-3.40	-2.39	2.67	40%	50.8	4389.43	1463.14	0.00
T60F	463	940	753	6.63%	23.13	23.13	-7.20	-5.23	10.69	31%	203.5	17579.99	5860.00	549.50
T60G	359	1116	895	8.29%	26.65	26.65	-7.46	-6.35	12.84	28%	244.3	21106.53	7035.51	836.35
T60H	322	1277	1024	9.90%	32.59	32.62	-10.58	-5.37	16.67	32%	317.1	27399.16	9133.05	753.41
T60J	293	1101	882	8.23%	21.31	21.31	-5.32	-4.72	11.27	25%	214.4	18525.41	6175.14	1099.01
T60K	242	1075	862	7.50%	15.64	15.64	-4.32	-4.93	6.39	28%	121.6	10510.14	3503.38	0.00
Total studyarea	1151	1114	893	8.25%	84.77	84.81	-24.32	-20.49	40.00	29%	761.1	65759.88	21919.96	3238.27
Present Day - 95% Assurance - GA's Excluded														
Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)	Usable GW (l/s) Assuming 40% EWR	Usable GW (m3/d) Assuming 40% EWR	Usable GW (m3/d) Assuming 80% EWR	Proposed additional m3/d abstraction
T60E	198	885	709	6.03%	8.47	8.47	-2.51	-2.39	3.56	30%	67.7	5853.31	1951.10	0.00
T60F	463	940	753	6.63%	23.13	23.13	-5.12	-5.23	12.78	22%	243.1	21006.93	7002.31	549.50
T60G	359	1116	895	8.29%	26.65	26.65	-2.06	-6.35	18.23	8%	346.9	29969.59	9989.86	836.35
T60H	322	1277	1024	9.90%	32.59	32.62	-5.76	-5.37	21.49	18%	408.9	35329.77	11776.59	753.41
T60J	293	1101	882	8.23%	21.31	21.31	-3.12	-4.72	13.47	15%	256.3	22143.18	7381.06	1099.01
T60K	242	1075	862	7.50%	15.64	15.64	-3.23	-4.93	7.48	21%	142.4	12300.08	4100.03	0.00
Total studyarea	1151	1114	893	8.25%	84.77	84.81	-13.55	-20.49	50.77	16%	965.9	83452.70	27817.57	3238.27
2020 - 95% Assurance - GA's Excluded														
Catchment	Surface Area (km^2)	MAP WR2005 (mm/a)	95% assured Rainfall (mm/a)	Ground water Recharge (% of MAP)	Recharge (Mm^3/a)	Total inflow (Mm^3/a)	Total outflow before losses Mm^3/a	Evapo-transpiration flow loss (Mm^3/a)	Net Baseflow (Mm^3/a)	GYMR Index % (Total outflow/ Total inflow)	Usable GW (l/s) Assuming 40% EWR	Usable GW (m3/d) Assuming 40% EWR	Usable GW (m3/d) Assuming 80% EWR	Proposed additional m3/d abstraction
T60E	198	885	709	6.03%	8.47	8.47	-3.25	-2.39	2.82	38%	53.7	4636.93	1545.64	0.00
T60F	463	940	753	6.63%	23.13	23.13	-5.96	-5.23	11.94	26%	227.1	19620.75	6540.25	549.50
T60G	359	1116	895	8.29%	26.65	26.65	-2.21	-6.35	18.09	8%	344.2	29737.03	9912.34	836.35
T60H	322	1277	1024	9.90%	32.59	32.62	-7.88	-5.37	19.37	24%	368.5	31836.28	10612.09	753.41
T60J	293	1101	882	8.23%	21.31	21.31	-3.24	-4.72	13.35	15%	254.0	21945.61	7315.20	1099.01
T60K	242	1075	862	7.50%	15.64	15.64	-3.36	-4.93	7.35	22%	139.9	12084.77	4028.26	0.00
Total studyarea	1151	1114	893	8.25%	84.77	84.81	-16.16	-20.49	48.17	19%	916.4	79175.52	26391.84	3238.27

Usable groundwater volumes were calculated for the different catchments based on two different percentages (40% and 80%) of baseflow required for the Ecological Requirement for the Reserve. This is indicated in **Table E2-1**

Working on a very conservative assumption of 80% of baseflow required for the Ecological Requirement of the Reserve, it can be seen in the last column of the table, that the proposed additional abstraction that was simulated in the groundwater model, is in general 10 times smaller than the usable groundwater volumes calculated during reserve determination.

Preliminary water demand figures for the planning study area that have been reported in other modules of the study are approximately 9000 m^3 per day for 2020. If this is compared to the 30 544 m^3 that was calculated in the groundwater reserve determination for 2020, it is clear that there is approximately 3 times the total project water requirement available from groundwater in the catchments in which the project area is located. The conclusion from the groundwater reserve determination exercise is therefore that there is enough groundwater available for usage in the Lusikisiki project area to meet the total project water demand without even having to rely on surface water should it be feasible.

Based on the known average abstraction rate that can be expected from a production borehole in the study area, it is determined however that it will not be feasible to abstract this total available groundwater volume from boreholes, as it would imply too many pump stations with associated high operation and maintenance costs. For this purpose, a numerical groundwater model had to be compiled to determine the optimum number and distribution of boreholes that can be developed within a Regional Well-field Area (RWA) without negatively impacting groundwater dependant springs and associated wetlands in this area.

E3 GROUNDWATER MODEL SIMULATIONS AND FINAL REGIONAL WELL-FIELD AREA BOREHOLE LOCALITIES

The following three scenarios were simulated in the Groundwater Model:

Scenario 1:

- Steady state present day water balance and flow conditions. This scenario was used to calibrate the flow model.

Scenario 2:

- Transient state to evaluate and simulate impacts of proposed water supply from existing boreholes drilled during feasibility study.

Scenario 3:

- Transient state to evaluate and simulate impacts of proposed water supply from both Scenario 2 boreholes and additional conceptual boreholes (Included a sensitivity analysis on recharge values as % of MAP and of Lower 95th percentile).

Abstraction at all 14 feasibility study boreholes that occur in the RWA, as indicated in Figure E3-1, as well as 9 conceptual boreholes were simulated in scenario 3.

Figure E3-2 and **Figure E3-3** indicate two outcomes of scenario 3. The first (3A) indicating the radius of influence for Feasibility and Conceptual boreholes pumped under MAP recharge conditions, and the second (3B) showing the radius of influence for Feasibility and Conceptual boreholes pumped under lower 95% assured recharge conditions.

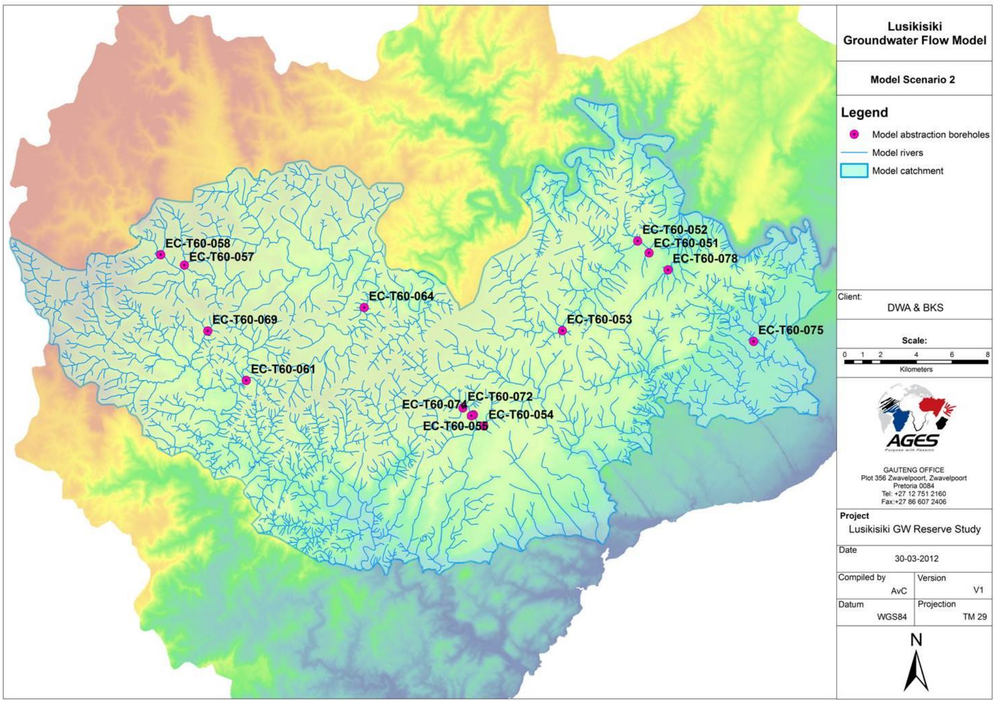

Figure E3-1: Scenario 2 simulation boreholes

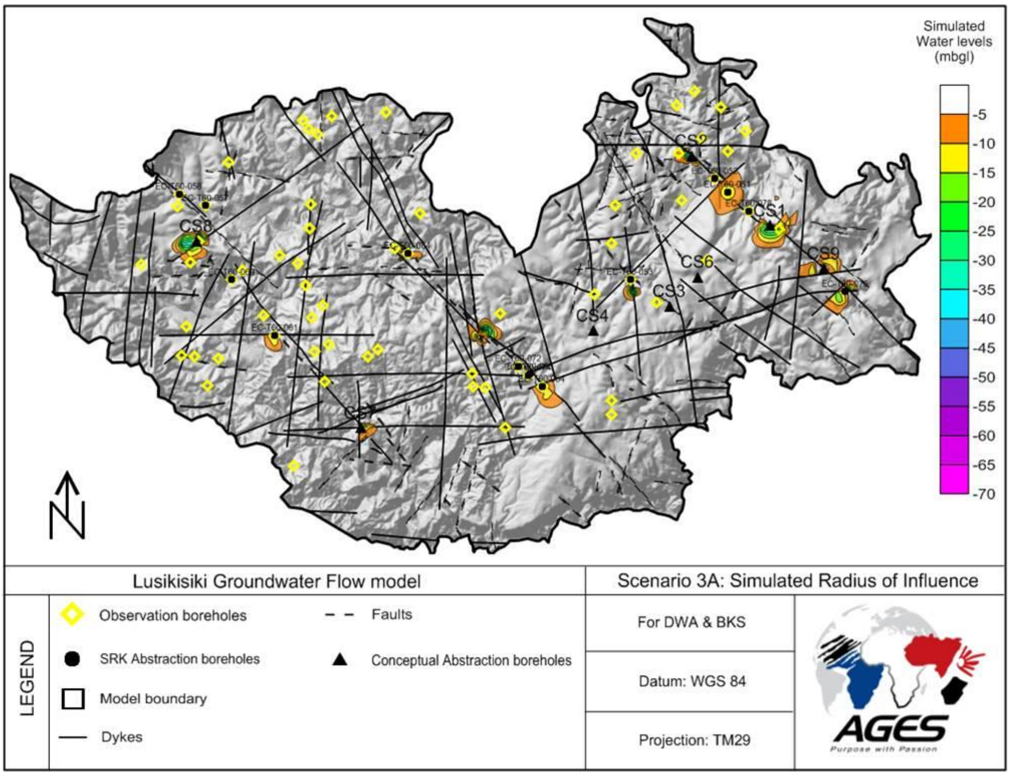

Figure E3-2: Scenario 3A simulation

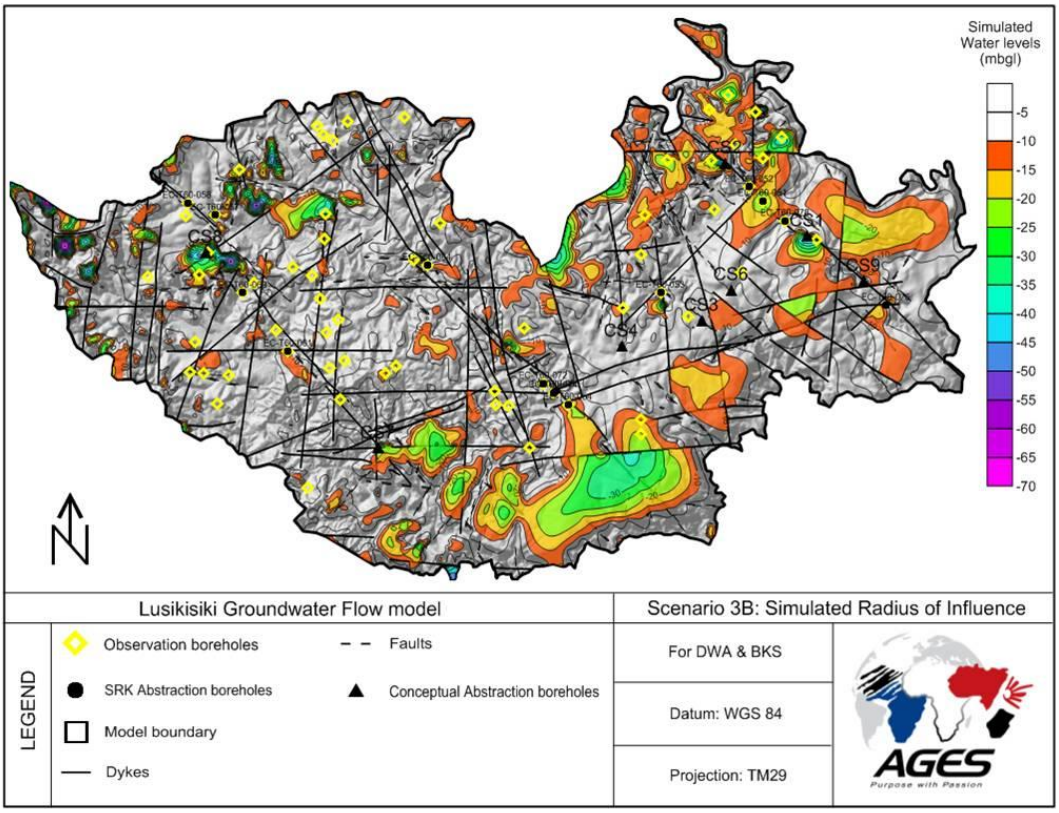

Figure E3-3: Scenario 3B simulation

Based on the scenario 3B simulation where it became apparent that groundwater level drawdowns at production boreholes may affect springs and wetlands if pumped under lower 95% assured recharge conditions, amendments were made to abstraction rates of feasibility boreholes as well as conceptual boreholes as is summarised in **Table E3-1**.

