FEASIBILITY AND IMPLEMENTATION OF GROUNDWATER PROTECTION ZONING IN SOUTH AFRICA

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ABSTRACT

Groundwater protection zoning is a supplemental methodology for groundwater protection that includes land use planning in groundwater management. Long-term protection through the use of protection zones will be balanced by the need for economic and social development by allowing more activities outside the protection zones. Stakeholder involvement is very important in this management process where protection will be implemented to benefit their socio-economic needs.

The delineation of a protection zone is the process that determines the geographical area that should be included in a protection zone program. This area of land is then managed to minimize the potential of groundwater contamination by human activities that occur on the land surface or in the subsurface.

Proper implementation of aquifer protection zoning will ensure water quality benefits in the long term. As a result, the unpolluted water sources will aid in good health of the people, animals and ecosystems. Additional secondary benefits are a healthier workforce and living environment and can add significantly to the economic well-being of the area.

User buy-in and institutional capacity are important components to ensure the successful implementation of aquifer protection zones. The aquifer protection zoning must therefore be combined with user education and institutional capacity and training.

An important benefit of the implementation of aquifer protection zones is that it can be done even with low budgets and little data availability. Monitoring and reassessment of the protection zones will be very important under such conditions.

INTRODUCTION

Even though the constitution of South Africa recognizes the right to a living environment that is not harmful, South Africa still has no policy to implement groundwater resource protection used for drinking water. Polluted groundwater reached national news with an outbreak of gastro-intestinal disease claiming 5 lives in Delmas, South Africa in August 2005. In addition to these lives, approximately 4300 deaths per year in South Africa are associated with contaminated water (Bourne & Coetzee, 1990).

An estimated two thirds of South Africa's population depends on groundwater for their domestic water needs, rendering it a strategic resource to protect for basic water needs. With this many people in South Africa reliant on groundwater as a primary source, there should be no hesitation to implement proper protection measures.

The implementation of an aquifer protection zone is the process of protecting a drinking water source by determining what geographic area should be managed to minimize the potential of groundwater contamination by human activities that occur on the land surface or in the subsurface.

The scientific delineation of these aquifer protection zones is concerned with the protection of drinking water and ecosystems, while striking a balance between controlling pollution and supporting local development. Effective and focused protection can be achieved through a differentiated protection approach such as aquifer protection zoning, where the local importance of aquifers is considered (DWAF, 2000). The communication of the benefits must be to communities, interested groups and policy makers for them to start implementing the protection of water resources on all management levels.

This paper aims to describe the policy implementation steps to protect drinking water and ecosystems for the benefit of people through aquifer protection zoning.

LEGAL FRAMEWORK

The Constitution of the Republic of South Africa (RSA, 1996) states in Section 24 that "Everyone has the right to an environment that is not harmful to their health or well-being". The National Water Act (RSA, 1998) further states in Section 3 that "As the public trustee of the nation's water resources the National Government, acting through the Minister, must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons and in accordance with its constitutional mandate".

In the National Water Act (NWA) (RSA, 1998) water resource management is enforced through a licensing system for different water uses, as defined in Section 21 of the NWA. These water uses all has an impact on the water quality of the resource to some extent. The NWA requires that both source- and resource directed measures are taken into consideration during the issuing of a water use licence.

Aquifer Protection Zoning is a proactive step towards the protection of important water resources and can be implemented through a variety of integrated regulatory actions, which include:

- *Differentiated protection* in Section 26.2 (RSA, 1998) to protect resources with the highest importance. Not all water resources can be protected to the same degree due to financial and human capacity constraints. Through the Reserve concept, drinking water and ecosystems have the highest level of protection in the NWA.
- *Classification* in Section 13.1.a (RSA, 1998) can be applied to the water resources by classifying the flow paths contributing to drinking water or ecosystems as more important than the parts not contributing. This approach will highlight the parts of the resource that are significant in terms of the implementation of the Reserve.
- *Resource Quality Objectives* (RQOs) Section 13.1.b (RSA, 1998) can be applied as the management objectives and can contain the delineated protection zone as well as the limitations for zones. Dinking water and wetland management objectives can be included here.
- *National information systems* in Section 139 & 140 (RSA, 1998) must store and provide data and information on the delineated protection zones for the protection, sustainable use and management of the specific water resources. Monitoring data related to the management of the protection zones must also be stored for the evaluation against management criteria.
- *Source Directed Controls (SDCs)* in Section 27, 28 & 29 (RSA, 1998) spells out considerations, conditions and essential requirements of licences. Source directed control measures will be used to formulate individual license conditions to implement the protection of aquifer protection zones.
- *Regulation or prohibition of land use practices* in Section 19 (RSA, 1998) that may affect groundwater quality. All land use authorisation are however not controlled through the NWA. Land use authorisation and management organisations need to check against the national information systems before approving land use applications. Collaboration with these institutions will be needed to successfully implement protection zoning.

