APPENDIX K

Monitoring Framework

This is an extract from the Ecological and Environmental Task Preliminary Phase Report for the TMG Aquifer Feasibility Study and Pilot Project. The Monitoring Framework comprises Chapter 6 of this report. It should be noted that as of November 2004 this Preliminary Phase report had not been approved by the City.

ENVIRONMENTAL MONITORING FRAMEWORK

1.1 OBJECTIVES OF THE TMGA ENVIRONMENTAL MONITORING PROGRAMME

The TMGA environmental monitoring programme will encompass a wide range of activities aimed at cataloguing, analysing and evaluating *the effects of bulk groundwater abstraction on the environment*. The purpose of which will be to provide the data required to make decisions concerning the acceptability of observed effects and allow for the translation of analytical conclusions into policy recommendations (after Power *et al*. 1995).

Hypothesis testing

Environmental monitoring can be regarded as attempts to test the ***null hypothesis*** *that "a particular set of human actions has no impacts on the environment" in the light of the* ***comparative null hypothesis*** *"what changes should be expected if there is no impact?" (Fairweather 1991; see Section 1.3). Thus optimal ways of detecting human impacts, including the norms of statistical hypothesis testing should be considered when designing a monitoring programme (Fairweather 1991, Power et al. 1995).*

There are two types of error that can occur in hypothesis testing:

- *Type I errors where the null hypothesis is rejected when it is true (false alarm) and;*
- *Type II errors where the null hypothesis is accepted when it is false (failure to detect actual impacts).*

Hypothesis testing commonly allows for easier control for a Type 1 error (i.e., avoid a false alarm) than for a Type II error, and thus favours the "take no action" option. However, avoidance of a Type II error is imperative in terms of the precautionary principle stipulated by NEMA.

Methods for increasing statistical power for a given statistical test (and thereby reducing the chances of a Type II error) include (after Fairweather 1991):

1. *Increase the overall sample size (n).*
2. *Include a longer time series in the monitoring data, i.e., sample for longer and more often.*
3. *Relax the significance level (and so increase the probability of a Type I error as a trade-off).*
4. *Re-evaluate (i.e., increase the effect size to be detected).*

Clearly, many of these methods for increasing statistical power have themselves cost implications, for instance, increasing sample sizes, or the length and frequency of sample collection. Others, however, have implications for the confidence in a particular outcome, for instance, relax the significance level and increasing the chances of 'detecting' an impact that does not occur. Thus, the final programme design will need to seek and establish a balance between providing data at an acceptable level of confidence, and at an acceptable cost.

1.2 A PRELIMINARY FRAMEWORK FOR THE ENVIRONMENTAL MONITORING PROTOCOL FOR THE TMGA PROJECT

1.2.1 Relationship TMGA Project and WRC Ecosystem Project

While the monitoring framework was developed in close co-operation with the WRC Ecosystem Project and part of the monitoring is envisaged to be carried out by the WRC Ecosystem Project, it is necessary to outline the responsibilities of both projects for the environmental monitoring.

In the shorter term, the TMGA environmental monitoring programme is complemented by the activities of the WRC Ecosystems Project, which aims to initiate an assessment of the ecological role of groundwater in the TMG aquifer systems (Brown et al, 2003).

The WRC Project was planned as a 24 month project with 6 months scoping, 12 months fieldwork, and 6 months analysis with the intention of coordinating these activities with the TMGA Project where possible. The project is expected to end mid 2005. The important point is that the TMGA Project must plan to pick up the monitoring at the end of the WRC Project's fieldwork phase – planned to be end of 2004 - unless the WRC Project receives follow-on funding from whatever source to continue monitoring.

The purpose of the WRC Ecosystems Project is largely to understand the link between surface GDEs being monitored and their groundwater sources. The monitoring for the TMGA Project, however, needs to verify whether the abstraction from the deeper aquifer has negative environmental impacts.