In the table it can be seen that the final recommendation is for only 9 Feasibility Study boreholes to be equipped and for an additional 8 conceptual boreholes to be drilled and equipped to finally abstract 2553 m³/day from the Regional Well-field Area. This is therefore the total volume of groundwater that is available for augmentation to the surface water scheme from the RWA and relates to 28% of the projected 2020 water demand of the Planning study area as reported in the Domestic Water Requirement Report.

Table E3-1: Final abstraction rates for Feasibility Study and Conceptual boreholes

Feasibility Study Boreholes suitable for production purposes							
			Feasibility study recommendations		*Amended Recommendation based on Model outcome*		
BH No	**Latitude**	**Longitude**	**24 hr yield (l/s)**	**Sustainable Yield m³/d**	**24 hr yield (l/s)**	**SustainableYield m³/d**	**DWAF GW Class**
EC-T60-051	-31.30908	29.7596	3.2	276.48	2.8	241.92	Class 2: Iron
EC-T60-052	-31.30313	29.75283	0.89	76.896	0.89	76.896	Class 2: Bacteria
EC-T60-053	-31.34855	29.70891	0.87	75.168	0.87	75.168	Class 2: Bacteria
EC-T60-054	-31.39673	29.66307	7.5	648	7.5	648	Class 1
EC-T60-055	-31.39117	29.65699	0.75	64.8	0.75	64.8	Class 1
EC-T60-057	-31.31655	29.4866	0.34	29.376	Not suitable		Class 2: Iron & chloride
EC-T60-058	-31.31135	29.47263	0.1	8.64	Not suitable		Class 2: Iron
EC-T60-061	-31.37449	29.52324	2.3	198.72	2.3	198.72	Class 2:Chloride, Bacteria, Iron
EC-T60-064	-31.33744	29.59236	0.6	51.84	0.6	51.84	Class 4:Iron & Bacteria
EC-T60-069	-31.34969	29.50047	0.13	11.232	Not suitable		Class 3:Coliforms
EC-T60-072	-31.38769	29.65072	1.5	129.6	1.5	129.6	Class 4:Coliforms
EC-T60-074	-31.39164	29.65579	0.34	29.376	Not suitable		Class 3:Bacteria
EC-T60-076	-31.25342	29.82075	0.4	34.56	Not suitable		Class 4:Iron & Bacteria
EC-T60-078	-31.31758	29.7708	0.94	81.216	0.94	81.216	Class 1
EC-T60-080	-31.33175	29.95383	0.51	44.064	Not suitable		Class 2: Iron
TOTAL from Feasibility Study boreholes m3/d						**1568.16**	
Conceptual Boreholes to be drilled in addition							
			Modelled abstaction rate		*Amended Recommendation based on Model outcome*		
BH No	**Latitude**	**Longitude**	**24 hr yield (l/s)**	**Sustainable Yield m³/d**	**24 hr yield (l/s)**	**SustainableYield m³/d**	**Predicted DWAF GW Class**
CS1	-31.323953	29.782225	1.8	155.52	0.9	77.76	Class 1
CS2	-31.293517	29.740798	1.8	155.52	1.2	103.68	Class 2: Bacteria
CS3	-31.360521	29.729742	1.8	155.52	1.8	155.52	Class 2: Bacteria
CS4	-31.371916	29.689779	1.8	155.52	1.8	155.52	Class 2: Bacteria
CS5	-31.373665	29.632007	1.8	155.52	1.3	112.32	Class 2: Bacteria
CS6	-31.347704	29.744705	1.8	155.52	1.8	155.52	Class 2: Bacteria
CS7	-31.415606	29.568576	1.8	155.52	1.5	129.6	Class 2:Chloride, Bacteria, Iron
CS8	-31.332684	29.482067	1.8	155.52	1.1	95.04	Class 2: Iron & chloride
CS9	-31.342976	29.810382	1.8	155.52	Not suitable		Class 4:Iron & Bacteria
TOTAL from Conceptual boreholes m3/d						**984.96**	
TOTAL - Feasibility + Conceptual boreholes m3/d						**2553.12**	

Figure E3-1 **indicates the distribution of already drilled and available feasibility study boreholes recommended for inclusion into the bulk augmented system as well as positions of conceptual boreholes that are recommended to be drilled.**

E4 STAND-ALONE SCHEMES

Figure E5-1 also indicates all communities that fall outside of the RWA. These communities need to be served by stand-alone schemes. These schemes will either serve single communities or small clusters of communities depending on local groundwater conditions. Water sources will involve springs as well as new boreholes that need to be developed. Detail regarding the clustering of these stand-alone communities as well as cost summaries to develop groundwater sources for all these clusters and communities are given in **Table E5-1**.

Several zones of higher groundwater potential were delineated outside of the RWA as indicated in **Figure E5-1**. These zones were used to cluster individual communities together where possible to minimise the number of stand-alone schemes. Six such clusters could be identified as summarised in **Table E5-1**.

The engineering team will have to look at areas that cannot practically and affordably be reached by bulk pipeline infrastructure (from blended surface + groundwater), and should this implicate that there are additional communities that need to be served by stand-alone schemes than the ones listed in the table mentioned above, AGES should look at development potential and costs for this to be included in the cost tables for stand-alone schemes.

E5 COST ESTIMATES FOR GROUNDWATER SOURCE DEVELOPMENT

Table E5-1 indicates cost for the groundwater source development component of clustered stand-alone schemes as well as individual stand-alone schemes. These costs exclude infrastructure and engineering design costs.

Table E5-2 indicates costs for the groundwater source development component of developing the additional conceptual boreholes that were simulated and optimised in the numerical groundwater model.

The following summary can be given for planning and budgeting purposes (Excluding VAT):

Conceptual borehole development cost - R 3 388 000

Cluster stand-alone scheme source development cost - R 6 674 800

Individual stand-alone scheme source development cost - R 37 218 800

It is recommended that these cost scenarios be re-visited once the optimum balance between groundwater and surface water volumes have been defined based on the most cost-effective infrastructure layouts.

E6 OPTIMISED INTEGRATED SURFACE WATER-GROUNDWATER INFRASTRUCTURE

Figure E5-1 should be used as a planning tool to determine the optimum lay-out of pumping and pipeline infrastructure required to utilise the 9 feasibility study and 8 conceptual boreholes. It should be aimed for these 17 boreholes to be fed into the bulk surface water scheme to allow effective blending to decrease elevated iron concentrations that are noted in some boreholes.

Integration with the surface water infrastructure planning team will determine the final lay-out of well fields versus stand-alone schemes to find the optimum balance that will result in the most cost effective approach in terms of capital expenditure as well as long term operation and maintenance costs.

Table E6-1: Cost for the groundwater source development component of clustered stand-alone schemes as well as individual stand-alone schemes

Village Name BKS	COMMUNITY	Demands in 2035 (Million m3 / year)			ESTIMATED GROUNDWATER POTENTIAL			SPRING USAGE		BOREHOLE USAGE		DRILLING REQUIREMENTS (Including utilisation of usable springs and existing boreholes)					Groundwater Source Development Cost Estimation (Excl VAT) (Including utilisation of usable springs and existing boreholes)				
		High Growth Scenario	Medium Growth Scenario	Low Growth Scenario	High	Mod	Low	Nr of usable springs	Spring yield (l/s)	Nr of usable boreholes	Borehole yield (l/s)	Nr of attempts to deliver 1 prod hole	Est avg Yield / bh (l/s) 24/24hr	Available volume per day per production bh m3/d	Nr of production bhs required to meet demand	Nr of drilling attempts to meet demand	Drilling cost @ R52000 / bh	Nr of bhs to be tested	Testing & Lab cost @ R17000/bh	Hydrogeological consulting cost	Total Groundwater development cost- Excluding engineering design and infrastructure
CLUSTER STAND-ALONE SCHEMES																					
CLUSTER 1																					
Nyathi	Kwanyathi A	0.039	0.034	0.031	X			3	0.4			3	2.3	198.72	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Upper Ntafufu - A	Upper Ntafufu A																				
CLUSTER 2																					
Ntshwabulo	Ntshwabulo	0.264	0.218	0.184	X			1	0.15			3	2.3	198.72	4.0	12.0	R 624,000.00	10.0	R 170,000.00	R 419,600.00	R 1,213,600.00
Ntongwane	Ntongwane																				
Ndayini - A	Ndayini A																				
Tafufu - B	Tafufu B																				
CLUSTER 3																					
Kwagingqi - A	Kwagingqi A	0.108	0.094	0.083	X			3	0.8	1	0.4	3	2.3	198.72	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Skhulu - B	Skhulu B																				
CLUSTER 4																					
Mantusini B	Mantusini B	0.227	0.19	0.154		X		3	0.65			3	1.6	138.24	4.0	12.0	R 624,000.00	10.0	R 170,000.00	R 419,600.00	R 1,213,600.00
Ntsamathe	Ntsamathe																				
CLUSTER 5																					
Gemvale	Gemvale	0.227	0.19	0.154	X			1	0.2			3	2.3	198.72	4.0	12.0	R 624,000.00	10.0	R 170,000.00	R 419,600.00	R 1,213,600.00
Mswakazi	Mswakazi																				
CLUSTER 6																					
Lower Ntafufu - B	Lower Ntafufu B	0.38	0.30	0.25		X		1	0.3			3	1.6	138.24	7.0	21.0	R 1,092,000.00	17.0	R 289,000.00	R 725,800.00	R 2,106,800.00
Mthambalala - B	Mthambalala B																				
																	TOTAL COST TO DEVELOP CLUSTER STAND-ALONE SCHEMES (VAT EXCL)				**R 6,674,800.00**

