uMgungundlovu District Municipality Environmental Management Framework: Water Yield

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[1] Project deliverables (including electronic copies) comprise *inter alia:* reports, maps, assessment and monitoring data, ESRI ArcView shapefiles, and photographs.

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1. INTRODUCTION

The uMngeni River system, which includes contributing tributaries and inter-basin transfers, forms a strategically important catchment that supplies water to a series of water supply dams, namely Midmar, Albert Falls, Nagle and Inanda Dams. The water supplied from these dams is essential for socio-economic development within the Pietermaritzburg-Durban development node – the second most important economic complex in South Africa after Gauteng. Due to the high water demands from these nodes, the uMngeni River catchment is no longer able to meet demands at reasonable levels of assurance. In order to supplement the shortfalls in water supply, the uMngeni catchment now receives water via an inter-basin transfer from the adjacent Mooi River catchment to the north (WRC, 2002). Spring Grove Dam has been developed purposefully to capture water from the upper Mooi River system. Water from Spring Grove is then pumped across into the uMngeni catchment. Both the Mooi and uMngeni catchments are 'closed' catchments, no longer open to streamflow reduction activities such as afforestation, expansion of irrigated agriculture or the construction of storage dams (Umgeni Water, 2011). Additional inter-basin transfers via the Mkhomazi River are now planned to account for future projections in water supply and demand.

The major water supply dams of the greater uMngeni catchment are without a doubt essential for providing water to the Pietermaritzburg-Durban node. However, a recent realisation is that the source of the water supply issue is largely embedded in the natural ecosystems that form the foundation of water provision within catchments (Jewitt *et al.*, 2015). The value of ecological infrastructure in supplementing, sustaining and, and even substituting for "built" infrastructure such as dams is now regarded as a key solution for water resource management. Ecological infrastructure is the "naturally functioning ecosystems that produce and deliver valuable services to people", for example healthy mountain catchments, grasslands, rivers, wetlands, corridors of natural habitat (SANBI 2013). Maintaining, or even enhancing, ecological infrastructure is particularly crucial for catchments that generate high water flows.

In light of the above situation, water yield is considered an important component to the overall function of the uMgungundlovu District Municipality (UMDM), and thus forms a key input to the Environmental Management Framework (EMF) process. GroundTruth was appointed by the Institute of Natural Resources (INR) to assess water yield in a manner that can be incorporated input into the EMF for the UMDM. Despite referring the elements of water resources of the District, the UMDM SEA and SEMP does not provide any information that can be used to evaluate and spatially define water yield across the District. Thus, the information contained therein was not considered any further for the development of this EMF.

2. WATER RESOURCES OF THE DISTRICT

The water resources of the uMgungundlovu District comprises a broad network of naturally connected rivers. These rivers are often closely linked to wetlands, and in some cases they are characterised by well-defined channel with a band of riparian habitat along the banks of the channel. The rivers are restricted to catchment areas, which collect and redistribute the water through the landscape. Rivers essentially form the natural conduits that receive water flows from catchment areas, with river flow starting in catchment headwaters and draining through the landscape towards the oceans (i.e. the source to sea concept).

The District is defined by several main catchments, namely the Mooi, uMngeni, Mkomazi, Mvoti, Lovu and Mlazi catchments as illustrated in Figure 2-1. The headwaters of the uMngeni catchment are comprised of mountain streams draining upland farming areas of the KwaZulu-Natal Midlands. A significant feature of the upper uMngeni catchment is the uMngeni Vlei, which produces sustained water flows for the uMngeni River (Figure 2-2). The uMngeni River eventually drains into the major water supply dams, namely Midmar Dam, Albert Falls, Nagle and Inanda Dams. Neighbouring catchments of the Mooi and Mkomazi Rivers receive their flow from headwater catchments of the Drakensberg. The Mooi River system contains two water transfer schemes, i.e. Mearns Weir on as Phase 1 of the Mooi-Mgeni Transfer Scheme, and Spring Grove Dam as Phase 2. Currently, the Mkomazi River system does not contain any major dams, however current water supply planning within the uMngeni River catchment includes plans to construct large dams on the Mkomazi River. These dams would then also contribute water to the uMngeni River catchment as an inter-basin transfer scheme.