> *The following constraints on the responsibilities of the WRC Ecosystems Project must be noted:*
>
> - *The fieldwork and monitoring phase is limited to 12 months.*
> - *The timing of the inputs from the TMGA project on the selection of TSAs might result in the sites utilised by the WRC Project not correlating exactly with the final selection by the TMGA Project.*
> - *The budget for the WRC Project will constrain the number of sites at which monitoring can be undertaken.*
> - *The project has no designated budget for drilling monitoring boreholes. However, DWAF has indicated to provide limited funding for drilling shallow and medium-depth boreholes.*

1.2.2 Underlying concepts

The framework for the Environmental Monitoring Protocol has been developed in line with an understanding of the physical geometry of the Peninsula Aquifer, the details of which are provided in the Hydrogeological Task. A schematic of the generic geological structure expected in most of the Target Site Areas (TSAs) is provided in **Figure 1.1**

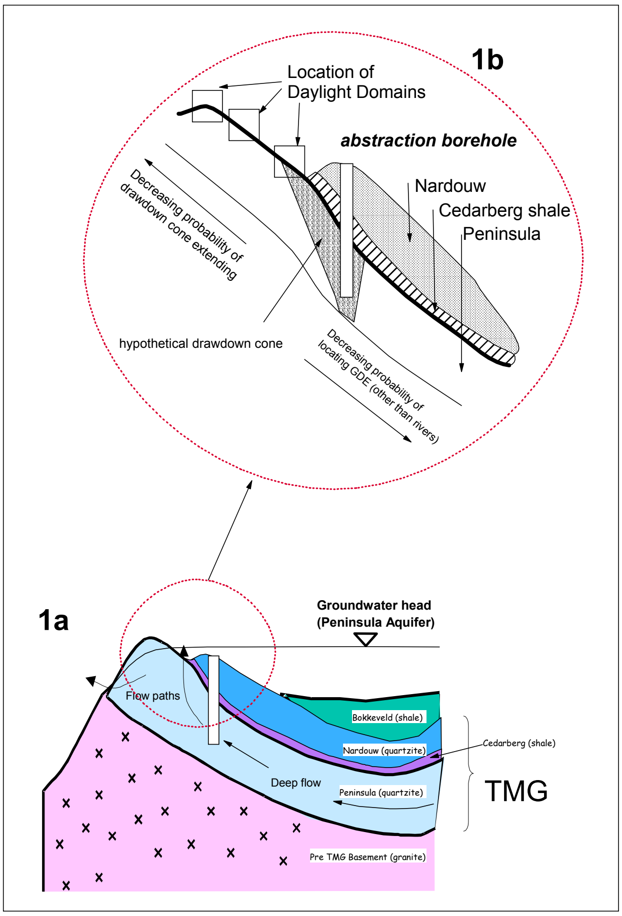

Figure 1.1 Schematic illustrating the relation between flowpaths in the confined Peninsula Aquifer and groundwater discharge areas

It is expected that the cone of depression in the confined Peninsula Aquifer due to abstraction, indicated by a drop of hydraulic pressure, will have measurable impact only on daylight domains upstream of the Cedarberg Shale band, and close by. No direct contact between aquifer and surface water downstream of the Cedarberg Shale band is anticipated due to the confined nature of the system. However, this has to be verified during the monitoring process. The probability of impact decreases with distance from the point of abstraction.

The drawdown affect is likely to be asymmetrical and could manifest itself either along preferred flow paths or within the fracture network, as determined by the orientation and interconnectivity of the geological structures within the Target Site Areas.

The outlined concept and monitoring framework is based on the current knowledge of the selected Target Site Areas and will be amended and refined during further phases of the study. Since the relationship between groundwater abstraction and groundwater dependent ecosystems is still an uncertainty, the monitoring programme has to be flexible, which will be reflected in the time scheduling and spatial distribution of the monitoring activities.

1.2.3 Monitoring locations

The framework envisaged for the TMGA Environmental Monitoring Protocol is outlined in Figure 1.2. The Protocol is divided into activities that will take place in four main locations, viz.:

1. **TMGA Abstraction Sites**, where drilling and abstraction during the TMGA Project will take place (i.e., the final short-list of pilot wellfields).

2. **Daylight Domains**, situated in spring and seep areas that are most probably in hydraulic connection with the TMGA Abstraction Sites.

3. **Interface Sites**, situated at the most downstream end of the catchments in which Daylight Domains are selected.