Village Name BKS	COMMUNITY	Demands in 2035 (Million m3 / year)			ESTIMATED GROUNDWATER POTENTIAL			SPRING USAGE		BOREHOLE USAGE		DRILLING REQUIREMENTS (Including utilisation of usable springs and existing boreholes)					Groundwater Source Development Cost Estimation (Excl VAT) (Including utilisation of usable springs and existing boreholes)				
		High Growth Scenario	Medium Growth Scenario	Low Growth Scenario	High	Mod	Low	Nr of usable springs	Spring yield (l/s)	Nr of usable boreholes	Borehole yield (l/s)	Nr of attempts to deliver 1 prod hole	Est avg Yield / bh (l/s) 12/24hr	Available volume per day per production bh m3/d	Nr of production bhs required to meet demand	Nr of drilling attempts to meet demand	Drilling cost @ R52000 / bh	Nr of bhs to be tested	Testing & Lab cost @ R17000/bh	Hydrogeological consulting cost	Total Groundwater development cost- Excluding engineering design and infrastructure
INDIVIDUAL STAND ALONE SCHEMES																					
Agate Terrace		0.015	0.013	0.012			X	0				3	0.6	25.92	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Bulani	Bulani	0.037	0.032	0.028			X	1	0.3			3	0.6	25.92	3.0	9.0	R 468,000.00	8.0	R 136,000.00	R 323,200.00	R 927,200.00
Dedeni	Dedeni	0.063	0.055	0.049			X	0				3	0.6	25.92	7.0	21.0	R 1,092,000.00	17.0	R 289,000.00	R 725,800.00	R 2,106,800.00
Ebuchele	Ebuchele	0.098	0.085	0.075			X	0				3	0.6	25.92	11.0	33.0	R 1,716,000.00	27.0	R 459,000.00	R 1,145,400.00	R 3,320,400.00
Elusibeni	Elusibeni	0.012	0.01	0.009			X	0				3	0.6	25.92	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Engcenga	Engcenga	0.024	0.021	0.019			X	0				3	0.6	25.92	3.0	9.0	R 468,000.00	8.0	R 136,000.00	R 323,200.00	R 927,200.00
Fakini	Fakini	0.011	0.01	0.009			X	0				3	0.6	25.92	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Goqwana - B	Goqwana B	0.016	0.014	0.012			X	4	0.7			3	0.6	25.92	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Khaleni - D	Khaleni D	0.01	0.008	0.007			X	0				3	0.6	25.92	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Khonjwayo - A	Khonjwayo A	0.005	0.004	0.003			X	0				3	0.6	25.92	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Kwa-Gangatha	Kwa-Gangatha	0.014	0.012	0.011		X		4	0.75			3	1.6	69.12	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Kwa Ndengane	Kwa Ndengane	0.019	0.017	0.015			X	0				3	0.6	25.92	3.0	9.0	R 468,000.00	8.0	R 136,000.00	R 323,200.00	R 927,200.00
Kwandayini	Kwandayini	0.03	0.026	0.023		X		0				3	1.6	69.12	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Kwandengane - B	Kwandengane B	0.003	0.003	0.003			X	0				3	0.6	25.92	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Kwandengane - C	Kwandengane C	0.005	0.004	0.004			X	0				3	0.6	25.92	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Lambasi - D	Lambasi D	0.051	0.045	0.04		X		0				3	1.6	69.12	3.0	9.0	R 468,000.00	8.0	R 136,000.00	R 323,200.00	R 927,200.00
Lambasi - E	Lambasi E	0.01	0.009	0.008		X		0				3	1.6	69.12	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Lambasi - F	Lambasi F	0.001	0.001	0.001			X	0				3	0.6	25.92	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Lambasi - G	Lambasi G	0.003	0.003	0.003		X		0				3	1.6	69.12	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Lower Ntafufu - A	Lower Ntafufu A	0.02	0.018	0.016			X	1	0.3			3	0.6	25.92	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Machibini		0.015	0.013	0.012			X	0				3	0.6	25.92	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Mantusini A	Mantusini A	0.042	0.037	0.033			X	1	0.3			3	0.6	25.92	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Matenku	Matenku	0.046	0.04	0.036			X	1	0.75			3	0.6	25.92	4.0	12.0	R 624,000.00	10.0	R 170,000.00	R 419,600.00	R 1,213,600.00
Mbotyi - D	Mbotyi D	0.002	0.002	0.002			X	0				3	0.6	25.92	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Mbotyi - F	Mbotyi F	0.018	0.016	0.014			X	1	0.1			3	0.6	25.92	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Mbotyi - I	Mbotyi I	0.011	0.009	0.008			X	0				3	0.6	25.92	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Mgugwana	Mgugwana	0.13	0.11	0.09		X		0				3	1.6	69.12	6.0	18.0	R 936,000.00	15.0	R 255,000.00	R 629,400.00	R 1,820,400.00
Msikaba - A	Msikaba A	0.005	0.004	0.004			X	0				3	0.6	25.92	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Mthambalala - D	Mthambalala D	0.02	0.018	0.016			X	1	0.2			3	0.6	25.92	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Nobadula	Nobadula	0.019	0.016	0.014			X	0				3	0.6	25.92	3.0	9.0	R 468,000.00	8.0	R 136,000.00	R 323,200.00	R 927,200.00
Noqhekwane	Noqhekwane	0.106	0.092	0.082			X	4	0.8			3	0.6	25.92	10.0	30.0	R 1,560,000.00	24.0	R 408,000.00	R 1,032,000.00	R 3,000,000.00
Ntlanjeni	Ntlanjeni	0.005	0.005	0.004			X	0				3	0.6	25.92	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Phumlo - B	Phumlo B	0.032	0.028	0.025			X	0				3	0.6	25.92	4.0	12.0	R 624,000.00	10.0	R 170,000.00	R 419,600.00	R 1,213,600.00
Port Grosvenor	Port Grosvenor	0.001	0	0			X	0				3	0.6	25.92	1.0	3.0	R 156,000.00	3.0	R 51,000.00	R 113,400.00	R 320,400.00
Tafufu - A	Tafufu A	0.041	0.035	0.031			X	1	0.2			3	0.6	25.92	4.0	12.0	R 624,000.00	10.0	R 170,000.00	R 419,600.00	R 1,213,600.00
Thakanelo - B	Thakanelo B	0.025	0.022	0.019			X	1	0.2			3	0.6	25.92	2.0	6.0	R 312,000.00	5.0	R 85,000.00	R 209,800.00	R 606,800.00
Thala	Thala	0.12	0.09	0.08		X		0		1	0.4	3	1.6	69.12	4.0	12.0	R 624,000.00	10.0	R 170,000.00	R 419,600.00	R 1,213,600.00
Thaleni - H	Thaleni H	0.065	0.057	0.051		X		0				3	1.6	69.12	3.0	9.0	R 468,000.00	8.0	R 136,000.00	R 323,200.00	R 927,200.00
Upper Tafufu	Marambeni A, Kwagangata, Kugangata, Entsengeni	0.141	0.123	0.109			X	4	0.8			3	0.6	25.92	13.0	39.0	R 2,028,000.00	32.0	R 544,000.00	R 1,355,200.00	R 3,927,200.00
Upper Ntafufu - B	Upper Ntafufu B	0.04	0.03	0.02			X	0				3	0.6	25.92	5.0	15.0	R 780,000.00	12.0	R 204,000.00	R 516,000.00	R 1,500,000.00
																	TOTAL COST TO DEVELOP STAND-ALONE SCHEMES (VAT EXCL)				**R 37,218,800.00**

Table E6-2: Cost for the groundwater source development component of developing the additional conceptual boreholes that were simulated and optimised in the numerical groundwater model

CONCEPTUAL BOREHOLE DEVELOPMENT COST											
				DRILLING REQUIREMENTS (To deliver conceptual boreholes)			Groundwater Source Development Cost Estimation (Excl VAT)				
BH No	Latitude	Longitude	Predicted DWA GW Class	Est avg Yield / bh (l/s) 24/24hr	Est available volume per day per conceptual bh m3/d	Nr of drilling attempts to deliver 1 conceptual bh	Drilling cost @ R52000 / bh	Nr of bhs to be tested	Testing & Lab cost @ R17000/bh	Hydrogeological consulting cost	Total Groundwater development cost- Excluding engineering design and infrastructure
CS1	-31.323953	29.782225	Class 1	0.9	77.76	3	R 156,000.00	2	R 34,000.00	R 169,600.00	**R 359,600.00**
CS2	-31.293517	29.740798	Class 2: Bacteria	1.2	103.68	4	R 208,000.00	3	R 51,000.00	R 228,400.00	**R 487,400.00**
CS3	-31.360521	29.729742	Class 2: Bacteria	1.8	155.52	3	R 156,000.00	2	R 34,000.00	R 169,600.00	**R 359,600.00**
CS4	-31.371916	29.689779	Class 2: Bacteria	1.8	155.52	3	R 156,000.00	2	R 34,000.00	R 169,600.00	**R 359,600.00**
CS5	-31.373665	29.632007	Class 2: Bacteria	1.3	112.32	4	R 208,000.00	3	R 51,000.00	R 228,400.00	**R 487,400.00**
CS6	-31.347704	29.744705	Class 2: Bacteria	1.8	155.52	3	R 156,000.00	2	R 34,000.00	R 169,600.00	**R 359,600.00**
CS7	-31.415606	29.568576	Class 2:Chloride, Bacteria, Iron	1.5	129.6	4	R 208,000.00	3	R 51,000.00	R 228,400.00	**R 487,400.00**
CS8	-31.332684	29.482067	Class 2: Iron & chloride	1.1	95.04	4	R 208,000.00	3	R 51,000.00	R 228,400.00	**R 487,400.00**
							TOTAL COST TO DEVELOP CONCEPTUAL BOREHOLES (VAT EXCL)				**R 3,388,000.00**

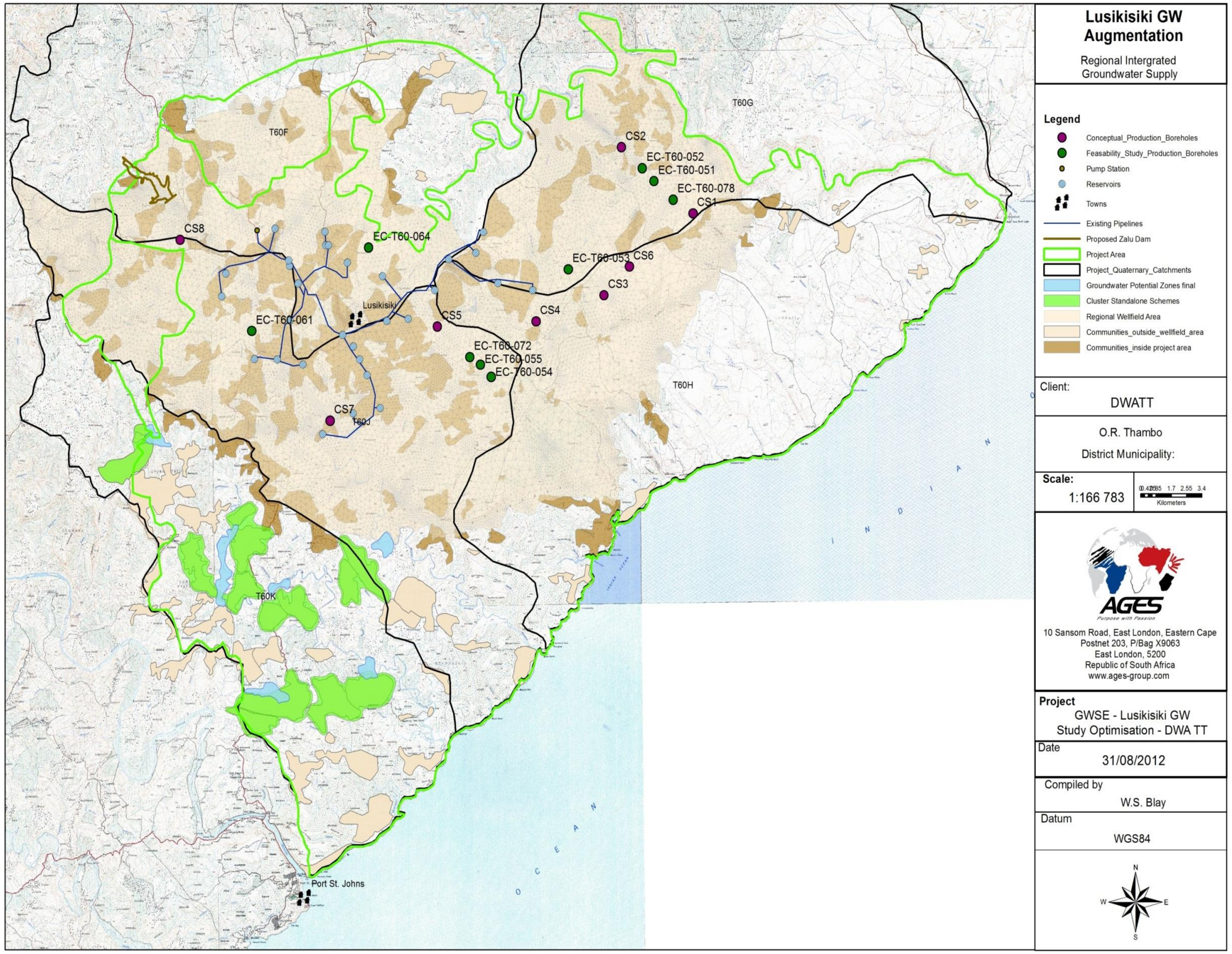

Figure E6-1: Integrated groundwater supply – regional well-field area vs stand-alone schemes

Appendix F

Hydrocensus and Spring Characterisation

Notations and terms

Advection is the process by which solutes are transported by the bulk motion of the flowing groundwater.

Anisotropic is an indication of some physical property varying with direction.

Cone of depression is a depression in the groundwater table or potentiometric surface that has the shape of an inverted cone and develops around a borehole from which water is being withdrawn. It defines the area of influence of a borehole.

A ***confined aquifer*** is a formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

The ***darcy flux,*** is the flow rate per unit area (m/d) in the aquifer and is controlled by the hydraulic conductivity and the piezometric gradient.

Dispersion is the measure of spreading and mixing of chemical constituents in groundwater caused by diffusion and mixing due to microscopic variations in velocities within and between pores.

Drawdown is the distance between the static water level and the surface of the cone of depression.

Effective porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices that are connected.

Groundwater table is the surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

A ***fault*** is a fracture or a zone of fractures along which there has been displacement.

Hydrodynamic dispersion comprises of processes namely mechanical dispersion and molecular diffusion.

Hydraulic conductivity (**K**) is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured perpendicular to the area [L/T]. Hydraulic conductivity is a function of the permeability and the fluid's density and viscosity.

Hydraulic gradient is the rate of change in the total head per unit distance of flow in a given direction.

Heterogeneous indicates non-uniformity in a structure.

***Karstic* topography** is a type of topography that is formed on limestone, gypsum, and other rocks by dissoloution, and is characterised by sinkholes, caves and underground drainage.

Mechanical dispersion is the process whereby the initially close group of pollutants are spread in a longitudinal as well as a transverse direction because of velocity distributions.

Molecular diffusion is the dispersion of a chemical caused by the kinetic activity of the ionic or molecular constituents.

Observation borehole is a borehole drilled in a selected location for the purpose of observing parameters such as water levels.

Permeability is related to hydraulic conductivity, but is independent of the fluid density and viscosity and has the dimensions L^2. Hydraulic conductivity is therefore used in all the calculations.

Piezometric head (ϕ) is the sum of the elevation and pressure head. An unconfined aquifer has a water table and a confined aquifer has a *piezometric surface*, which represents a pressure head. The piezometric head is also referred to as the hydraulic head.

Porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

Pumping tests are conducted to determine aquifer or borehole characteristics.

Recharge is the addition of water to the zone of saturation; also, the amount of water added.

Sandstone is a sedimentary rock composed of abundant rounded or angular fragments of sand set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material.

Shale is a fine-grained sedimentary rock formed by the consolidation of clay, silt or mud. It is characterised by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

Specific storage *(S_0),* of a saturated confined aquifer is the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head. In the case of an unconfined (phreatic, watertable) aquifer, *specific yield* is the water that is released or drained from storage per unit decline in the watertable.

Static water level is the level of water in a borehole that is not being affected by withdrawal of groundwater.

Storativity is the two-dimensional form of the specific storage and is defined as the specific storage multiplied by the saturated aquifer thickness.

Total ***dissolved solids*** (TDS) is a term that expresses the quantity of dissolved material in a sample of water.

Transmissivity *(T)* is the two-dimensional form of hydraulic conductivity and is defined as the hydraulic conductivity multiplied by the saturated thickness.

An ***unconfined, watertable*** *or* ***phreatic aquifer*** are different terms used for the same aquifer type, which is bounded from below by an impermeable layer. The upper boundary is the watertable, which is in contact with the atmosphere so that the system is open.

Vadose zone is the zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table.

