Hydrology and land use in the Ga-Selati catchment

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Developing markets for watershed protection services and improved livelihoods

Based on evidence from a range of field sites the IIED project, 'Developing markets for watershed services and improved livelihoods' is generating debate on the potential role of markets for watershed services. Under this subset of markets for environmental services, downstream users of water compensate upstream land managers for activities that influence the quantity and quality of downstream water. The project purpose is to increase understanding of the potential role of market mechanisms in promoting the provision of watershed services for improving livelihoods in developing countries.

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Table of contents

Acronyms and abbreviations

CMA	Catchment Management Authority
IIED	International Institute for Environment and Development
NWA	The National Water Act (South Africa)
PES	Payments for Environmental Services
WUA	Water User Association

Executive summary

The Ga-Selati River in north-eastern South Africa has its source in rugged mountain uplands. Descending a steep escarpment, it flows through savanna lowland where it is heavily utilised for irrigated agriculture. The increasing demands for water by agriculture have resulted in less for other downstream users, notably private game farms and tourist activities, as well as limiting the means to dilute polluted water from the large mining operation at Phalaborwa. The river is small by international standards, having an annual flow of only about 9 million m^3/yr or about 290 l/s in the upper catchments. This rises to 43 million m^3/yr or about 4,900 l/s at its midpoint from where it does not gain any further volume. Flow is highly variable because the region, being close to the southern tropic, experiences occasional severe droughts and floods.

The farming practice of directing water through unlined channels at irrigation schemes contributes to the wastage of water. Sixty percent or more of all water abstracted from the Ga-Selati River and its tributaries near the Legalameetse Nature Reserve is probably lost this way. The quality of the existing water distribution infrastructure is also declining. The reduced flows have an impact on the commercial irrigators because they cannot extract the water they want for agricultural production. Downstream, private game reserves want more water flowing through their properties so as to increase the aesthetic experiences of their paying clients and to increase the value of their properties. The expansion of settlements and clearing of land for agriculture are leading to increased erosion, surface sealing, declining vegetation cover, and degradation.

During droughts, the Ga-Selati River is dry for most of its length. At Phalaborwa, where the Ga-Selati River reaches its confluence with the Olifants River, the quality of effluent and runoff from the mine and town is particularly poor. The need for good quality water to dilute the poor quality effluent is immense. South Africa also has international obligations to ensure that water flowing into Mozambique is of an acceptable quality.

Given the existence of increasing competition for water, with the present abstractions from the Ga-Selati River and its associated groundwater entities, the outlook for constant delivery of water is negative. The principal challenge is how this situation is going to be turned around. Payments for environmental services (PES) have been suggested as one possible solution. With this approach, downstream users of water pay upstream communities and occupiers of land to undertake certain activities, or to not do them, with the objective of increasing the downstream supply of water in such a way that the whole system benefits.

There are a number of interventions that will make a difference on the Ga-Selati River system:

1. Reduce water losses in the irrigation schemes by using pipes to convey water from source to field edge.
2. Where night storage dams exist, clean these and line them with a more impervious material.
3. Return excess water that is no utilised by the irrigation schemes to the Ga-Selati River, rather than letting it run to waste as at present.
4. Regulate water abstractions from both river and boreholes, particularly those close to the river.
5. Possibly remove the avocado orchard in the middle of the Legalameetse Nature Reserve ─ it uses water but is probably not financially or economically viable.
6. Remove the eucalypts and acacia species invading the grasslands of the upper mountain watershed.

The impacts of the above interventions have been estimated and are given in Table 1 below. These values illustrate current use and possible water savings that could be achieved in the Selati Irrigation Scheme. These quantities do not include other independent and unregulated irrigators below the scheme. Evaporation from the Ga-Selati River presents a special problem, however. To get water from the upper catchment to Phalaborwa requires that the evaporative demand from the river surface and the riparian zone for the majority of the length of the river be satisfied before excess water is available for downstream use. Table 1 below reflects this increased supply to the evaporative demand in the column detailing New Practise Savings.

Table 1: Baseline or current water use and possible savings if efficiency measures are adopted and land use practices are changed along the upper Ga-Selati River

	Baseline current use (m^3/yr)	**New Practice Savings (m^3/yr)**
Alien vegetation - current - after 10 years	-1,637,760	1,637,760 3,688,000
Legalameetse ‘Avocado Orchard’	-279,840	279,840
Irrigation	-7,144,000	0
Evaporation	-492,750	- 985,500
Wetlands	0	0
Total	**- 9,554,350**	**932,100** **2,982,340**

The payments for environmental services (PES) need not necessarily be in the direct transfer of cash, but might be an investment in better irrigation technology in the upper catchments. Or it may be the funding of a Catchment Resource Management Committee or similar body that endeavours to achieve certain water delivery targets. This approach will only be successful when economic, social, and ecological needs of the whole catchment are met.