4. **TMG Aquifer Control Sites**, situated in hydrotects/fracture zones that are not expected to be influenced by drilling or abstraction from the TMGA.

The information gathered at these sites will be used in combination to assess whether or not large-scale abstraction of water from the TMG Aquifer is responsible for any impacts detected during monitoring. The envisaged data collection at each of these sites and the various responsibilities for data collection are outlined in Sections 1.2.4 to 1.2.7. The decision process of relating the monitoring results (effects) in the different sites to the groundwater abstraction (cause) is explained in Section 1.2.8.

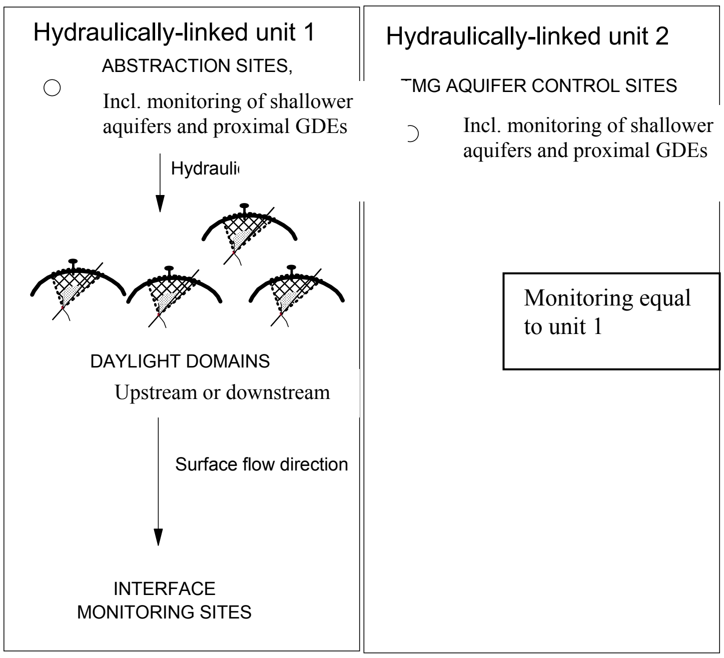

Figure 1.2 Framework for the TMGA Environmental Monitoring Protocol

1.2.4 Abstraction sites

The abstraction sites will be those TSAs that are selected for further exploration and where drilling for abstraction purposes takes place. In addition to the abstraction boreholes itself, which will be drilled into the confined Peninsula Aquifer and will be monitored continuously, several other 'control' monitoring activities are envisaged, *viz.:*

Peninsula aquifer monitoring boreholes

Monitoring boreholes will be drilled into the same aquifer that is being abstracted from by the TMGA Project. These boreholes would be situated along the same fracture system. The water levels in the monitoring boreholes and in the abstraction boreholes will be monitored continuously during abstraction.

Nardouw aquifer(s) monitoring boreholes

Monitoring or control boreholes have to be drilled into aquifer(s) overlying those being abstracted from by the TMGA Project but which are themselves not being abstracted from by the TMGA project (Figure 1.3). It is envisaged that these boreholes would be situated between 500 and 1500 m away from the TMGA abstraction boreholes, depending on the geological settings. Furthermore, monitoring boreholes on both sides of faults in the vicinity might be required.

The water levels in the control boreholes will be monitored continually during Exploratory and Pilot Phase. These are required to identify and verify any hydraulic connection between the two aquifers.

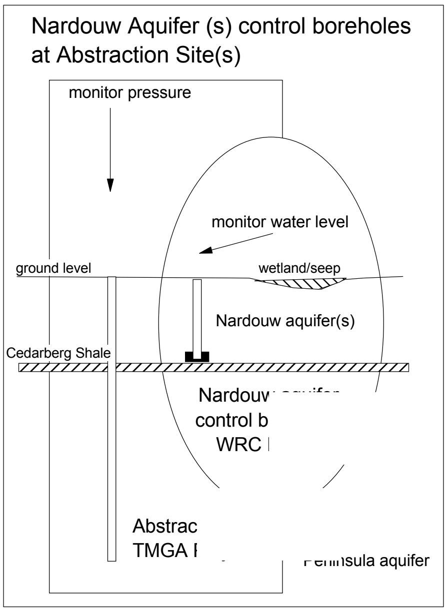

Figure 1.3 Schematic of an Abstraction Site, showing the Nardouw aquifer control boreholes

Wetland or seep monitoring

Wetlands and seeps within an approximately 1500 m radius of the TMGA abstraction boreholes will also be monitored. The following sorts of data will be collected:

- Wetted extent in the dry and wet season.
- Patterns of inundation/wetness.
- Inflow and outflow, if appropriate
- Soil moisture.
- Species structure.