Water table is the surface between the vadose zone and the groundwater, that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

Environmental Screening**:** Screening determines whether or not a development proposal requires environmental assessment, and if so, what level of assessment is appropriate. Screening is therefore a decision-making process that is initiated during the early stages of the development of a proposal

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F1 INTRODUCTION

F1.1 BACKGROUND

The investigation involved the hydrocensus of 62 villages that has not been hydrocensused in the previous feasibility studies. Selective groundwater sampling was carried out in order to determine the general groundwater quality, geohydrological site characterisation and the characterisation of springs and seeps.

F1.2 TERMS OF REFERENCE

With reference to the DWA Term Tender W0202WTE rates on which AGES (Pty) Ltd has been appointed, a cost estimate is given for the following inputs that were defined based on the conclusions and recommendations as in the proposal document:

F1.3 SCOPE OF WORK

AGES was appointed to render the following geohydrological services in the project area:

- Complete the hydrocensus at the remaining 62 communities in the study area that were not covered in the earlier study
- Selective water sampling – Boreholes (15) – Springs – (20)
- Characterise springs and seeps in different hydrogeological terrains / GMU's
- Process & integrate hydrocensus data for incorporation into the GYMR and groundwater model
- Integrate updated groundwater use statistics from hydrocensus for finalization of groundwater-surface water use balance. Define final augmentation and optimum groundwater infrastructure requirements (Capex & Opex).

F1.4 LOCATION OF THE PROJECT AREA

The project area is located in quaternary catchments T60 F, G, H, J, K and in the OR Tambo District of the Eastern Cape Province as indicated in **Figure F1-1**.

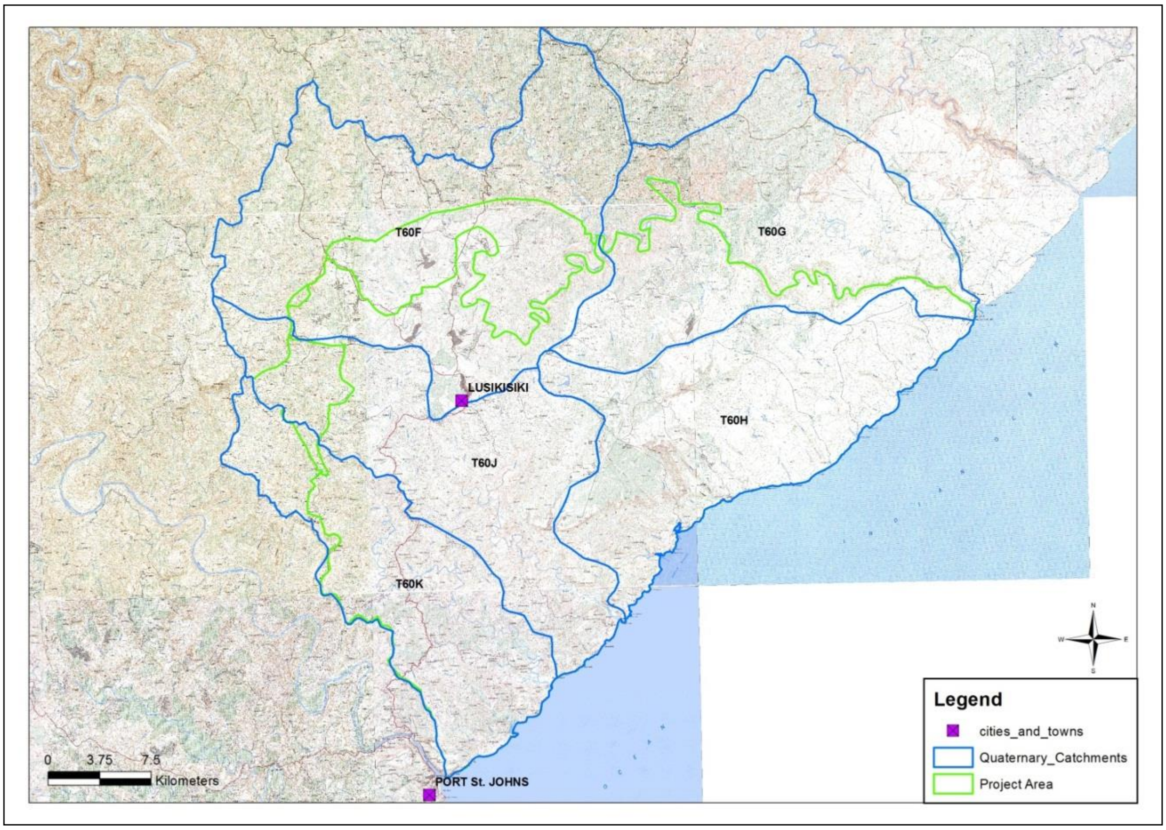


Figure F1-1: Regional Locality of the Project Area (Topo Map)

F1.5 INFORMATION SOURCES

The following information sources were utilized during the investigation:

- Geological maps
  - 3128 UMTATA ; scale 1 : 250 000
- Geohydrological maps
  - 2928 DURBAN; scale 1 : 500 000
- Topographical maps
  - 3129 Series Topographical maps, scale 1 : 50 000

F2 METHODOLOGY

F2.1 BACKGROUND NOTES FROM THE RESERVE DETERMINATION REPORT

"The mean groundwater level in the study area is calculated at 10.1 mbgl based on old and new NGDB data as well as GRIP data for T60F. Shallow water level results from saturated aquifer conditions and almost no groundwater abstraction. Numerous springs and seeps are also a testament of the saturated groundwater conditions. Water level data in the study area is very sparse and it will be good if some additional water level data could be obtained in order to have a good water level distribution across the study area for modelling. Also, no groundwater monitoring of water levels in the study area is currently being conducted. Monthly groundwater levels are also for instance required in order to apply the EARTH method for recharge estimation.

Recharge is estimated to be 8.25% for total Tender study area. Recharge is based on a weighted mean of quaternary catchment coverage of study area.

Quaternary recharge obtained from Woodford lower variable recharge estimates for quats in Eastern Pondoland Basin study (2001). Woodford (2001: 65) notes that the true recharge is probably in the order of his lower variable recharge estimates.

SRK estimated a mean percentage of recharge for the study area of 12.8%. This recharge estimate need to be quantified and is possibly too high.

Due to sparse borehole water quality info (basically only newly drilled SRK boreholes), the chloride method cannot be applied with enough confidence to estimate recharge. Evaluation of chloride method for study area based on newly drilled SRK boreholes equates to recharge percentage of 3.8%.

The numerous springs (and not seeps) in the study area present a unique way of gaining a lot of high quality representative chloride values and general chemical water quality for groundwater. As springs represent moving groundwater of the aquifers in the study area, they are regarded as the best possible points for obtaining chloride values for recharge estimates. Some hyper saline springs do occur in study area near large tectonic structures as noted by Woodford (2001). Woodford (2001) also states that EC and other macro- and isotopic-constituents of the water may be used to obtain a first order approximation of the sustainability of the resource (i.e. whether it is a spring or a seep and thus perennial or not).

Very little information on boreholes and production boreholes are available for the southern part of the study area that was not covered during earlier studies. Preliminary indication is that the Bulk Water Supply Scheme will not be able to reach this area and that it will be reliant on groundwater from springs and boreholes almost 100%. The extent, yield capacity of successful boreholes and groundwater quality need to be verified.

It was important during this study to distinguish between springs and seeps. Springs are normally located down in the lower valleys of incised rivers or at places where a shallow water table cuts the topography. Springs are perennial and especially in the study area due to the high MAP and very little groundwater use.

Seeps are typically the discharge of infiltrated rainwater from the vadose zone or perched aquifer, where the infiltrated rainwater has not yet reached the water table or saturated aquifer (Woodford, 2001). Seeps are typically non-perennial, do not present sustainable supplies of groundwater for communities and will create the idea that groundwater is not sustainable. Seeps do not represent aquifer water quality characteristics

There is currently an imbalance in the 95% assurance of supply GYMR model. Correcting the imbalance has not been attempted as it is expected that the cause is a large flow component that cannot currently be sufficiently quantified. The cause for imbalance is suspected to be one of the following:

Springs and seeps losses and evaporation of such water. This component is expected to be the most likely causal flow component as it is known to be underestimated, especially in the study area. Only hydrocensused springs from NGDB, GRIP and limited SRK studies were used in the calculation of this flow component. It is known that there are many more springs and seeps in the study area and it is recommended that proper surveys, via imagery or physical site visits be done completely for smaller representative areas (based on geology units or catchment units) and that the number of springs and seeps obtained in these areas, be extrapolated to larger areas of similar character.

Old base flow estimates are too conservative and current Lusikisiki RWSS study base flow estimates are not available yet.

Recharge is expected to be lower than is currently thought: older estimates of recharge has been used although these estimates made by Woodford (2001) for the EPBS are assumed to be in line as recharge is comparably higher in the study area than the Karoo due to high MAP and multitude of lineaments. Sparse chloride values estimate does however show a much lower recharge in the order of 3.8%. The available chloride data is not considered enough for the chloride method to be used currently in recharge estimation. Selective sampling during hydrocensus surveys can assist to get more accurate and representative recharge estimations.

Evapotranspiration expected to be the least probable flow component cause as a riparian buffer zone of 2.5m on each side of drainage has already been applied to all drainages. Due to incised nature of rivers in the study area and little riparian vegetation in T60F, the Evapotranspiration from plants-flow component is not expected to be the cause for imbalance. No site survey of riparian vegetation has however been attempted in the study area due to budget and previous time constraints. Inputs from other modules will be required once available.

The draft present day GYMR shows that based on recharge of 8.25%, a 95% assurance of supply precipitation of 893mm/a, the study area has a surplus groundwater availability of approximately 55.8 million m^3/a (1769 ℓ/s) after all losses, BHN Reserve and the EWR of 100% of base flow have been subtracted. This will change significantly with more accurate data.

Another present day scenario GYMR where the MAP (1114mm/a) is used in groundwater recharge will also be run. Future groundwater augmentation scenarios will also be done.

Springs and seeps are the primary sources of water supply to remote villages and it has been found that even when communities have potable water supply from reticulation networks, these sources are still used. The frequency and character of these springs need to be better quantified."

F2.2 CHEMICAL WATER ANALYSES

Water samples were taken at every fourth village to get a regional indication of the water quality trends. The samples were submitted to a laboratory and analysed as far as its physical, chemical and microbiological quality is concerned.

Results were evaluated by using the document: Quality of Domestic Water Supplies; Volume 1; Assessment Guide; Second Edition 1998; Water Research Commission No. TT101/98 as well as the recommended limits set in SABS 241 of 1984. The purpose of this Guide is to answer the following questions:

- Is the water suitable for domestic use?
- If not, what can be done to make it suitable for use?

This Guide allows the quality of water supplied for domestic use to be assessed by using a simple classification system. The system shows the nature of the effects of water quality on the domestic user for a range of concentration values for those substances commonly encountered in water. The information is presented in a simplified format so that a wide spectrum of users of the Guide will be able to understand the concepts of water quality as it affects the domestic user. The Water Quality Assessment Guide defines the following classes as shown in **Table F2-1**.

Table F2-1: Water quality assessment guide

Class 0	**Ideal water quality**	Suitable for lifetime use
Class 1	**Good water quality**	Suitable for use, rare instances of negative effects.
Class 2	**Marginal water quality**	Conditionally acceptable. Negative effects may occur in some sensitive groups.
Class 3	**Poor water quality**	Unsuitable for use without treatment. Chronic effects may occur.
Class 4	**Dangerous water quality**	Totally unsuitable for use. Acute effects may occur.

F3 RESULTS

F3.1 SITE GEOHYDROLOGY

Site Geology:

According to the geological map 3128 (Umtata) the project area is underlain by the Ecca formation, the Dwyka formation of the Karoo Supergroup sequence of rocks and the Natal Group Sandstones (**Figure F8-1**).

Ecca Formation

The Ecca formation consists of dark grey shale, mudstone and sandstone. The average dip angle of the formation is 3 degrees north-west with dolerite intrusions striking in the same direction over the entire project area. Parts of the project area are covered by dolerite sills with dolerite dykes intersecting the sills.

Dwyka Formation

The dwyka formation consists of tillite an associative glacial deposit. The general strike of dolerite dykes through the formation is north-west.

Natal Group Sandstones

The light grey quartzitic sandstone occurs in the eastern parts of the project area has a dip of 2 degrees to the west. Dolerite dykes and lineaments have a strike consistent with the other formations mentioned in a north-west direction.

Site Hydrogeology:

According to hydro geological maps 3126 (QUEENSTOWN) and 2928 (DURBAN) the project area is underlain by argillaceous rocks (sandstone and mudstone of the Ecca Formation), Diamictite (Tillite from the Dwyka Formation) and arenaceous rocks (Quartzitic Sandstone of the Natal group Sandstones) with groundwater occurrences expected to be in intergranular and fractured zones, with yields at successful boreholes expected between 0.5 and 2.0 litres per second over a 12 hour duty cycle and yields of 2 to 5 l/s are expected in the Natal group sandstones.

Groundwater Potential:

Based on site observations and according to the geological and hydrogeological maps the groundwater potential of the project area is deemed to be medium. On site observation revealed that the groundwater potential of the project can be characterised as medium due to the project being dominated by mountains and flowing hills.

F3.2 HYDROCENSUS

The hydrocensus was conducted at 62 communities, which were not covered during the previous investigation, in order to determine the number of existing springs and boreholes. A total of 4 boreholes, as well as 89 springs and seeps were identified during the survey. Of the surveyed springs, 98% are currently in use as indicated in **Figure F3-1** below.