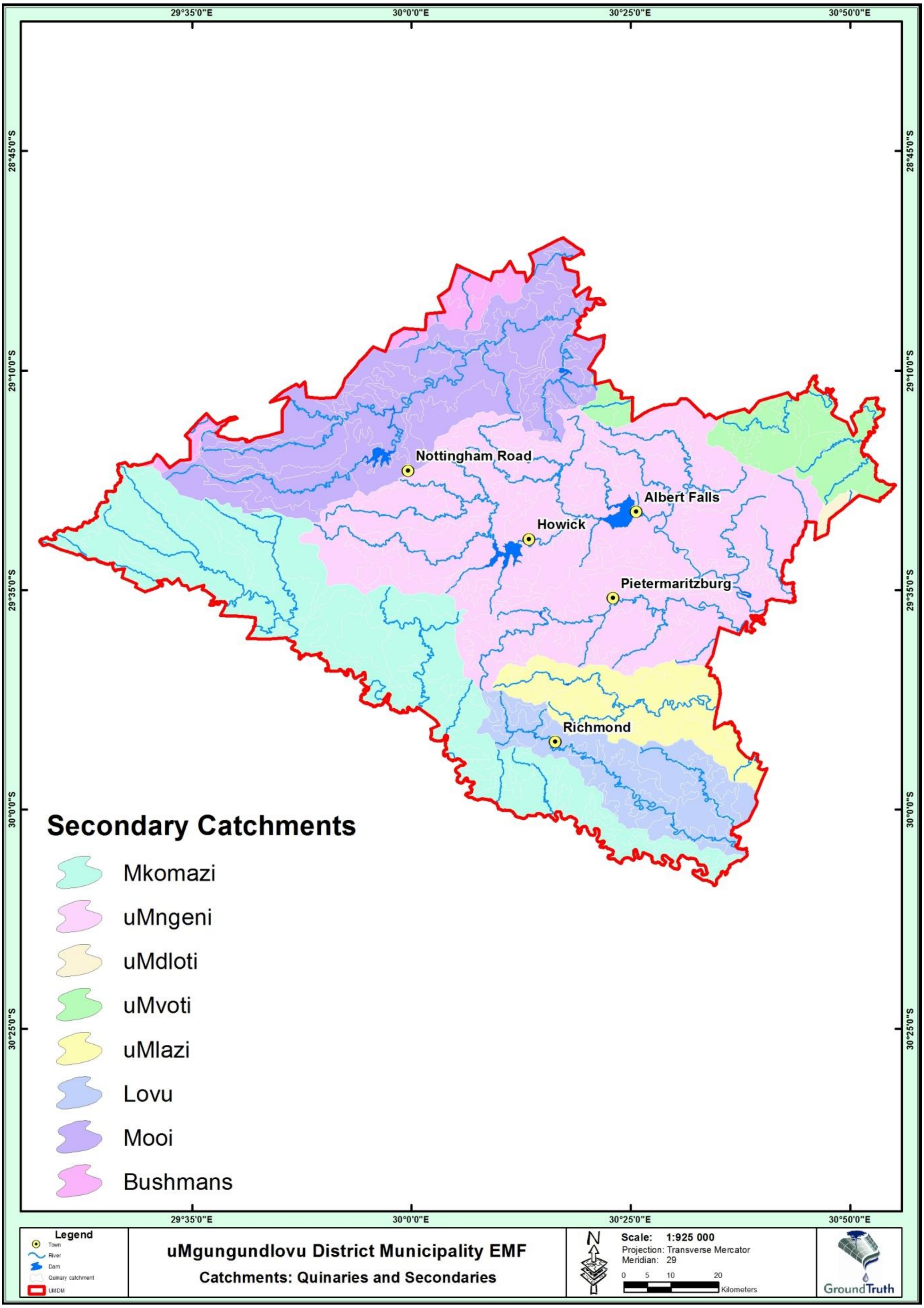

Figure 2-1 Main catchments of the uMgungundlovu District as defined by Secondary Catchments