The selection of wetland and or seeps for monitoring and the type of monitoring depend on possible hydraulic connectivity between the abstraction sites and the ecosystem as well as sensitivity, dependency and importance of that ecosystem.

Responsibility for monitoring:

The establishment of all exploration boreholes in the Exploration Phase and the abstraction boreholes in the Pilot Wellfield Phase will be the responsibility of the TMGA Project.

The establishment of all monitoring boreholes and other monitoring infrastructure will be the responsibility of the City of Cape Town and or DWAF, based on the monitoring protocols, which will be developed by the TMGAA during the Exploration Phase.

The monitoring of borehole water levels, wetlands and seeps in the proximity of the abstraction site will be the responsibility of the City of Cape Town and or DWAF, but co-ordinated by the TMGA project.

1.2.5 Daylight domains

Daylight Domains will be confined to perennial systems as these are expected to be dependent on groundwater discharge during the dry season. Domains will be selected on seepage or spring areas associated with perennial tributaries that are (identified by the Hydrogeological Task as being) most probably in hydraulic connection with the boreholes selected in the TSAs in which drilling will take place. The extent of a Daylight Domain will be defined by the point at which diffuse, or point source, discharge of groundwater forms a single, measurable surface channel, suitable for fitment of a V-notch weir (Figure 6.4).

It is envisaged that a combination of measurements of water volume and distribution, chemistry (eg. macro chemistry, trace elements, isotope analysis), biological community structure, and weather patterns (including rainfall & temperature) will be collected at each Daylight Domain. These sites will also be the focus of Detailed Research Projects that may or may not be undertaken as part or follow-up of the WRC Ecosystem Project to further the understanding of the relationship between surface ecosystems and groundwater.

It is likely that the flow and chemistry measured at the V-notch weirs will represent a combination of ground- and surface water contributions. Thus, the areas upstream of the V-notch weirs (i.e., the hatched area in Figure 6.4) are where cause and effect will need to be established in order to determine the relationships between co-dependent variables. Thus the V-notch monitoring points should be situated as close as possible to where spring flow, seepages and local runoff converge, as the contributions to these flows (and the concomitant complications in separating cause and effect) increase exponentially with distance downstream of this point.