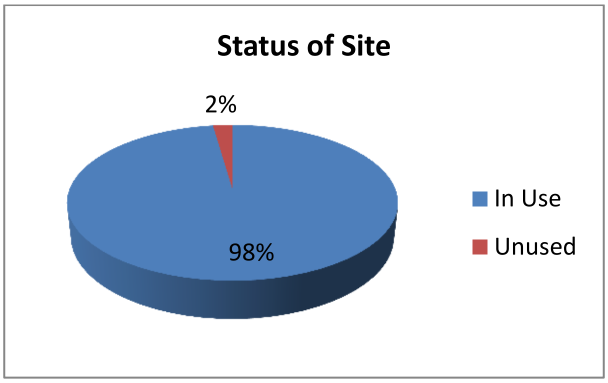


Figure F3-1: Geosite status

F3.3 SPRINGS AND SEEPS CHARACTERISATION

Perennial springs make up a total of 79%, the remaining 21% are non-perennial (seasonal) springs or more likely seeps as indicated in **Figure F3-2**. The large amount of perennial springs could be attributed to the high MAP in the project area resulting in high groundwater recharge of approximately 8.25% for the total Tender study area as discussed in the reserve determination. The average yield of the 89 springs is 0.21 ℓ/s.

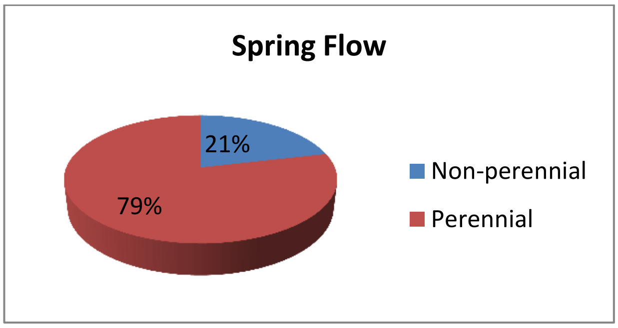
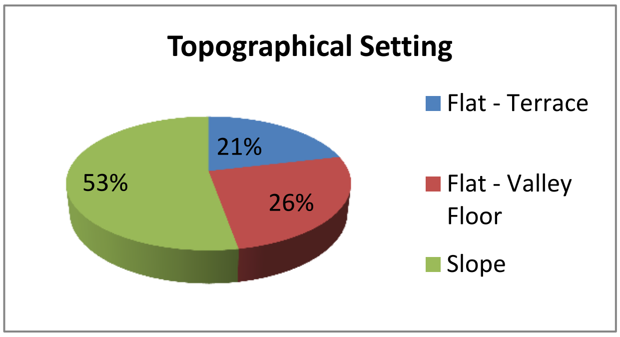


Figure F3-2: Spring flow perennial versus non-perennial

The topographical settings of the springs are as follows: 53% on slopes, 26% on or close to valley floors and 21% are located on terraces. *"Springs are normally located down in the lower valleys of incised rivers or at places where a shallow water table cuts the topography. Springs are perennial and especially in the study area due to the high MAP and very little groundwater use. Seeps are typically the discharge of infiltrated rainwater from the vadose zone or perched aquifer, where the infiltrated rainwater has not yet reached the water table or saturated aquifer (Woodford, 2001)."*



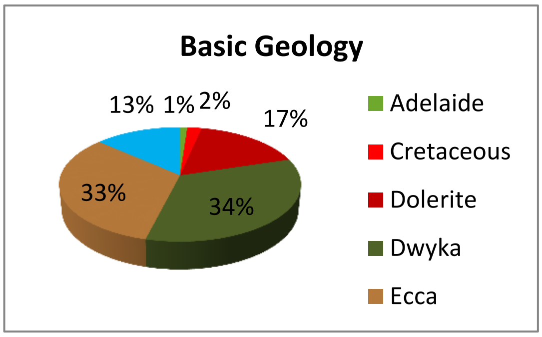
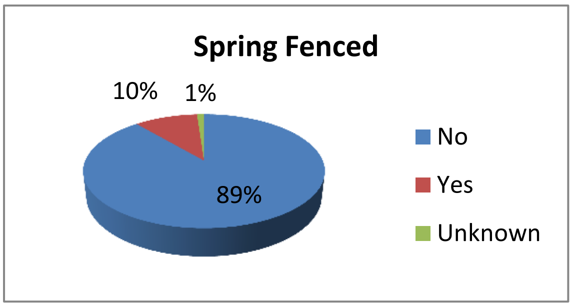


Figure F3-3: Topographical setting of springs **Figure F3-4: Geological setting of springs**

The majority of springs 34% are located in the Dwyka formation followed by 33% in the Ecca formation. Pollution sources do occur in close proximity to springs and seeps although 72% of springs are expected to have a low chance of being polluted. In the project area there is a general absence, 89% of springs, in the protection/fencing of springs that can result in the source being polluted or damaged by animals to an extent where it can no longer be equipped for production purposes. **Figure F3-5** indicates that 89% of springs are not fenced off for protection of the springs it is vital that they be fenced off. Springs have a low pollution hazard as indicated **Figure F3-6** which can be ascribed to the remote location of springs.

Springs are more abundant in the Lower Karoo GRU in comparison to the Msikaba GRU which has more high yielding springs than low yielding springs.



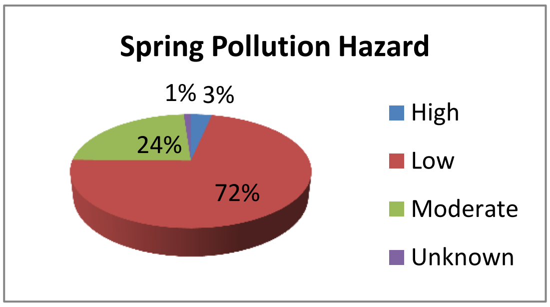


Figure F3-5: Spring protection or fenced **Figure F3-6: Spring Pollution hazard**

Chemical water analysis

Water samples of the springs were submitted to Monitor Laboratories and to Talbot & Talbot Laboratories, an accredited water laboratory in Pietermaritzburg for detailed chemical analysis. The results of the water analyses are discussed as follows.

Sampling was conducted at every fourth village in order to obtain representative values for the water chemistry in the study area. Forty percent of samples that were taken classified as DWAF Class 2 (Marginal water quality) due to moderate concentrations of Chloride 228 mg/ℓ, Iron concentrations from 0.75 to 0.92 mg/ℓ, a Fluoride concentration of 1.06 mg/ℓ and Turbidity units ranging from 1.4 to 3.3 NTU. The water from two of the sample also classify as DWAF Class 3 Poor water quality due to Turbidity units of 23.3 and 40.7 NTU.

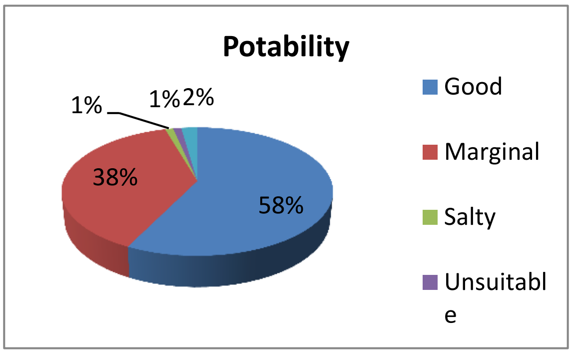


Figure F3-7: Water potability

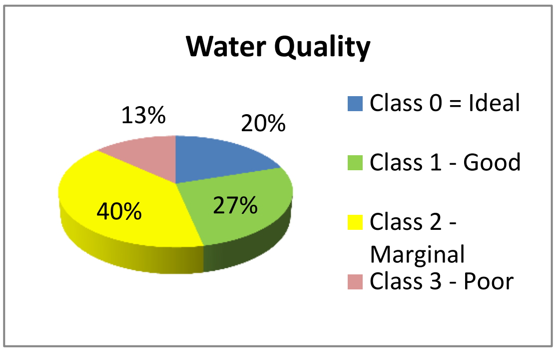


Figure F3-8: Geosite water quality according to DWA standards

From previous projects conducted in the Mbizana Area the piper diagram in **Figure F3-9** has been created in order to display the difference in groundwater composition compared to the geological formation in which it occurs.

There is a definite difference in groundwater characteristics as indicated on the piper diagram, groundwater from the Ecca formation, NGS and Dwyka formation is of the sodium -bicarbonate (Na-HCO3) type of water that is typical of deeper fresh groundwater that has undergone ion exchange. The groundwater from the NGS and the Dwyka formation tends to be more calcium-sulphate (Ca-SO4) that is typical of gypsum groundwaters and mine drainage.

The overall classification as indicated in **Figure F3-10** of the water samples is more sodium-bicarbonate (Na-HCO3) that indicates fresh groundwater of deep origins that has infiltrated aquifers and has undergone ion exchange.

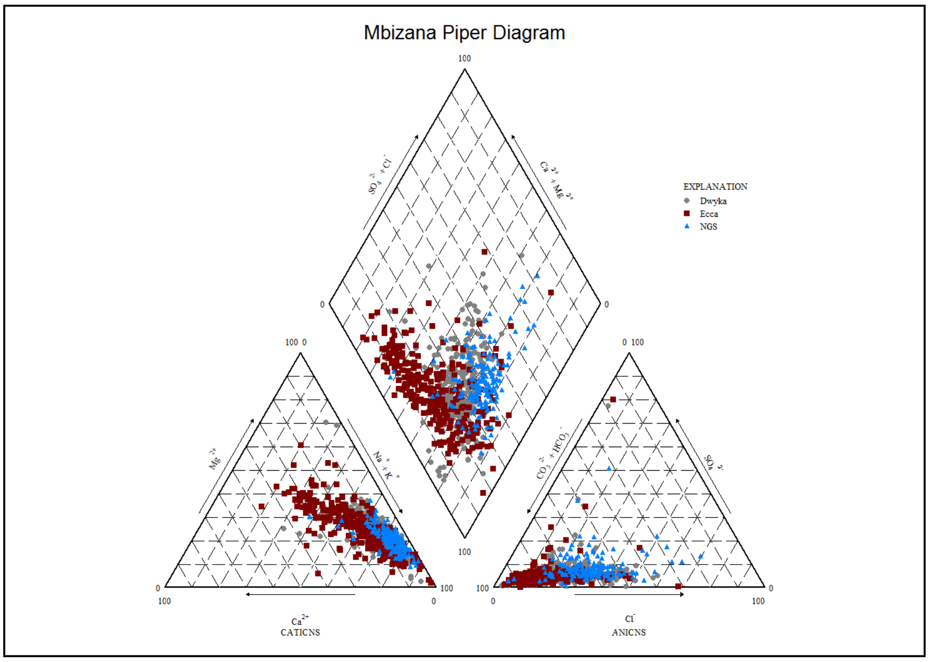


Figure F3-9: Piper diagram of groundwater chemistry in the Mbizana Area

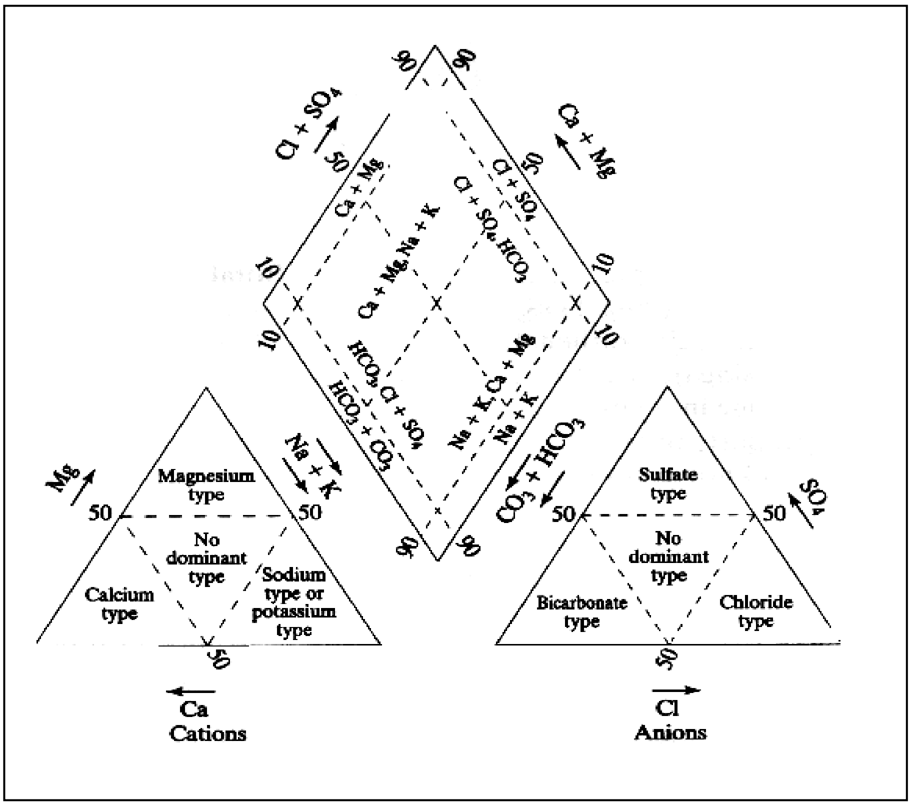


Figure F3-10: Piper diagram water chemistry classification (Kehew 2001)

Water analysis data as received from the laboratory is given in section F9 of this document.

Brief treatment options for the problem constituents are described in the tables and paragraphs to follow.