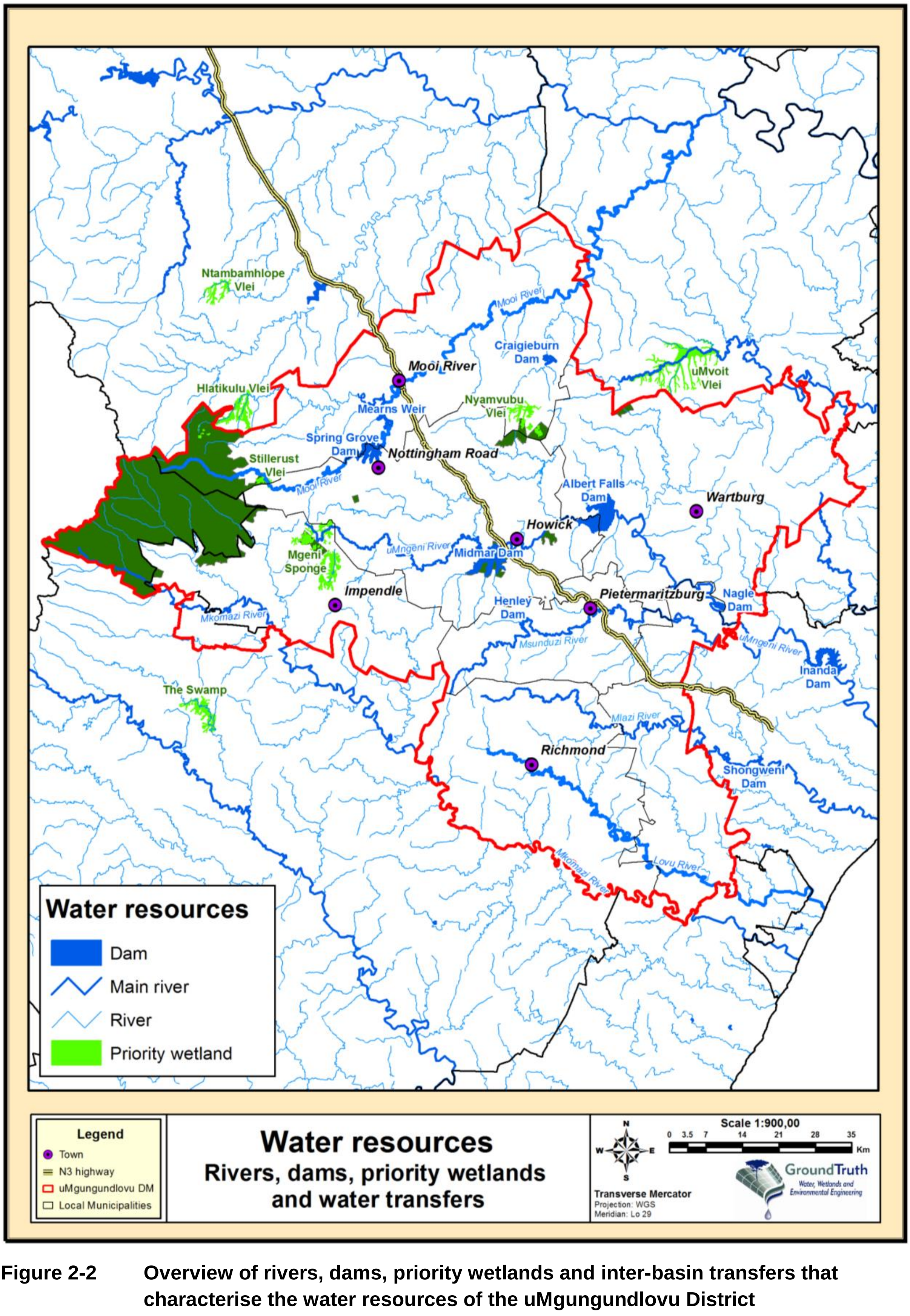

Figure 2-2 **Overview of rivers, dams, priority wetlands and inter-basin transfers that characterise the water resources of the uMgungundlovu District**

3. INPUT INTO THE uMGUNGUNDLOVU DISTRICT EMF

3.1 Hydrological modelling

A detailed, daily time-step hydrological model, which is able to operate at an appropriate spatial scale for the EMF was used. For this purpose, the Agricultural Catchments Research Unit (*ACRU*) model was selected as a suitable tool for simulating water yield from catchments. The *ACRU* model is based on the following concepts (Smithers and Schulze 2004):

- It is a physical conceptual model, i.e. physical processes are represented explicitly, and important processes are simulated;
- *ACRU* is not a parameter fitting or optimising model, i.e. variables (rather than optimised parameter values) are estimated from physically-based characteristics of the catchment;
- The model integrates water budgeting and runoff production components of the terrestrial hydrological system;
- *ACRU* is a daily time-step model which uses daily climate input data.
- The model makes use of daily multi-layer soil water budgeting, and has been developed into a versatile total evaporation model as conceptualised in Figure 3-1.
- *ACRU* is a multi-level model, with multiple options or alternative pathways available in many of its routines, depending on the level of input data available, or the detail of output required.