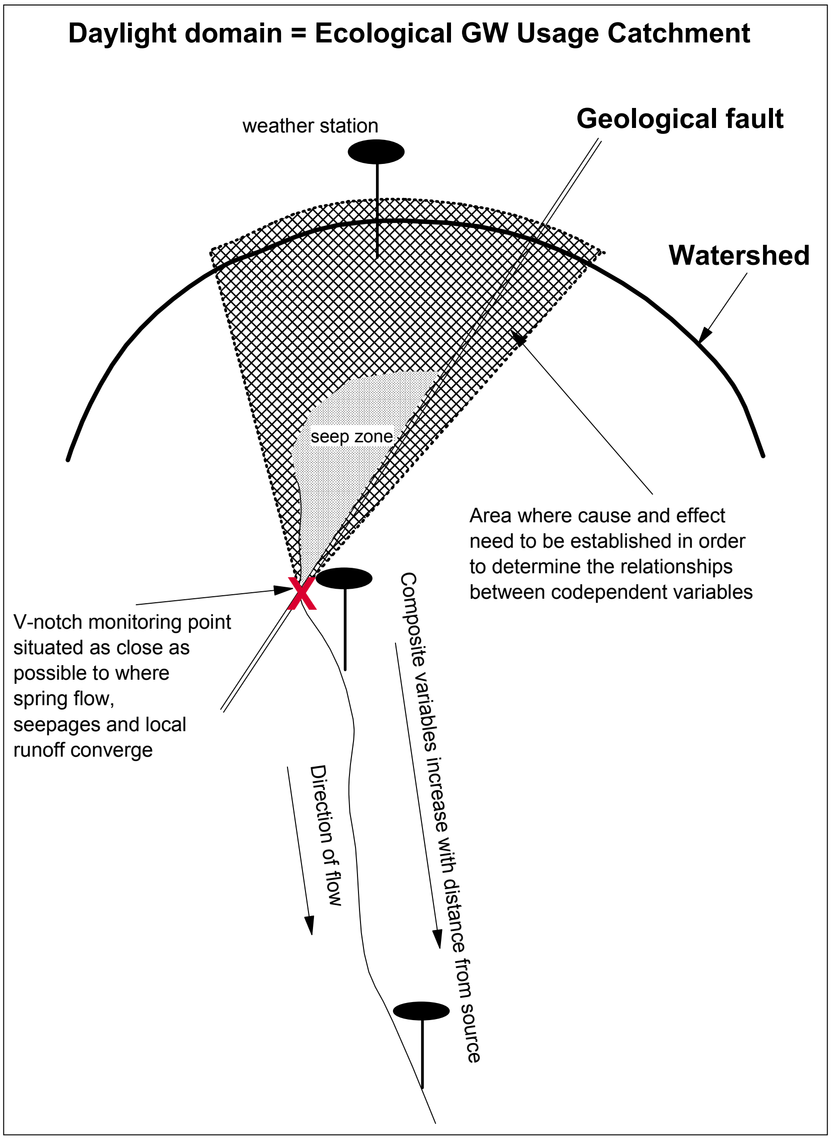

Figure 1.4 Schematic of the Daylight Domains

Selection of Daylight Domains

The seeps, springs, wetlands, and important terrestrial vegetation in the areas most likely to be in hydraulic connection with the boreholes selected in the TSAs in which drilling will take place will be identified and mapped. The initial identification of GDEs linked to the Target Site Areas will be probabilistic, taking into account sensitivity, dependency and importance. Thereafter, they will be grouped according to common characteristics. One or more areas will be selected for monitoring from each of the resultant groups.

The detailed monitoring programme, as well as the temporal and spatial distribution of the monitoring will be developed site specific on the basis of the principle understanding of the hydrological and ecological processes involved. Figure 1.5 gives an overview of the potential GDEs and aspects to be considered.

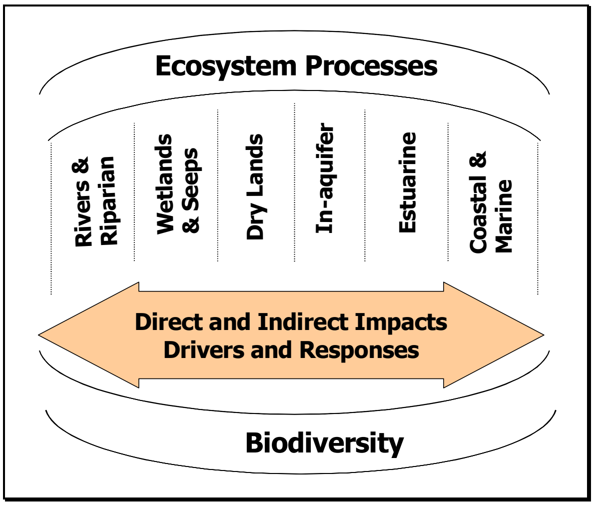

Figure 1.5 Groundwater Dependent Ecosystems (GDEs) and cross-cutting aspects Biodiversity and Ecosystem Processes

Responsibility for monitoring:

The selection of suitable daylight domains and the site specific monitoring requirements will be undertaken by the TMGA project.

The establishment of V-notch weirs, and the weather stations, and the collection of data from these will fall within the ambit of the TMGA Project. However, it is the responsibility of the City of Cape Town and or DWAF to establish the monitoring infrastructure and to undertake the monitoring as and if required by the TMGA Project.