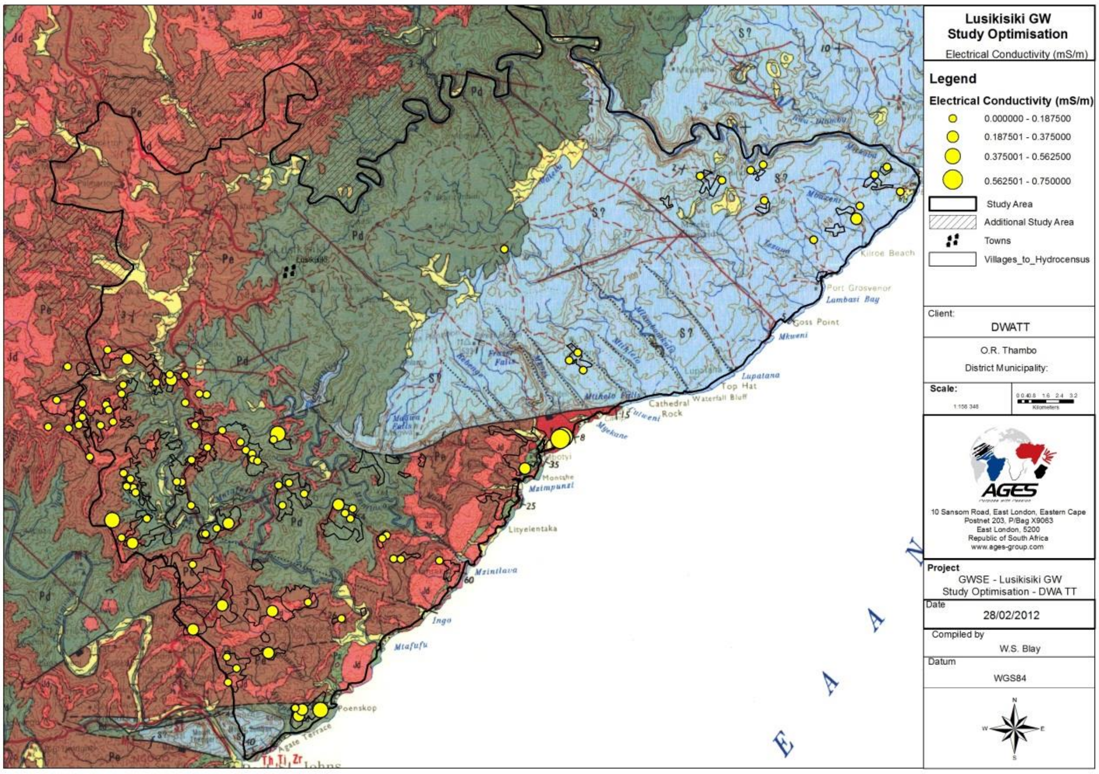


Figure F3-11: Hydrocensus geosite electrical conductivities.

The electrical conductivity (EC) was measured during the hydrocensus at each of the geosites where possible. There is a relatively even spread of electrical conductivities over all of the geological formations, some geosites indicate elevated EC concentrations in localized zones primarily associated with the Ecca group and coastal regions.

F4 SUMMARY

The hydrocensus was conducted at 62 communities that were not covered during the previous investigation in order to determine the number of existing springs and boreholes. A total of 4 boreholes and 89 springs and seeps were identified during the survey.

The majority of springs 34% are located in the Dwyka formation followed by 33% in the Ecca formation. Pollution sources do occur in close proximity to springs and seeps although 72% of springs are expected to have a low chance of being polluted. In the project area there is a general absence, 89% of springs, in the protection/fencing of springs that can result in the source being polluted or damaged by animals to an extent where it can no longer be equipped for pro Springs are more abundant in the Lower Karoo GRU in comparison to the Msikaba GRU which has more high yielding springs than low yielding springs.

Sampling was conducted at every fourth village in order to obtain representative values for the water chemistry in the study area. 40% of samples that were taken classify as DWAF Class 2 (marginal water quality) due to moderate concentrations of Chloride 228 mg/ℓ, Iron concentrations from 0.75 to 0.92 mg/ℓ, a Fluoride concentration of 1.06 mg/ℓ and turbidity units ranging from 1.4 to 3.3 NTU. The water from two of the sample also classify as DWAF Class 3 Poor water quality due to Turbidity units of 23.3 and 40.7 NTU.

The electrical conductivity (EC) was measured during the hydrocensus at each of the geosites where possible. There is a relatively even spread of electrical conductivities over all of the geological formations, some geosites indicate elevated EC concentrations in localized zones primarily associated with the Ecca group and coastal regions.

F5 CONCLUSIONS

"*Springs are normally located down in the lower valleys of incised rivers or at places where a shallow water table cuts the topography. Springs are perennial and especially in the study area due to the high MAP and very little groundwater use. Seeps are typically the discharge of infiltrated rainwater from the vadose zone or perched aquifer, where the infiltrated rainwater has not yet reached the water table or saturated aquifer (Woodford, 2001).*"

There is a definite difference in groundwater characteristics from the Ecca formation, NGS and Dwyka formation is of the Sodium - Bicarbonate (Na-HCO3) type of water that is typical of deeper fresh groundwater that has undergone ion exchange. The groundwater from the NGS and the Dwyka formation tends to be more Calcium – Sulphate (Ca-SO4) that is typical of gypsum groundwaters and mine drainage.

F6 REFERENCES

A. C. Woodford and L. Chavallier., 'Regional Characterization and Mapping of Karoo Fractured Aquifer Systems – An Integrated Approach Using Geographical Information System and Digital Image', Water Research Commission, Pretoria, 2002.

SRK (Pty) Ltd., 'Investigating the Potential to supplement the Lusikisiki Rural Water Supply Scheme (LRWSS), Lusikisiki Groundwater Feasibility Study Phase 2', DWA Report No P WMA 12/000/00/1507: SRK (Pty) Ltd, 2009.

UWP Engineers., 'Eastern Pondoland Basin Study', Johannesburg: UWP Engineers, 2001.

F7 HYDROCENSUS SUMMARY

Table F7-1: Hydrocensus summary

Village	DWAF Source Nr	Date Surveyed	Time Surveyed	Latitude (South)	Longitude (East)	Altitude [mamsl]	Site Type	Status of Site
Mswakazi	SP 1	2011-12-13	15:30	-31.55452	29.52294	248	Spring	In Use
Nkodusweni	SP 1	2011-12-14	08:40	-31.54226	29.54091	177	Spring	In Use
Taleni	EC-T60-1153	2011-12-14	10:30	-31.52081	29.52337	360	Borehole	Unused
Khululeka Resort	EC-T60-1154	2011-12-14	11:15	-31.54987	29.61289	216	Borehole	Unused
Bholani	EC-T60-1155	2011-12-14	16:00	-31.567	29.56848	137	Spring	In Use
Mantusini	EC-T60-1156	2011-12-14	16:30	-31.54547	29.57103	177	Spring	In Use
Umtweni	SP 1	2011-12-15	09:15	-31.56903	29.54333	180	Spring	In Use
Umtweni	SP 2	2011-12-15	08:00	-31.58215	29.54365		Spring	In Use
Umtweni	SP 3	2011-12-15	08:42	-31.5749	29.54903	128	Spring	In Use
Sikulu	SP 1	2011-12-15	11:00	-31.49969	29.54515		Spring	In Use
Sikulu	SP 2	2011-12-15	11:30	-31.50217	29.53805	261	Spring	In Use
Mbiza (Sikulu)	EC-T60-1157	2011-12-15	12:10	-31.505	29.52992	234	Borehole	Destroyed
Mbiza (Sikulu)	EC-T60-1158	2011-12-15	12:30	-31.50506	29.5314	224	Borehole	Unused
Mbiza (Sikulu)	SP 3	2011-12-15	13:05	-31.50531	29.5315	233	Spring	In Use
Ntafufu	SP 1	2011-12-15	14:00	-31.49007	29.5229	196	Spring	In Use
Mgugwini	SP 1	2011-12-16	14:45	-31.50632	29.48036	380	Spring	In Use
Mgugwini	SP 2	2011-12-15	15:10	-31.50921	29.48688	345	Spring	In Use
Ndayeni (Kwaginqgi)	SP 1	2011-12-15	16:00	-31.49724	29.47506	283	Spring	In Use
Ndayeni (Kwaginqgi)	SP 2	2011-12-15	16:30	-31.49676	29.49596	238	Spring	In Use
Ndayeni	SP 3	2011-12-16	08:00	-31.48318	29.48923	299	Spring	In Use
Mpophomeni	SP 1	2011-12-16	09:10	-31.4805	29.48797	314	Spring	In Use
Mpophomeni	SP 2	2011-12-16	09:40	-31.47992	29.48404	350	Spring	In Use
Mpophomeni	SP 3	2011-12-16	10:00	-31.47294	29.48219	370	Spring	In Use
Mkhuna	SP 1	2011-12-16	10:45	-31.47603	29.48645	342	Spring	In Use
Sandlulube	EC-T60-1159	2011-12-16	11:30	-31.47777	29.5143	320	Spring	In Use
Sandlulube	SP 1	2011-12-16	12:00	-31.47799	29.51736	308	Spring	In Use
Kugcobani (Ngxanexasini)	SP 1	2011-12-19	08:30	-31.4665	29.52346	345	Spring	In Use
Kugcobani	SP 2	2011-12-19	09:10	-31.46026	29.53308	351	Spring	In Use
Kugcobani (Emachibini)	SP 3	2011-12-19	10:00	-31.44864	29.52585	417	Spring	Unused
Mfihlela	SP 1	2011-12-19	10:45	-31.4515	29.54216	448	Spring	In Use
Mfihlela	SP 2	2011-12-19	11:00	-31.45775	29.55329	366	Spring	In Use
Mfihlela	SP 3	2011-12-19	11:45	-31.46185	29.5565	360	Spring	In Use
Kuxhaka	SP 1	2011-12-20	08:00	-31.45677	29.5732	413	Spring	In Use
Kuxhaka	SP 2	2011-12-20	08:30	-31.45375	29.57592	413	Spring	In Use
Mathombe	SP 1	2011-12-20	09:00	-31.46381	29.56021	395	Spring	In Use
Mathombe	SP 2	2011-12-20	10:15	-31.46676	29.56046		Spring	In Use
Mathombe	SP 3	2011-12-20	10:40	-31.46765	29.56335	385	Spring	In Use
Ntsamathe	SP 1	2011-12-20	11:15	-31.49073	29.57808	363	Spring	In Use
Ntsamathe	SP 2	2011-12-20	12:00	-31.48033	29.57587	328	Spring	In Use
Matane	SP 1	2011-12-20	14:00	-31.47924	29.58222	342	Spring	In Use
Matane	SP 2	2011-12-20	14:45	-31.48482	29.59133	321	Spring	In Use
Mnceba (Mbotyi)	SP 1	2012-01-11	08:50	-31.45719	29.74843	24	Spring	In Use
Mbotyi	SP 1	2012-01-11	10:30	-31.47321	29.72504	50	Spring	In Use
Mnceba (Mbotyi)	SP 2	2012-01-11	12:20	-31.45803	29.74673	31	Spring	In Use
Buchele	SP 4	2012-01-10	17:30	-31.49075	29.61206	257	Spring	In Use
Buchele	SP 3	2012-01-10	17:10	-31.49523	29.61578	228	Spring	In Use
Buchele	SP 2	2012-01-10	16:50	-31.49799	29.61925	225	Spring	In Use
Buchele	SP 1	2012-01-10	16:20	-31.49283	29.62073	247	Spring	In Use
Fatyini	SP 2	2012-01-10	15:20	-31.5069	29.64097	270	Spring	In Use
Fatyini	SP 1	2012-01-10	14:50	-31.50861	29.63828	243	Spring	In Use
Nonjonjo	SP 2	2012-01-10	13:30	-31.51912	29.64503	182	Spring	In Use
Manteku	SP 1	2012-01-10	11:50	-31.52038	29.67276	122	Spring	In Use
Nonjonjo	SP 1	2012-01-10	12:50	-31.51931	29.64951	181	Spring	In Use
Cutwini (Lambase Place)	EC-T60-1160	2012-01-12	14:10	-31.35938	29.7142		Borehole	Unused
Ndindindi (Kudimfi)	SP 1	2012-01-12	15:45	-31.32272	29.83298	391	Spring	In Use
Ndindindi (Dimfi)	SP 2	2012-01-12	16:30	-31.32493	29.84614	330	Spring	In Use
Kwarnole	SP 1	2012-01-13	14:20	-31.33575	29.87151	320	Spring	In Use
Phalane	SP 2	2012-01-13	13:10	-31.31981	29.86356	298	Spring	In Use
Phalane	SP 1	2012-01-13	12:20	-31.3172	29.87104	285	Spring	In Use
Cutwini	SP 1	2012-01-13	08:30	-31.41752	29.75257	230	Spring	In Use
Kugcuthe	SP 1	2012-01-16	10:15	-31.35627	29.90113	128	Spring	In Use
Kwanyawuza	EC-T60-079	2012-01-16	11:50	-31.33908	29.92929	84	Borehole	Unused
Kwanyawuza	SP 1	2012-01-16	12:30	-31.34558	29.92714	85	Spring	In Use
Ndengane	SP 1	2012-01-16	14:40	-31.32304	29.93837	100	Spring	In Use
Ndengane	EC-T60-080	2012-01-16	15:00	-31.33173	29.95384	51	Borehole	Unused
Ndengane B	SP 2	2012-01-17	08:40	-31.31898	29.94595	80	Spring	In Use
Komani	SP 1	2012-01-17	15:30	-31.43237	29.52868	452	Spring	In Use
Komani	SP 2	2012-01-17	16:00	-31.43291	29.53317	428	Spring	In Use
Komani B	SP 3	2012-01-17		-31.4369	29.52013		Spring	In Use
Mnkuntayini	SP 1	2012-01-18	09:30	-31.42271	29.52014	493	Spring	In Use
Emabheleni (Kwagangatha)	SP 2	2012-01-18	11:00	-31.42205	29.51085	473	Spring	In Use
Emabheleni (Kwagangatha)	SP 3	2012-01-18	12:30	-31.42628	29.50275	439	Spring	In Use
Emazizini (Kwagangatha)	SP 1	2012-01-18	14:15	-31.4089	29.47355	513	Spring	In Use
Emazizini (Kwagangatha)	SP 2	2012-01-18	15:30	-31.41375	29.48554	476	Spring	In Use
Mnkuntayini	SP 2	2012-01-18	16:30	-31.42495	29.51186	458	Spring	In Use
Cutwini	SP 2	2012-01-13	09:00	-31.41345	29.75786	240	Spring	In Use
Cutwini	SP 3	2012-01-13	09:30	-31.42247	29.76093	229	Spring	In Use
Ntsimbini	SP 1	2012-01-19	12:00	-31.43187	29.48164	472	Spring	Unused
Ntsimbini	SP 2	2012-01-18	12:50	-31.42724	29.48265	390	Spring	In Use
Goqwana	SP 1	2012-01-19	14:30	-31.43738	29.47219	580	Spring	In Use
Goqwana	SP 2	2012-01-19	15:00	-31.44016	29.47368	588	Spring	In Use
Goqwana	SP 3	2012-01-19	15:30	-31.44635	29.47621	608	Spring	In Use
Goqwana	SP 4	2012-01-19	16:00	-31.44808	29.46871	592	Spring	In Use
Kwabhala	SP 1	2012-01-19	16:45	-31.44852	29.43696	588	Spring	In Use
Kwabhala	SP 2	2012-01-19	17:15	-31.44945	29.4493	544	Spring	In Use
Kwabhala	SP 3	2012-01-19	17:45	-31.44773	29.4555	557	Spring	In Use
Kwabhala	SP 4	2012-01-20	08:00	-31.46424	29.46174	585	Spring	In Use
Nzondeni	SP 1	2012-01-20	08:40	-31.44368	29.45777	587	Spring	In Use
Nzondeni	SP 2	2012-01-20	09:20	-31.43655	29.45793	527	Spring	In Use
Nzondeni	SP 3	2012-01-20	10:35	-31.43466	29.44244	504	Spring	In Use
Nyati	SP 1	2012-01-20	11:45	-31.41737	29.44925	527	Spring	In Use
Noqhekwane	SP 1	2012-01-20	14:40	-31.59667	29.58855	97	Spring	In Use
Noqhekwane	SP 2	2012-01-20	15:00	-31.59587	29.58433	73	Spring	In Use
Noqhekwane	SP 3	2012-01-20	15:30	-31.60000	29.58624	97	Spring	In Use
Noqhekwane	SP 4	2012-01-20	16:00	-31.59713	29.59957	26	Spring	In Use
Mtabalala	SP 1	2011-12-14	16:13	-31.54106	29.59287		Spring	In Use