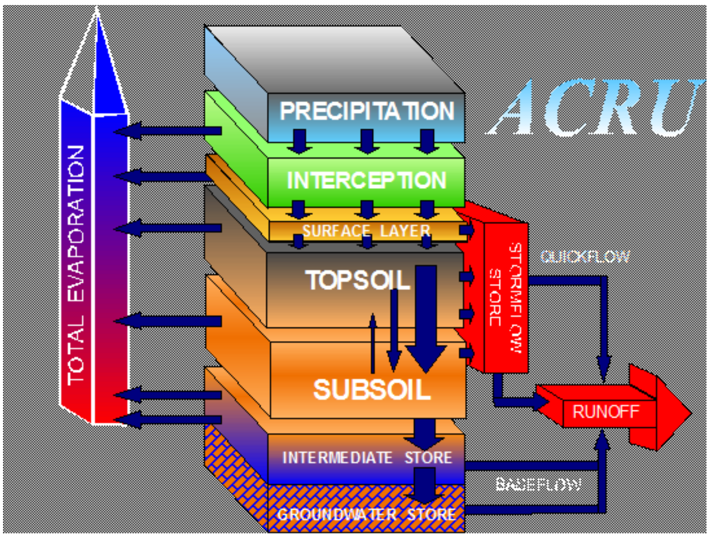

Figure 3-1 Schematic representation of the water budget in the *ACRU* model (Schulze 1995)

The *ACRU* model has already been set up for the uMngeni catchment, which is divided into 145 sub- catchments (Warburton *et al.*, 2010). Each sub-catchment has thus been configured based on soils, altitude, topography, land cover, water management practices and gauging stations within the uMngeni catchment. For this model the 2000 National Land Cover (NLC 2000), together with soils information from Schulze *et al.* (2008). Where no better information was available, default input values obtained from the *ACRU* User Manual (Smithers and Schulze, 2004) was used. A full description of the model set-up is provided in Warburton *et al.* (2010). This configuration of the *ACRU* model was recently updated as part of the Green Fund uMngeni Ecological Infrastructure Project (Jewitt *et al.*, 2015; Hughes *et al*., *In Press*). In this case, the project made use of the more recent land cover data, i.e. the 2011 KwaZulu-Natal Province land cover dataset (EKZNW and GTI, 2013), with refinements made using mapped and ground-truthed data of invasive alien wattle species provided by Umgeni Water (dated 2007).

For other areas of the District that have not been included in the uMngeni model setup (e.g. the Mooi, Mkomazi, Mvoti, etc.), a new modelling process needed to be carried out. For the catchments outside of the uMngeni catchment, the *ACRU* model was setup using the quinary catchments dataset that has been developed for the entire South Africa. The boundaries of quinary catchments have been delineated using an altitude split of quaternary catchments into smaller upper, middle and lower lying areas that represent relatively homogeneous hydrological response zones (Schulze and Horan, 2010; Schulze *et al.*, 2010). Each quinary catchment has been setup using a suite of data and information that includes daily rainfall, daily temperature, daily reference evaporation, land cover and soils (Schulze *et al.*, 2010).

In both instances the *ACRU* model was run using historical climate data from 1961 to 1999 (Lynch, 2004). This is the most comprehensive database readily available for the country, and sufficiently representative of the catchment's climate, covering significant periods of flood and drought. The model was run separately for each sub-catchment, and the output results analysed. Key components of the river flow regime that were considered for further analysis in order to quantify and map water supply/yield. These include:

- ***Annual streamflow –*** representing the provision of water throughout the year for domestic, industrial, ecological and recreational use. This is essentially the total volume of water yielded by a catchment (also referred to as water supply); and
- ***Dry-season baseflow –*** an important flow component that represents water supply that is maintained by during the dry-season, running from August to October.

Results for streamflow and dry-season baseflow were generated as a depth of water in millimetres for the entire catchment (i.e. quinary and sub-catchments). This allows for uniformity in terms of comparing water yield values between the different catchments within the District. Annual streamflow and dry-season baseflow values where then categorised using ranked quantile values, ranging from 1 to 4 thus represented four categories of water yield from low to very high. The ranked results are illustrated respectively in the following maps for streamflow (Figure 3-2) and dry-season baseflow (Figure 3-3).