- *Clean-up of contaminated soils and groundwater* in Section 19 & 20 (RSA, 1998) to prevent groundwater contamination.
- *Recovery of cost in* Section 26.4f & 56 (RSA, 1998) including environmental and resource costs, in particular with the polluter pays principle. Water use charges related to protection zones can be used to fund the direct and related costs of water resource management, development and use inside the protection zone. Water use pricing policies must also provide adequate incentives for efficient land and water use in aquifer protection zones.

BENEFITS

Proper implementation of aquifer protection zoning will ensure water quality benefits in the long term As a result, the unpolluted water sources will aid in good health of the people, animals and ecosystems. Additional secondary benefits are a healthier workforce and living environment and can add significantly to the economic benefits.

summarises the various benefits of protection zoning for different stakeholders and institutions.

Table 1 Benefits to various beneficiaries when implementing aquifer protection zones.

Benefit	Beneficiary
Prevent Water quality related Deaths	Water Users, Health Service providers
Protect drinking water and ecosystems to implement the Reserve	Water Management institutions
Prevent pollution and ensuring sustainable use of existing water resources	Water Users, Water Service providers, Water Management Institutions
Purification Cost is minimized when no pollutants reach the borehole.	Water Service providers, Municipalities, Tax payer
Sustainable Natural functioning of ecosystems, Ecosystem goods and services	Water Users, Terrestrial and aquatic ecosystems
Healthy workforce	Water Users, Industry
Recreation is promoted with clean water	Water Users
Property value is maintained	Land Owners

In delineating protection zones, a careful balance between economic benefits and protection needs to be attained. If a large amount of land is placed into the protection zone, the local community may be affected in terms of economic development. Constraints placed on the zones may not allow them the very activities that sustain them economically e.g. agricultural activities. However, if the protection zone established around the water resource is too small, the health of the community could be impacted if water supplies are contaminated.

Because protection zoning inevitably involves land-use decisions, which are outside the jurisdiction of water resources agencies, it crucial to take the appropriate institutions and national, provincial and local levels of government on board.

IMPLEMENTATION OF PROTECTION ZONES

Appropriate legislation is important to ensure the protection of groundwater resources, but is not enough in itself. **Plans, programmes and measures** are required to put legislation into **practice**, which require adequate capacity and resources. Successful protection zone implementation should also include the unique circumstances of local communities.

These plans include assessing the sources of water and setting courses of action to deal with the assessment results. The following steps should be considered when developing a protection zone plan (adapted from Pollution Probe, 2004):

- Involve stakeholders
- Define the aquifer characteristics
- Identify potential threats
- Protection zone delineation
- Database of protection zones
- Monitoring of protection zone status

Involve Stakeholders

Local leaders and members of the water users should be involved early in the process to ensure a successful aquifer protection zone plan. Stakeholders could include municipal, provincial and national government agencies, including but not limited to: ministries of environment, natural resources, agriculture and public health agencies; environmental groups; industry and business representatives; farmers; scientists; planners; engineers; academics and individuals who are interested in or play key roles in the catchment management community.

Groundwater is often the sole source of water when addressing the historical backlog of community water supplies in terms of the Water Services Act (RSA, 1997) under the country's Reconstruction and Development Programme. The DWAF must ensure through their authorisation processes for water use that the health and well-being of people are not compromised (RSA, 1998). User education is important (Powell et al., 1994) in the context of water users associations where stakeholders must be able to recognise risks and be informed and capacitated to manage their water resources for their own benefit.

Aquifer protection zone delineation can focus the resources of management institutions to sustain the most important aquifer contributions to Basic Human Needs and ecological structure and function.

South Africa currently has about 1.95 million households without basic water access (Schreiner, 2007). It is essential to ensure the sustainability of the water resources they are dependant on. Pollution of these resources will make them unavailable for basic water provision, creating an additional challenge to provide them again with water. These clean water supplies effectively contribute to reduction or even eradication of incidents of water borne disease such as cholera.

Implementation of protection zones will prevent harmful contaminants from entering the capture zones of water supply boreholes, and will reduced purification cost saving both the water service providers and water users.

Define the aquifer characteristics

Characterisation of the water supply role and ecosystem dependence of aquifers must be defined in the catchment, including groundwater flow directions, and recharge and discharge areas, to help identify the locations where groundwater is vulnerable to contamination. Information on the cultural and social characteristics of the catchment community should be obtained to better understand the community's needs, and to gather information that will be useful when holding public consultations.