F8 PROJECT MAPS

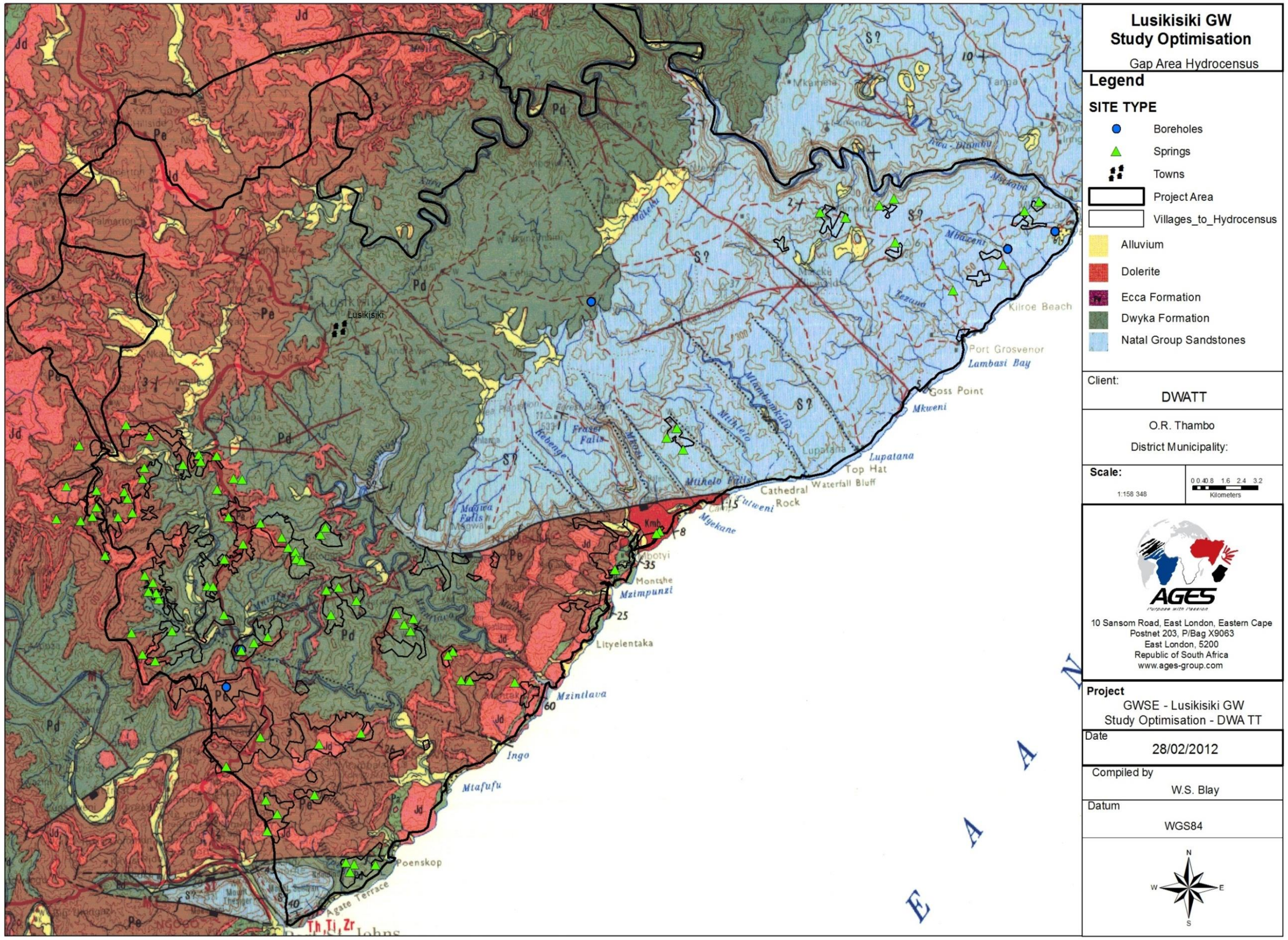


Figure F8-1: Geological background

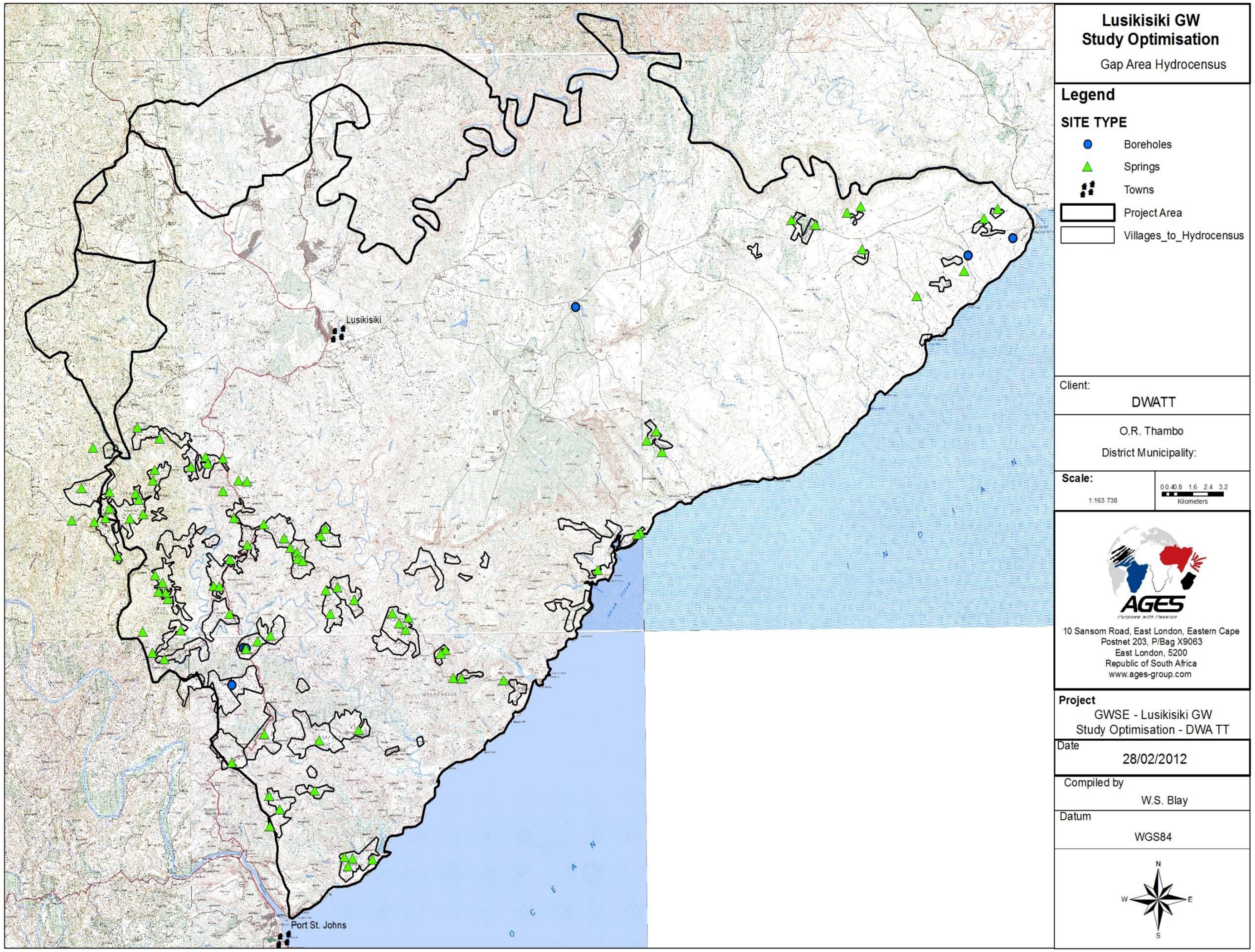


Figure F8-2: Topographical background

F9 WATER CHEMISTRY

Lusikisiki

Borehole Id	Mnceba SP 2
Date Sampled	11-Jan-12
Drinking water class	**3**
Sample Number	1074/12

					Class
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	66.00	0
	Total Dissolved Salts	*TDS*	mg / l	368.00	0
	pH Value	*pH*		7.30	0
	Turbidity		NTU	40.70	3
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l	4.70	0
	Chloride	*Cl*	mg / l	134.00	1
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.43	0
	Iron	*Fe*	mg / l	0.11	1
	Total Hardness	$CaCO_3$	mg / l	45.00	0
	Magnesium	*Mg*	mg / l	8.00	0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	0.04	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l	0.50	0
	Sodium	*Na*	mg / l	99.00	0
	Sulphate	SO_4	mg / l	31.10	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the classification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l	0.17	
	P - Alkalinity	$CaCO_3$	mg / l	10.00	
	M - Alkalinity	*CaCO3*	mg / l	58.00	
	Calcium Hardness	*CaCO3*	mg / l	12.00	
	Magnesium Hardness	*CaCO3*	mg / l	33.00	
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	PO_4 as P	mg / l		

Lusikisiki

Borehole Id	Ndengane SP 1
Date Sampled	16-Jan-12
Drinking water class	**1**
Sample Number	1075/12

					Class
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	17.00	0
	Total Dissolved Salts	*TDS*	mg / l	89.00	0
	pH Value	*pH*		5.20	1
	Turbidity		NTU	0.70	1
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l	1.50	0
	Chloride	*Cl*	mg / l	33.00	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.19	0
	Iron	*Fe*	mg / l	0.10	1
	Total Hardness	$CaCO_3$	mg / l	18.00	0
	Magnesium	*Mg*	mg / l	3.50	0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	1.91	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l	0.02	0
	Sodium	*Na*	mg / l	21.00	0
	Sulphate	SO_4	mg / l	1.33	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the clasification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l	0.14	
	P - Alkalinity	$CaCO_3$	mg / l	10.00	
	M - Alkalinity	*CaCO3*	mg / l	10.00	
	Calcium Hardness	*CaCO3*	mg / l	4.00	
	Magnesium Hardness	*CaCO3*	mg / l	14.00	
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ as P	mg / l		

Lusikisiki

Borehole Id	Komani SP 1
Date Sampled	17-Jan-12
Drinking water class	**3**
Sample Number	1076/12

Group	Parameter	Symbol	Unit	Value	*Class*
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	19.00	0
	Total Dissolved Salts	*TDS*	mg / l	161.00	0
	pH Value	*pH*		6.00	1
	Turbidity		NTU	23.30	3
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l	2.80	0
	Chloride	*Cl*	mg / l	23.00	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.36	0
	Iron	*Fe*	mg / l	0.10	1
	Total Hardness	$CaCO_3$	mg / l	18.00	0
	Magnesium	*Mg*	mg / l	2.60	0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	2.35	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l	0.20	0
	Sodium	*Na*	mg / l	24.00	0
	Sulphate	SO_4	mg / l	1.87	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the clasification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l	0.10	
	P - Alkalinity	$CaCO_3$	mg / l	10.00	
	M - Alkalinity	*CaCO3*	mg / l	37.00	
	Calcium Hardness	*CaCO3*	mg / l	7.00	
	Magnesium Hardness	*CaCO3*	mg / l	11.00	
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ *as P*	mg / l		