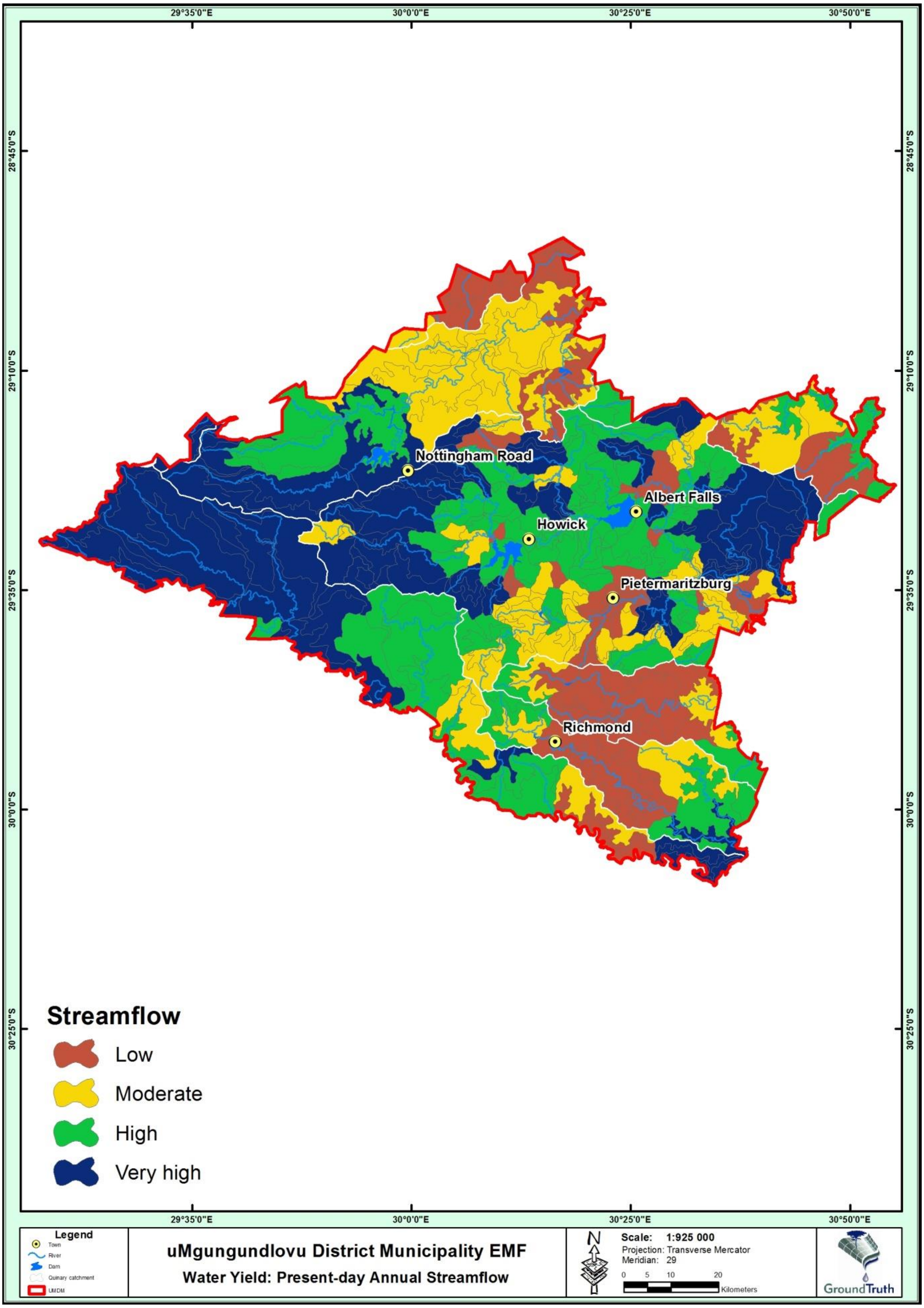

Figure 3-2 **Average annual streamflow (in millimetres) produced from catchments draining the uMgungundlovu District**