Identify Potential Threats

An inventory of the potential threats to the catchments long-term sustainability needs to be maintained. This must include potential point and non-point sources of contamination as well as activities that impact water quantity, such as urban development.

Contamination of groundwater sources has been observed world-wide, and it is becoming self-evident that concentrated human activity will lead to even more groundwater contamination. Groundwater studies in several African countries show that the contamination of water-supply aquifers is mainly due to the improper placement of land-based activities such as agriculture, industries, waste disposal (Banoeng-Yakubo et al., 2006; Boukari et al., 2006; Nkhuwa, 2006; Usher et al., 2004) and excreta disposal (Nkhuwa, 2006; Deme et al., 2006; Vogel et al., 2006). In Zambia and Ethiopia the presence of human in the aquifer recharge areas have contaminated groundwater with serious public health implications and risks for users in the future (Nkhuwa, 2006; Alemayehu et al., 2006).

Contamination of drinking water occurs when all three the following components exist;

- A potential source of contamination,
- A pathway to an underlying aquifer and
- A potential user of the water.

Groundwater protection zoning is based on the identification and understanding of groundwater flow paths from recharge areas towards potential users.

The potential threats can be ranked according to their degree of risk in impairing water sources. areas in which water sources are vulnerable to these threats can now be identified. Decision makers can use this information to prioritize and decide which threats need to be managed most immediately to prevent, reduce or eliminate risks to water sources.

The link between human health and water quality is recognised world wide (WHO, 2006) with local South African drinking water standards available (DWAF, 1996) to prevent water related sickness. Many employers across all industry sectors recognise the benefits of a healthy workforce as it has a clear impact on their business - in areas including productivity, motivation, absence management and staff retention (Greaves, 2007).

The protection of wetlands and other ecosystems can be managed relative to their importance for ecologic and human use (EPA Australia, 2005). Wetlands do have a purifying effect on contaminated water, but can get damaged due to excessive pollutant loads. Various ecosystem goods and services will be lost, impacting directly on the communities dependant on them.

Farmers can be compensated financially when they ensure the natural functioning of wetlands and ecosystems (Vermont, 2005). Ecological compensations are measures that will protect and restore ecosystems close to their natural state, in the middle of intensively cultivated landscapes achieving a sustainable soil management (decreasing nitrate and phosphorus), promoting species diversity, strengthening nature within settlements and vivifying the landscape (Vermont, 2005).

Protection zone delineation

Many countries world-wide have implemented borehole protection zones, also called groundwater supply protection areas or wellhead protection zones, with the special focus of protecting domestic water supplies against pollution (Foster et al., 2002).

These borehole protection zones have to protect the groundwater from:

- contaminants that decay with time, where subsurface residence time is the best measure of protection; and
- non-degradable contaminants, where flow path-dependent dilution must be provided

Protection zones are delineated to achieve **different levels of protection**, depending on the distance and type of the pollution source from the drinking water source. The size and shape of the aquifer protection zone depends upon the hydrogeologic characteristics of the aquifer system, and the design and operational characteristics of the borehole(s) used to pump water from the aquifer system.

The size and shape of the borehole protection zone depends upon the hydrogeologic characteristics of the aquifer system and the design and operational characteristics of the well(s) used to pump water from the aquifer system. The goal of borehole protection plans is to protect groundwater within the borehole protection zone by managing the potential risk of contamination that may be posed from potential contaminant sources that are located within the *Zone of Contribution* of the well.

The number of zones defined to cover these functions varies between countries, but is usually from 2-4. The typical zones delineated are shown in Figure 1. The protection achieved by each of these zones are: (Adapted from Jolly and Reynders (1993) and Chave et al. (2005)):

- A *Wellhead Operational Zone* immediately adjacent to the site of the borehole or wellfield to prevent rapid ingress of contaminants or damage to the borehole (also referred to as the ‘Accident Prevention Zone’).
- An *Inner Protection Zone* based on the time expected to be needed for a reduction in pathogen presence to an acceptable level (often referred to as the ‘Microbial Protection Area’).
- An *Outer Protection Zone* based on the time expected to be needed for dilution and effective attenuation of slowly degrading substances to an acceptable level. A further consideration in the delineation of this zone is sometimes also the time needed to identify and implement remedial intervention for persistent contaminants.
- A further, much larger zone sometimes covers the total catchment area of a particular abstraction where all water will eventually reach the abstraction point. This is designed to avoid long term degradation of quality.