Lusikisiki

Borehole Id	Ndindindi SP 2
Date Sampled	12-Jan-12
Drinking water class	**1**
Sample Number	1077/12

Group	Parameter	Symbol	Unit	Value	Class
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	14.00	0
	Total Dissolved Salts	*TDS*	mg / l	83.00	0
	pH Value	*pH*		5.20	1
	Turbidity		NTU	0.70	1
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l	1.60	0
	Chloride	*Cl*	mg / l	24.00	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.17	0
	Iron	*Fe*	mg / l	0.10	1
	Total Hardness	$CaCO_3$	mg / l	18.00	0
	Magnesium	*Mg*	mg / l	3.40	0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	2.15	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l	1.30	0
	Sodium	*Na*	mg / l	11.00	0
	Sulphate	SO_4	mg / l	0.67	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the classification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l	0.16	
	P - Alkalinity	$CaCO_3$	mg / l	10.00	
	M - Alkalinity	*CaCO3*	mg / l	10.00	
	Calcium Hardness	*CaCO3*	mg / l	4.00	
	Magnesium Hardness	*CaCO3*	mg / l	14.00	
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ as P	mg / l		

Lusikisiki

Borehole Id	Goqwana SP 2
Date Sampled	19-Jan-12
Drinking water class	**2**
Sample Number	1078/12

					Class
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	10.00	0
	Total Dissolved Salts	*TDS*	mg / l	75.00	0
	pH Value	*pH*		6.00	1
	Turbidity		NTU	1.40	2
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l	2.80	0
	Chloride	*Cl*	mg / l	16.00	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.11	0
	Iron	*Fe*	mg / l	0.10	1
	Total Hardness	$CaCO_3$	mg / l	17.00	0
	Magnesium	*Mg*	mg / l	2.40	0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	1.61	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l	0.20	0
	Sodium	*Na*	mg / l	11.00	0
	Sulphate	SO_4	mg / l	0.30	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the clasification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l	0.12	
	P - Alkalinity	$CaCO_3$	mg / l	10.00	
	M - Alkalinity	*CaCO3*	mg / l	10.00	
	Calcium Hardness	*CaCO3*	mg / l	7.00	
	Magnesium Hardness	*CaCO3*	mg / l	10.00	
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ *as P*	mg / l		

Lusikisiki

Borehole Id	Kwarmole SP 1
Date Sampled	13-Jan-12
Drinking water class	**1**
Sample Number	1079/12

Group	Property	Symbol	Unit	Value	Class
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	10.00	0
	Total Dissolved Salts	*TDS*	mg / l	48.00	0
	pH Value	*pH*		5.10	1
	Turbidity		NTU	0.60	1
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l	1.20	0
	Chloride	*Cl*	mg / l	21.00	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.14	0
	Iron	*Fe*	mg / l	0.10	1
	Total Hardness	$CaCO_3$	mg / l	11.00	0
	Magnesium	*Mg*	mg / l	1.90	0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	0.07	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l	0.30	0
	Sodium	*Na*	mg / l	13.00	0
	Sulphate	SO_4	mg / l	0.30	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the classification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l	0.16	
	P - Alkalinity	$CaCO_3$	mg / l	10.00	
	M - Alkalinity	*CaCO3*	mg / l	10.00	
	Calcium Hardness	*CaCO3*	mg / l	3.00	
	Magnesium Hardness	*CaCO3*	mg / l	8.00	
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ *as P*	mg / l		

Lusikisiki

Borehole Id	Manteku SP 1
Date Sampled	10-Jan-12
Drinking water class	**2**
Sample Number	1080/12

Group	Property	Symbol	Unit	Value	Class
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	18.00	0
	Total Dissolved Salts	*TDS*	mg / l	106.00	0
	pH Value	*pH*		6.30	0
	Turbidity		NTU	3.30	2
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l	1.70	0
	Chloride	*Cl*	mg / l	39.00	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.20	0
	Iron	*Fe*	mg / l	0.10	1
	Total Hardness	$CaCO_3$	mg / l	16.00	0
	Magnesium	*Mg*	mg / l	2.90	0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	0.31	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l	0.70	0
	Sodium	*Na*	mg / l	23.00	0
	Sulphate	SO_4	mg / l	3.82	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the clasification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l	0.09	
	P - Alkalinity	$CaCO_3$	mg / l	10.00	
	M - Alkalinity	*CaCO3*	mg / l	10.00	
	Calcium Hardness	*CaCO3*	mg / l	4.00	
	Magnesium Hardness	*CaCO3*	mg / l	12.00	
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ as P	mg / l		

Lusikisiki

Borehole Id	Kwabhala SP 1
Date Sampled	19-Jan-12
Drinking water class	**2**
Sample Number	1081/12

Group	Parameter	Symbol	Unit	Value	Class
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	7.00	0
	Total Dissolved Salts	*TDS*	mg / l	47.00	0
	pH Value	*pH*		5.30	1
	Turbidity		NTU	0.20	1
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l	1.60	0
	Chloride	*Cl*	mg / l	12.00	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	1.06	2
	Iron	*Fe*	mg / l	0.09	1
	Total Hardness	$CaCO_3$	mg / l	11.00	0
	Magnesium	*Mg*	mg / l	1.70	0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	1.55	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l	0.20	0
	Sodium	*Na*	mg / l	6.90	0
	Sulphate	SO_4	mg / l	0.30	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the clasification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l	0.11	
	P - Alkalinity	$CaCO_3$	mg / l	10.00	
	M - Alkalinity	*CaCO3*	mg / l	10.00	
	Calcium Hardness	*CaCO3*	mg / l	4.00	
	Magnesium Hardness	*CaCO3*	mg / l	7.00	
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ as P	mg / l		

Lusikisiki

Borehole Id	**Mswakazi SP 1**
Date Sampled	13-Dec-11
Drinking water class	**0**
Sample Number	2011/2036

Group	Parameter	Symbol	Unit	Value	Class
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	44.90	0
	Total Dissolved Salts	*TDS*	mg / l		0
	pH Value	*pH*		8.08	0
	Turbidity		NTU		0
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l		0
	Chloride	*Cl*	mg / l	34.30	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.33	0
	Iron	*Fe*	mg / l	0.01	0
	Total Hardness	$CaCO_3$	mg / l		0
	Magnesium	*Mg*	mg / l		0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	0.01	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l		0
	Sodium	*Na*	mg / l		0
	Sulphate	SO_4	mg / l	10.00	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the classification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l		
	P - Alkalinity	$CaCO_3$	mg / l		
	M - Alkalinity	*CaCO3*	mg / l		
	Calcium Hardness	*CaCO3*	mg / l		
	Magnesium Hardness	*CaCO3*	mg / l		
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ as P	mg / l		

Lusikisiki

Borehole Id	Nkodusweni SP 1
Date Sampled	14-Dec-11
Drinking water class	**0**
Sample Number	2011/2037

Group	Property	Symbol	Unit	Value	*Class*
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	35.60	0
	Total Dissolved Salts	*TDS*	mg / l		0
	pH Value	*pH*		7.47	0
	Turbidity		NTU		0
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l		0
	Chloride	*Cl*	mg / l	35.20	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.10	0
	Iron	*Fe*	mg / l	0.01	0
	Total Hardness	$CaCO_3$	mg / l		0
	Magnesium	*Mg*	mg / l		0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	0.01	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l		0
	Sodium	*Na*	mg / l		0
	Sulphate	SO_4	mg / l	8.00	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the classification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l		
	P - Alkalinity	$CaCO_3$	mg / l		
	M - Alkalinity	*CaCO3*	mg / l		
	Calcium Hardness	*CaCO3*	mg / l		
	Magnesium Hardness	*CaCO3*	mg / l		
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ as P	mg / l		

Lusikisiki

Borehole Id	Mantusini EC-T60-1156
Date Sampled	14-Dec-11
Drinking water class	**0**
Sample Number	2011/2038

Group	Property	Symbol	Unit	Value	Class
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	33.40	0
	Total Dissolved Salts	*TDS*	mg / l		0
	pH Value	*pH*		7.16	0
	Turbidity		NTU		0
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l		0
	Chloride	*Cl*	mg / l	37.00	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.37	0
	Iron	*Fe*	mg / l	0.01	0
	Total Hardness	$CaCO_3$	mg / l		0
	Magnesium	*Mg*	mg / l		0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	0.40	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l		0
	Sodium	*Na*	mg / l		0
	Sulphate	SO_4	mg / l	12.00	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the classification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l		
	P - Alkalinity	$CaCO_3$	mg / l		
	M - Alkalinity	*CaCO3*	mg / l		
	Calcium Hardness	*CaCO3*	mg / l		
	Magnesium Hardness	*CaCO3*	mg / l		
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ as P	mg / l		

Lusikisiki

Borehole Id	Matane SP 2
Date Sampled	20-Dec-11
Drinking water class	**2**
Sample Number	2011/2039

	Parameter	Symbol	Unit	Value	*Class*
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	112.40	1
	Total Dissolved Salts	*TDS*	mg / l		0
	pH Value	*pH*		6.96	0
	Turbidity		NTU		0
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l		0
	Chloride	*Cl*	mg / l	228.00	2
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.20	0
	Iron	*Fe*	mg / l	0.01	0
	Total Hardness	$CaCO_3$	mg / l		0
	Magnesium	*Mg*	mg / l		0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	0.05	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l		0
	Sodium	*Na*	mg / l		0
	Sulphate	SO_4	mg / l	5.00	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the clasification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l		
	P - Alkalinity	$CaCO_3$	mg / l		
	M - Alkalinity	*CaCO3*	mg / l		
	Calcium Hardness	*CaCO3*	mg / l		
	Magnesium Hardness	*CaCO3*	mg / l		
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ as P	mg / l		

Lusikisiki

Borehole Id	Ndayini SP 2
Date Sampled	15-Dec-11
Drinking water class	**2**
Sample Number	2011/2040

Group	Parameter	Symbol	Unit	Value	*Class*
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	31.30	0
	Total Dissolved Salts	*TDS*	mg / l		0
	pH Value	*pH*		6.26	0
	Turbidity		NTU		0
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l		0
	Chloride	*Cl*	mg / l	37.00	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.01	0
	Iron	*Fe*	mg / l	0.92	2
	Total Hardness	$CaCO_3$	mg / l		0
	Magnesium	*Mg*	mg / l		0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	1.91	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l		0
	Sodium	*Na*	mg / l		0
	Sulphate	SO_4	mg / l	10.00	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the clasification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l		
	P - Alkalinity	$CaCO_3$	mg / l		
	M - Alkalinity	*CaCO3*	mg / l		
	Calcium Hardness	*CaCO3*	mg / l		
	Magnesium Hardness	*CaCO3*	mg / l		
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ as P	mg / l		

Lusikisiki

Borehole Id	Matombe SP 3
Date Sampled	20-Dec-11
Drinking water class	**1**
Sample Number	2011/2041

					Class
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	40.70	0
	Total Dissolved Salts	*TDS*	mg / l		0
	pH Value	*pH*		6.42	0
	Turbidity		NTU		0
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l		0
	Chloride	*Cl*	mg / l	56.50	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.01	0
	Iron	*Fe*	mg / l	0.15	1
	Total Hardness	$CaCO_3$	mg / l		0
	Magnesium	*Mg*	mg / l		0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	5.81	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l		0
	Sodium	*Na*	mg / l		0
	Sulphate	SO_4	mg / l	8.00	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the clasification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l		
	P - Alkalinity	$CaCO_3$	mg / l		
	M - Alkalinity	*CaCO3*	mg / l		
	Calcium Hardness	*CaCO3*	mg / l		
	Magnesium Hardness	*CaCO3*	mg / l		
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ *as P*	mg / l		

Lusikisiki

Borehole Id	Sandlulube EC-T60-1159
Date Sampled	16-Dec-11
Drinking water class	**2**
Sample Number	2011/2042

Group	Parameter	Symbol	Unit	Value	*Class*
Micro-biological properties	**Viable organisms**				0
	Faecal coliforms				0
	Total coliforms				0
Physical Properties	**Electrical Conductivity**	*EC*	mS / m	19.10	0
	Total Dissolved Salts	*TDS*	mg / l		0
	pH Value	*pH*		6.76	0
	Turbidity		NTU		0
Chemical properties	**Arsenic**	*As*	mg / l		0
	Cadmium	*Cd*	mg / l		0
	Calcium	*Ca*	mg / l		0
	Chloride	*Cl*	mg / l	23.10	0
	Copper	*Cu*	mg / l		0
	Fluoride	*F*	mg / l	0.12	0
	Iron	*Fe*	mg / l	0.75	2
	Total Hardness	$CaCO_3$	mg / l		0
	Magnesium	*Mg*	mg / l		0
	Manganese	*Mn*	mg / l		0
	Nitrate	*N*	mg / l	2.24	0
	Nitrate	NO_3	mg / l		0
	Potassium	*K*	mg / l		0
	Sodium	*Na*	mg / l		0
	Sulphate	SO_4	mg / l	12.00	0
	Zinc	*Zn*	mg / l		0
Chemical properties (not required for the classification of domestic drinking water supply)	**Ammonia**	NH_4	mg / l		
	P - Alkalinity	$CaCO_3$	mg / l		
	M - Alkalinity	*CaCO3*	mg / l		
	Calcium Hardness	*CaCO3*	mg / l		
	Magnesium Hardness	*CaCO3*	mg / l		
	Carbonate	*CaCO3*	mg / l		
	Bicarbonate	HCO_3	mg / l		
	Silica	*Si*	mg / l		
	Phosphor	$P0_4$ as P	mg / l		