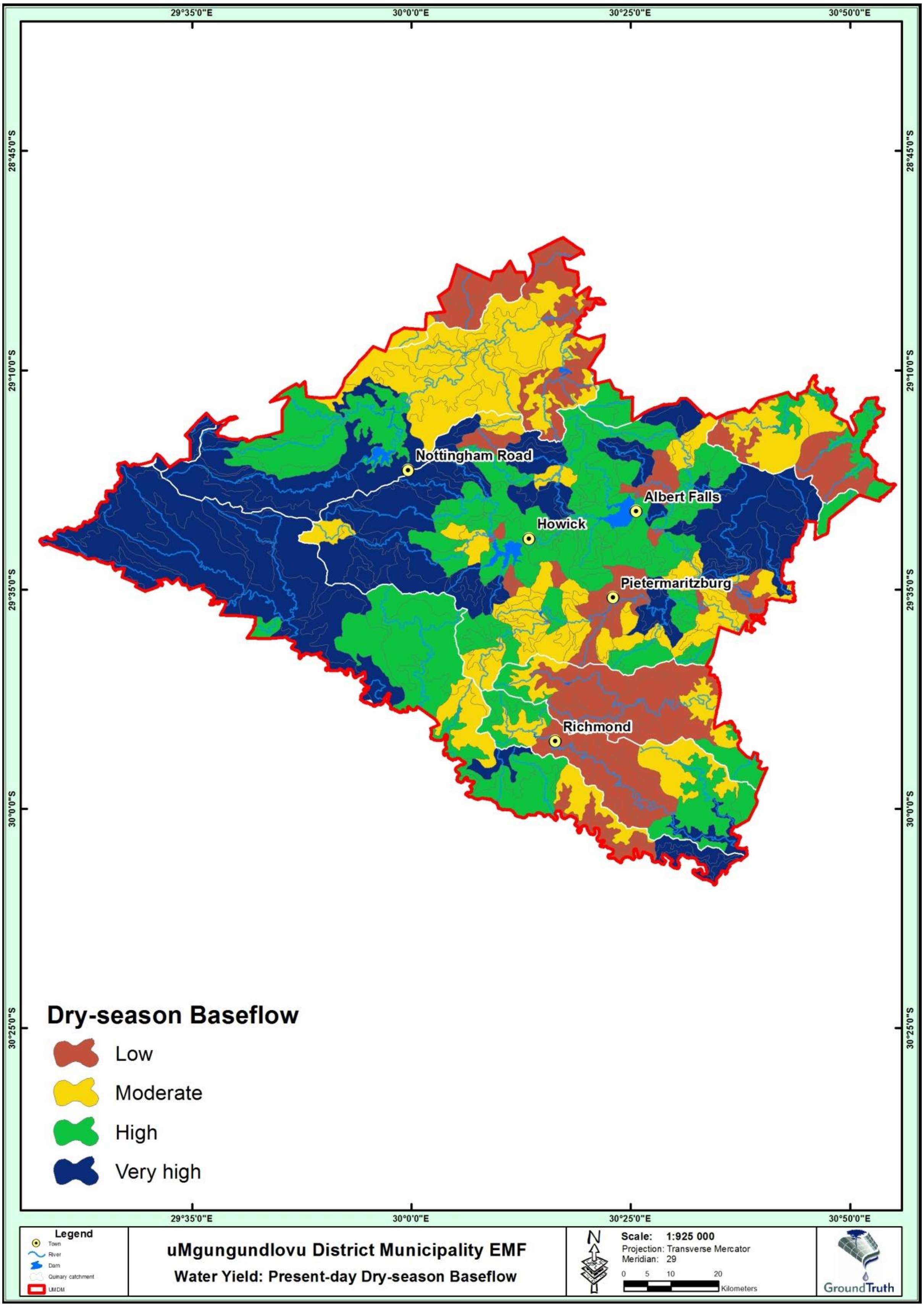

Figure 3-3 **Average dry-season baseflow (in millimetres) produced from catchments draining the uMgungundlovu District**

3.2 Social-ecological considerations of water yield

Additional information was integrated with the “pure” water yield values in order to accommodate the social-ecological importance of water flow within the UMDM. This included the following datasets:

- ***Catchments that supply water to major water supply dams*** **–** Major water supply dams, such as Midmar and Springrove Dams, are important in terms of meeting demands for bulk water supplied to urban areas (e.g. Pietermaritzburg and Durban). These catchments are given a value of 1, representing a higher weighting to account for socio-economic importance of water supply.
- ***Ecological Importance (EI) and Ecological Sensitivity (ES) of aquatic ecosystems*** **–** Available information of Ecological Importance (EI) and Ecological Sensitivity (ES) obtained from the 2014 DWS PES EI ES assessment of rivers throughout South Africa was used to determine the importance and/or sensitivity of catchments. Catchments with a very high/high EI and/or ES are prioritised in terms of maintaining river flows to sustain the ecological requirements of the systems. Catchments with a high/very high EI and/or ES are given a value of 1, representing a higher weighting to account for the aquatic ecological importance of water supply.