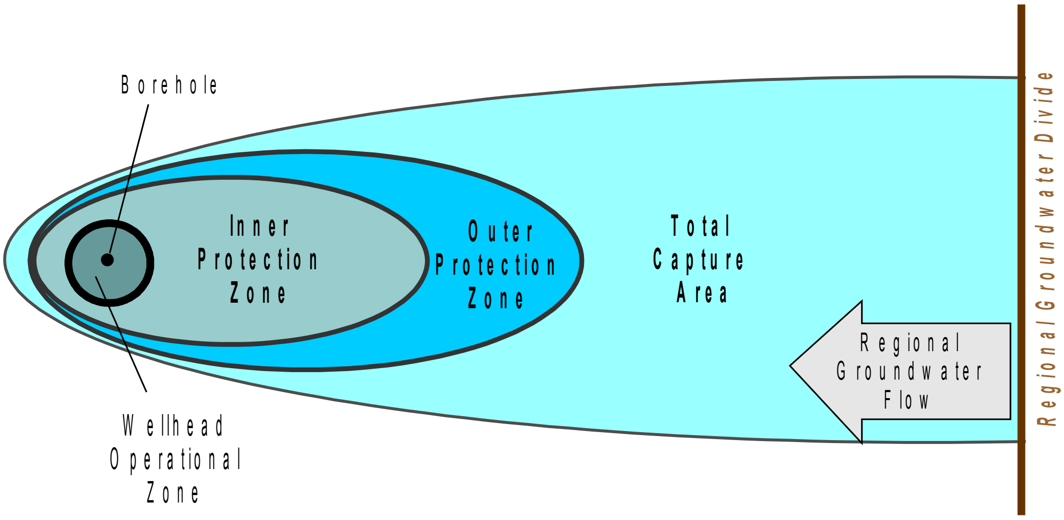

Figure 1 Common protection areas delineated around drinking water supplies.

With each protection zone comes specific land use constraints. These constraints are of increasing strictness moving from the outer protection zone to the wellhead operational zone. By placing some form of regulatory control on activities taking place on land which overlies vulnerable aquifers, their impact on the quality (and in some cases quantity) of the abstracted water can be minimised (US-EPA, 1995). The concept can be applied to currently utilized groundwater and to unused aquifers which might be needed at some time in the future. Table 2 gives a list of land use constraints according to each zone.

Table 2 Land use constraints for protection zones (Jolly and Reynders, 1993; Xu and Braune, 1995; Forster *et al.*, 2002).

Zones	Land Use Constraints
Wellhead operational zone	All constraints of inner protection zone and outer protection zone Agriculture Traffic – both pedestrian and automotive
Inner protection zone	All constraints of outer protection zone Informal waste disposal Cattle kraals Sewage sludge Small settlements Pit latrines Mining Fuel storage Cemeteries Workshops Farm stables and sheds Roads and railways Parking lots
Outer protection zone	Hospitals Wastewater and sewage treatment facilities Solid waste sites Feedlots Airports and military facilities Oil refineries

	Chemical plants and nuclear reactors Large informal settlements using pit latrines Storage of hazardous substances underground

No single protection zoning delineation method can be applied or recommended for all aquifers in South Africa. The choice of delineation method depends upon factors such as aquifer type, the perceived level of threat to the aquifer, the size and vulnerability of the population that may be potentially affected, and the economic resources that a community is willing or able to spend (WDEQ, 2001; Massone and Sagua, 2005, Chave et al., 2005). User buy-in and institutional capacity are important components to ensure the successful implementation of aquifer protection zones. The aquifer protection zoning must therefore be combined with user education and institutional capacity and training (Wolosoff & Endreny, 2003).

Database of protection zones

A database of all areas delineated as aquifer protection zones must be established. This is to make sure that special protection is implemented under specific local legislation for the protection of their surface water and groundwater, and/or the conservation of habitats and species directly depending on these waters.

This database of aquifer protection zones must be kept under review and up to date.

Monitoring of protection zone status

An essential component of any groundwater protection programme is water level and -quality monitoring. This is required to assess the initial conditions and to confirm the effectiveness of the protection measures.

A monitoring strategy for an aquifer protection zone is generally designed to perform three functions - source release detection, ambient trend monitoring, and early warning detection (Carter et al., 1987). Verification monitoring is needed to quantify uncertainties in many of the more complex aquifers, especially fractured aquifers (Muldoon. & Bradbury, 2005; Xu and Van Tonder, 2002).

The monitoring within each aquifer protection zone must include (US-EPA, 2004):

1) Monitoring of the chemical composition of the groundwater, including specification of the contributions from human activity.
2) Monitoring of the associated surface systems, including terrestrial ecosystems and bodies of surface water, with which the groundwater body is dynamically linked.
3) Monitoring of the water balance components, which should include water levels, rainfall, discharge and abstraction.