1.2.6 Interface sites

Hydrological data collected at DWAF gauging weirs will be required from the lower reaches of perennial river systems, possible near major confluences, where rivers flow into impoundments or at the head of estuaries. The data collected at these sites will comprise routine DWAF hydrological data, collected at established gauging weirs. These will be used to assess whether there are any catchment level changes correlated with large-scale groundwater abstraction (Figure 1.6).

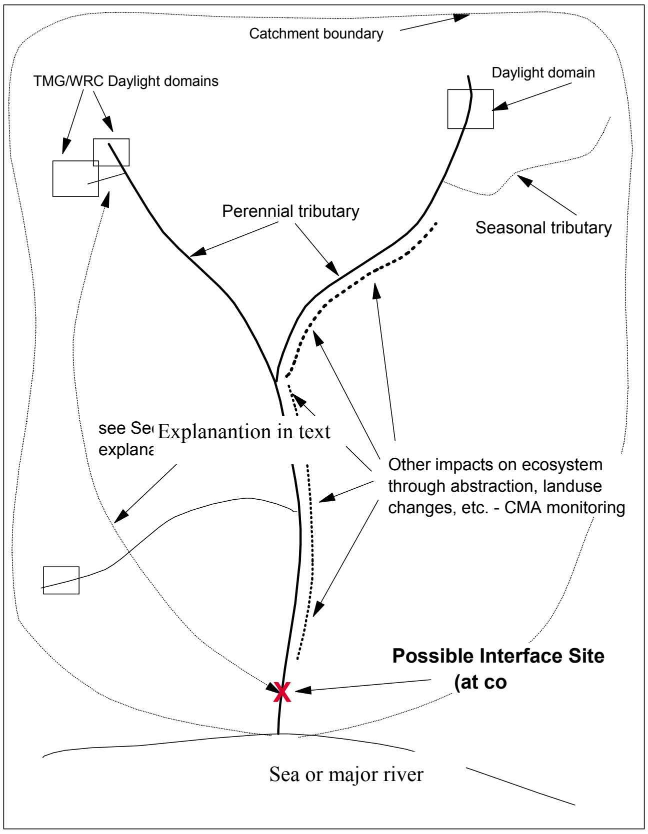

Figure 1.6 Schematic of a perennial river catchment indicating the possible locations of Daylight Domains and Interface Sites

Biophysical data collected as part of the monitoring programmes associated with the Ecological Reserve or the River Health Programme will also be used to assess the significance of reported hydrological changes, if any.

Responsibility for data collection:

The identification of suitable DWAF gauging weirs will be done within the TMGA Project; however, the data collection will be undertaken by DWAF as part of its routine hydrological monitoring.

Selection of Interface Sites

The selection of Interface Sites will be guided by the following criteria:

- Presence of Daylight Domains in the catchment;
- Present Ecological Condition of the ecosystem, which will relate to the sensitivity of the system and the likelihood of detecting change;
- The availability and quality of hydrological records will be important, i.e., presence and accuracy of gauging weirs;
- The Interface Sites will focus on perennial rivers or tributaries.

1.2.7 TMG Aquifer control sites

TMG Aquifer Control Sites will be established on hydrotects/fracture systems that are not connected with the fracture network targeted at the abstraction site and that is not influenced by other abstraction activities. The following boreholes and monitoring sites will be established (Figure 1.7):

- A single borehole in the Peninsula Aquifer of a similar depth to those at the Abstraction Sites (in the order of 300 to about 600 m);
- One or more boreholes in overlying unconfined aquifers; e.g. aquifers in the Nardouw subgroup and or shallow primary aquifers (in the order of 20 to less than 200 m).
- Wetland, seep and or stream flow monitoring sites in the proximity of the boreholes have to be set up, similar to the monitoring at the TMGA abstraction site