3.3 Integrated water yield importance

Four water yield categories were used to represent water yield sensitivity using the summed values of annual streamflow (1 to 4), dry-season baseflow (1 to 4), supply to water supply dams to represent socio-economic importance (0 or 1) and aquatic ecosystem importance/sensitivity (0 or 1). The Jenks Natural Breaks categorisation method was used in ArcGIS to assign the summed/integrated value water yield value for each catchment to one of the following sensitivity classes as shown in Table 3-1. Figure 3-4 illustrates the spatial distribution and extent of the water yield sensitivity zones as they are located within the district.

Table 3-1 Water yield sensitivity categories for the uMgungundlovu District

Sensitivity level	Summed water yield value
Very High Sensitivity	Catchments with a very high water yield value (i.e. combined score greater than and equal to 9)
High Sensitivity	Catchments with a high water yield value (i.e. combined score of 7 and 8)
Medium Sensitivity	Catchments with a moderate water yield value (i.e. combined score of 5 and 6)
Low Sensitivity	Catchments with a low water yield value (i.e. combined score less than and equal to 4)

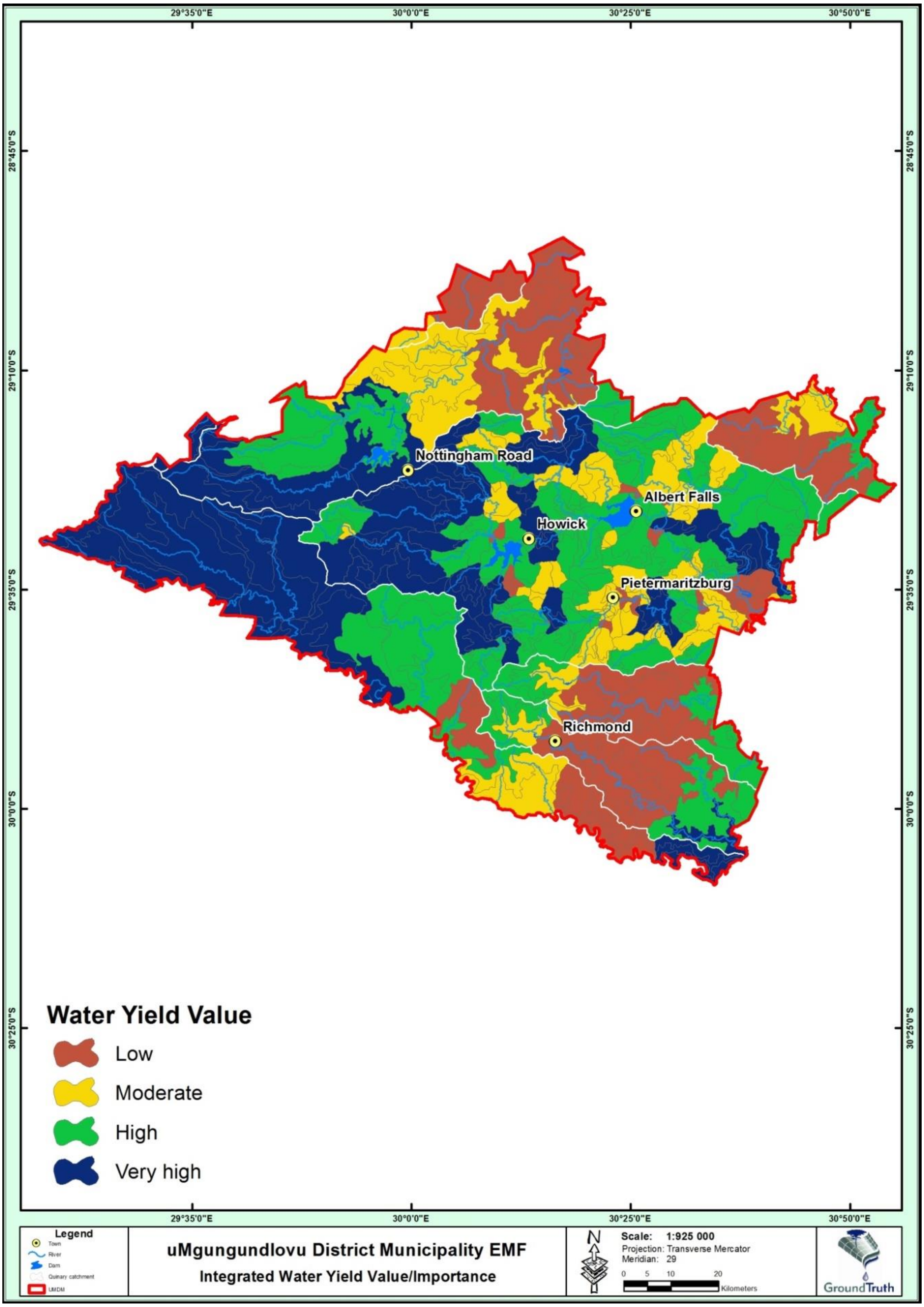

Figure 3-4 **Water yield value for all catchments draining the uMgungundlovu District as an integration of streamflow, dry-season baseflow, socio-economic importance and aquatic ecological importance**

3.4 Constraints, limitations and recommendations

The following constraints and limitations apply to the water yield component of the EMF:

- ***Modelling approach –*** the approach followed is pertinent to assess the degree to which various runoff units are affected by land use, however, with limited abilities to represent the interconnectedness of the catchment systems. The complexity of a physically-based model like *ACRU* has great advantages for assessing hydrology in small catchment networks, with limitations experienced when working with larger, more complex networks of catchments as for the UMDM. These limitations include:
    - The model slows down severely as the input file becomes bigger;
    - The amount of parameters for each runoff units is too large (greater than 70) making it prone to errors;
    - Even though the model is calibrated based on historical data, in the absence of a calibration procedure using more resent data and monitoring, and on the basis that the catchment systems are rapidly changing, the validity of the outputs becomes questionable; and
    - The limited capabilities of the *ACRU* user interface to visualise results makes it difficult to rapidly assess output validity.