These monitoring programmes should be integrated with local protection measures, as in Water Services Plans, WUA Management Plans, Catchment Management Strategies.

COST BENEFIT FOR PROTECTION ZONING

The economic value of protection of water depends on the user as well as on the use to which it is put (Kemper et al., 2003). Environmental and resource benefits provide indirect economic benefits, while the reduction in purification cost will result in direct savings to users (US-EPA, 1996). The economic benefit of implementing proactive aquifer protection zoning is far less than the cost incurred due to pollution cleanup and purification of drinking water (US-EPA, 1995).

In September 2005 a typhoid and diarrhoea outbreak at Delmas due to contaminated borehole water caused a month long health crises. A total of 3 000 people were diagnosed with diarrhoea, 561 with typhoid infections and 5 deaths occurred according to official figures. The community claims that more than 49 deaths were caused due to the typhoid and diarrhoea (Groenewald & Dibetle, 2005; Masinga, 2005).

A simple time of travel protection zone for the community boreholes could have prevented the typhoid outbreak. The cost of implementing aquifer protection zones for Delmas, should as a minimum need to include public participation, awareness building, user training, scientific delineation, monitoring, sampling and data evaluation. The total capital cost over an arbitrary 10 year management period (5% inflation considered) to implement and manage this protection zone is estimated at R3 million.

The emergency cost incurred to solve the typhoid and diarrhoea outbreak included medical cost, human resources and the trucking in of clean water. The direct investment cost of the outbreak totals R3.2 million without consideration of the loss of income for the sick and deaths. When this cost is considered for the 5 official deaths the economic cost of the contamination event exceeds R9 million.

The economic benefit of preventing contamination for the Delmas case therefore far outweighs the cost of solving and cleaning up the problem after it has happened. Especially sensitive communities like Delmas are a concern, where typhoid and diarrhoea has hit HIV-positive people harder because of their compromised immune systems. This will explain the much higher death rate experienced by the community. Management agencies must take note of the social vulnerability of communities (Cutter et al., 2003) when evaluating environmental and economic effects.

CHALLENGES

There is an immense challenge of trying to narrow the interfaces between science - government processes and science - society processes to achieve national and regional development goals. Institutional and human resource capacity is needed to formulate and implement policy and legislation for sustainable groundwater utilization at all levels (Wolosoff & Endreny, 2003).

The widespread awareness of key stakeholders at all levels about the hydrological and ecosystem function of groundwater and its vulnerability to human impacts is needed to achieve sustainable development of this critical resource. Communities need to be knowledgeable about their drinking water resources to avoid the negative economic impacts that groundwater contamination could cause (Wolosoff & Endreny, 2003).

Due to the linkage between land uses and groundwater contamination (NWQMS, 1995; Usher et al., 2004; Wolosoff & Endreny, 2003) an inventory of land use and potential contamination sources must be compiled and maintained (Alemayehu et al., 2006; Boukari et al., 2006). This data can be used to inform and educate water users and managers about the benefit of implementing aquifer protection zoning.

CONCLUSION

Implementing aquifer protection zoning will benefit users and is feasible in South Africa. This is already a well established protection methodology in developed countries to protect valuable groundwater and surface water resources.

Ecosystem benefits, health benefits to the users and financial savings to the management institutions are some of the benefits of properly implemented protection zoning. These benefits enable the recovery of implementation cost and strengthen the urgency and importance of the implementation of protection zoning. Implementing and management cost of an aquifer protection zone for Delmas over a ten year period is comparable to the health remediation cost for one typhoid outbreak.

Still, zoning measures need local understanding, acceptance and control to be able to be meaningful. Appropriate participation of the key stakeholders and the general public is a requisite for sustainable development of a scarce resource. This is valid particularly for groundwater, because it is invisible and often poorly understood but is very vulnerable to pollution and is often the only source of water for a community.

Resource classification can highlight the significance of aquifers used for drinking water and those where groundwater is also important for aquatic and terrestrial ecosystems. Aquifer protection zoning is feasible in South Africa and can form a complementary protection measure to protect important water resources.

Common principles are needed in order to coordinate efforts to improve the protection of drinking water in terms of quality and quantity. In the same breath, the promotion of sustainable water use to protect aquatic ecosystems, terrestrial ecosystems and wetlands directly depending on these water resources also need to be enforced.

The implementation of protection zones ensures **early action** and stable **long-term planning** of important resources considering the natural time lag in the resource renewal.

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