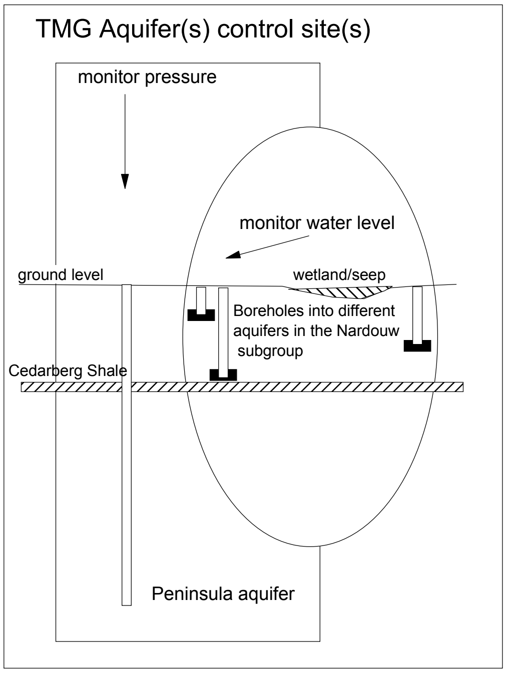

Figure 1.7 Schematic of the TMG Aquifer Control Site

The water levels in these boreholes and the condition of the wetland, seep zone and or stream will be monitored continually from the time that they are first established. The interval and duration of measurement will be decided upon, once the detailed monitoring protocol has been established. The minimum duration of measurement is until the end of the Pilot Phase, assuming the TMGA project continues into the Pilot Phase.

Responsibility for monitoring:

The establishment of TMG Aquifer control sites and the collection of data from these sites will fall within the ambit of both the TMGA Project and the WRC Ecosystems Project, as follows:

The WRC Ecosystems Project undertook a preliminary selection of suitable control sites.

The responsibility for boreholes into the Nardouw and Peninsula will need to be determined at a stage when more information is available.

The WRC Ecosystems Project will establish shallow and medium-depth boreholes in Control Sites selected to meet the objectives of the WRC study.

The establishment and beginning of monitoring of the ecosystems fall within the ambit of the WRC Ecosystem Project. However, the monitoring should continue beyond the time line of the WRC Ecosystem Project.

1.2.8 Decision-tree using the different types of monitoring sites

A flow chart for assessing impacts detected by the TMGA monitoring activities is given in Figure 6.8. The assessment will start at each site, where changes are recorded. However, in order to correctly relate cause and effect, it is required to exclude other possible causes and to check for effects at a level closer to the abstraction site.

Changes detected at Interface Sites

Hydrological and/or biological changes detected at the Interface Sites could arise from any number of upstream uses or abuses of the system, including land use changes, abstraction of surface and groundwater, impoundments, and discharges from urban areas. Such uses of the systems, and control of their impacts on the natural environment, fall under the ambit of catchment management, and the various tools available for assisting with such, e.g., the Ecological Reserve, licensing and control of point source pollution.

Thus, management considerations must be brought into the assessment of the possible cause of any changes detected at the Interface Sites. If these point to large-scale groundwater abstraction, then the monitoring data from the Daylight Domains will need to be evaluated to determine whether or not cause can be attributed to large-scale groundwater abstraction. If no impacts are detected at the Daylight Domains, the inference will be that groundwater abstraction is not having a major effect at the Interface Sites (provided the Daylight Domains are correctly sited).