- ***Differing model setups –*** two different model setups and configurations were used to simulate water yield using the *ACRU* model. As a result the results could not be compared directly. To account for this discrepancies, the results were analysed separately in order to define water yield thresholds (i.e. low, moderate, high, very high) that are applicable to each of the two broad catchment areas (i.e. uMngeni catchment versus the other catchment areas). Ranked values (from 1 to 4, i.e. low to very high) were then derived for each of the broad areas to allow for an unbiased comparison of water yield for the entire District.
- ***Date of land cover –*** catchment flow response is strongly influenced by land cover and land use. The land cover datasets employed by the two modelling exercises are for different periods of time (i.e. 2000 NLC versus the 2011 KNZLC). Thus is it can be expected that there will be differences in water yield due to differing spatial and temporal scales.
- ***Catchment scales –*** the defined boundaries for the uMngeni sub-catchments and the quinaries covering the other areas did not match up. Thus a process of edge matching (i.e. aligning boundaries between the two different catchment coverages) and cleaning was required in order to display the data in an explicit manner.

As mentioned above, there were several limitations in the modelling approach and in using the model in the context of this EMF. It is assumed that the model may be used as a managing and planning tool in the future. On this basis, the following recommendations are provided to help overcome some of the limitations in the modelling approach.

General recommendations:

- Given the dynamics and uncertainty (e.g. land use, climate, population) of the system modelled, it is important for the model to be flexible with the inputs and outputs, as well as be able to rapidly assess the impact of a multitude of scenarios;
- Stakeholders should be involved in some of the modelling process (e.g. what exists, what should be, what can be) to gain an understanding of the dynamics of the system, and be able to meaningfully contribute to solutions; and
- A simpler model with greater flexibility could benefit the various stakeholders greatly from modeller to local communities.

ACRU **specific improvement recommendations:**

- Improvement of the input system so that input data can be directly extracted from GIS data and formatted to the correct format.
- Improvement of the UI interface so that outputs can be rapidly visualised and compared against each other

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