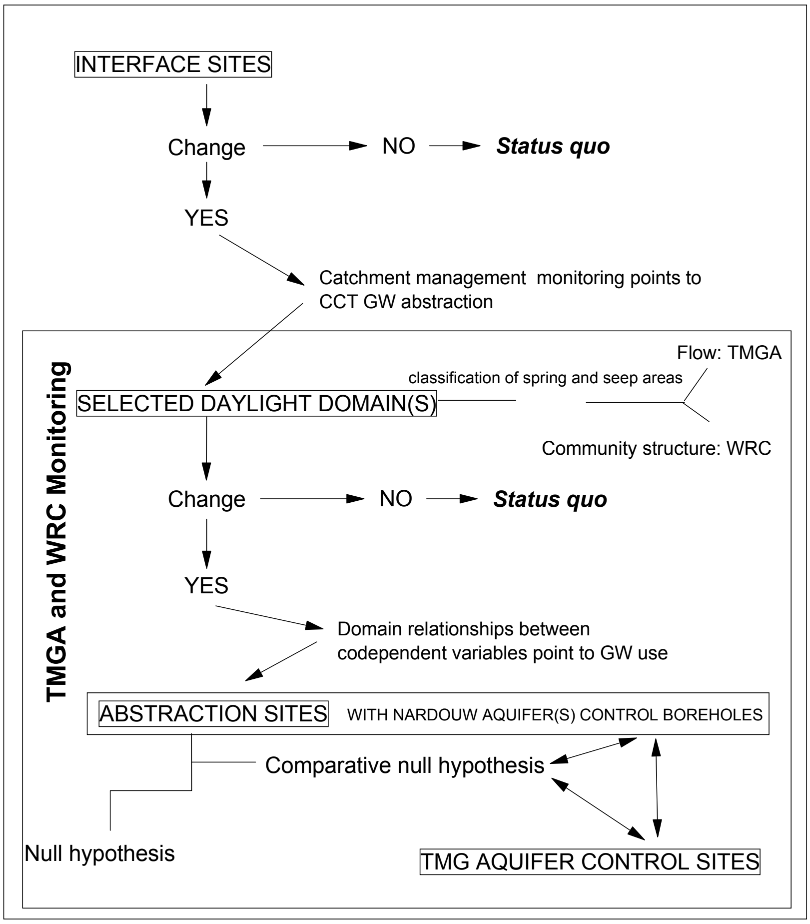

Figure 1.8 Flow chart for assessing impacts detected by the TMGA monitoring activities

Changes detected at Daylight Domains

The cause and effect relationships determining the relationships between co-dependent variables will need to be established for the Daylight Domains in order to assess whether changes in groundwater availability are a result of large-scale groundwater abstraction.

Changes detected in Monitoring and Nardouw Control Boreholes

If the above-mentioned assessment at the daylight domains point towards groundwater abstraction as a possible cause, analysis of the water level records from the monitoring and Nardouw control boreholes can be used to either verify or reject the assumed cause – effect relationship.

Changes detected at TMG Control Sites

In order to distinguish between changes in water level of the monitoring boreholes caused by groundwater abstraction and natural changes, the weather and water level records from the TMGA control site will be analysed.

1.3 THE NULL AND COMPARATIVE NULL HYPOTHESES

The programme aims to approach the problem of monitoring potential impacts from groundwater abstraction through addressing the following null and comparative hypotheses (see also Section 1.3.1):

> ***The Null Hypothesis:***
> *"Large-scale groundwater abstraction from the TMG aquifer will not result in any changes in surface ecosystems outside of the normal variation for those systems".*
>
> ***The Comparative Null Hypothesis:***
> *The comparative null hypothesis is the understanding of changes that form part of the normal variation for the ecosystem under review, both in the short-term, e.g. seasonal, medium term, e.g. 10 year wet and dry cycles, and in the long-term, e.g., climate change, against which data generated by a monitoring programme are assessed.*

Section 1.2.1 above provides an indication of the division of tasks between the TMGA and the WRC TMG Ecosystems Project. Essentially, the activities associated with assessing the **null hypothesis** will fall within the ambit of the TMGA Project, while those associated with developing the **comparative null hypothesis** will be undertaken within the WRC TMG Ecosystems Project.

1.3.1 Developing the comparative null hypothesis

Understanding the natural fluctuations within any ecosystem is essential to successful monitoring. In rivers, for instance, changes in the position and extent of sandbars could be natural shifts well within the long-term norm for a river. Shifts in the species composition of fish communities can occur naturally during dry and wet cycles, around some dynamic equilibrium. Added to this are the compounding effects of global events such as climate change, leading to changes in rainfall regime and hence water supply to aquatic ecosystems (both in terms of volume and distribution). A monitoring programme should be able to distinguish between natural and anthropogenic, flow-related or flow-unrelated change.

The comparative null hypothesis is the understanding of changes that form part of the normal variation for the ecosystem under review, both in the short-term, e.g. seasonal, medium term, e.g. 10 year wet and dry cycles, and in the long-term, e.g., climate change, against which data generated by a monitoring programme are assessed.

The Ecological and Environmental Task Team propose to establish this baseline through:

1. an analysis of the extant long-term data sets, such as rainfall and snowmelt records, temperature, streamflow gauge records, water quality records and possible remote sensing data;
2. a review of previous studies (e.g., New 2002) on, *inter alia*, climate change to assist in building up an understanding of long-term trends and patterns; adherence to a statistically relevant approach.