Threats to the process of improving the equitable sharing of water in the region are: the increasing population of rural poor in the upper catchments; their demand for land and other natural resources; failure by local and regional authorities to regulate water abstractions from the river and nearby groundwater resources; and failure to conserve the natural resources of the Legalameetse Nature Reserve. The possibility also exists that despite changes in water use practices in the upper catchment, the intended beneficiaries might not receive the additional water they have paid for, which could lead to a withdrawal of funding and therefore failure of the PES approach in this case.

1. Introduction

In regions where there is strong competition for limited water resources, economic activity will be constrained, social benefits reduced, and ecological integrity of river systems challenged. If abundance of water is then necessary for wealth creation, actions that sustain streamflows and reduce waste will add value. This study outlines the competition for water in a river system in north-eastern South Africa that is emblematic of water resource demands and conflicts throughout South Africa.

The Ga-Selati River and its catchment are characterized by the demands for water and land by a large and poor rural population; by intensive irrigated agriculture; by the need for maintenance of river flows through private game reserves and the Kruger National Park for ecological and aesthetic reasons; and for improving the water quality of seepage and runoff from a large mine. The availability of water therefore dominates the whole catchment.

The objective of this study is to suggest ways of achieving a sustainable and equitable use of water through the use of payments for environmental services and through trade-offs. This paper looks at the problem by describing the hydrological setup (water sources, sinks and storages). It then describes the value addition of water by each of the users and the efficiency of use by each user sector. The paper then goes on to describe opportunities for PES, and makes recommendations for possible approaches.

The Ga-Selati catchment at first hand appears to be a quite suitable site for the establishment of PES. It has a profile of relatively wealthy lower catchment water users. These are: the very large mining operation at Phalaborwa, numerous other small mining operations, and private game farms which cater to relatively wealthy local and overseas visitors.

In the mid-upper catchment, commercial farmers (in contrast to subsistence farmers) utilise substantial portions of the water from the Ga-Selati for irrigation purposes. Surrounding these farms are extensive areas of villages inhabited by poor people who have few natural assets and are making increasing demands on the remaining natural resources (grazing, wood, clean water), including utilising a nature reserve in the steep uplands that was originally established to protect the headwaters from human-induced degradation.

2. Background

2.1 Topography and vegetation

The headwaters of the Ga-Selati River are located in the Drakensberg Mountains of Limpopo Province, north-eastern South Africa (longitude 30° 15", latitude 24° 08"). The upper catchment, the chief water resource for the drier plains, is only 3-5% of the total Ga-Selati River catchment area. After a short run of 3-5 km of mountain upland, and dropping 800 m from its roughly 1,600 m origin, the headwater stream exits the montane area onto the lowveld, which is a relatively flat and low-lying savanna (500-600 m above sea level). Thereafter, the river drops another 500 m over the next 90 km to its confluence with the larger Olifants River at the Phalaborwa Mine.

The upper catchments are comparatively moist, with annual rainfalls of more than 1,500 mm/yr, most of which occurs within the summer rainfall season when more than 100mm/month usually falls. Here, the topmost ridges are primarily a *Loudetia simplex – Diheteropogon filifolius* grassland (Midgley et al. 1997) ─ typically hard, unpalatable grasses of open mountain *sourveld* where soils are thin and stony. The term "sourveld" refers to the adaptive response by grasses to high rainfall, the continuous leaching of nutrients, and dry-season fires, to which the plants respond by translocation of nutrients to the root systems during the dry months. The grazing value of these grasslands is therefore very low.

On the steep escarpment slopes there are patches of Afro-montane (or Afro-temperate) forest, analogous to the global Warm Temperate Forest Biome. These evergreen forests are species-rich and occur in small and fragmented patches, primarily in east-facing fire-protected refugia, where the cliffs and rock faces restrict the passage of wildfires. The forests obtain considerable quantities of their moisture from mists that develop around the elevated altitudes during the summer monsoon.

The lower plains, known in South Africa as lowveld, comprise a mixed savanna. This vegetation type is a response to the prevailing climate of high temperatures, relatively low rainfalls, and a long dry season, i.e., there is a high seasonality of rainfall. In southern Africa, savannas have been classified as being arid or relatively humid (Scholes 1997). Arid savanna trees tend to have fine leaves whilst the more humid savanna trees tend to be broad-leaved. These are quite broad classifications and the boundary between them has been defined as an annual rainfall amount of about 600 mm (Huntley and Walker 1985). The lowveld in this region has a rainfall of between 450-600 mm per annum (decreasing eastwards), putting the area on the boundary between the two classifications. During the winter dry season, the broad-leaved trees drop their leaves, particularly in the drier east, adding biomass to the senescent grasses and increasing fuel loads. Fires are therefore a feature of the lowveld savannas during winter.

One of the outstanding features of the riparian zones in the lowveld is the existence of the tree *Breonadia salicina* (common names: Matumi or Mingerhout). This is quite a large tree that can grow to nearly 30 m; mature trees can have a trunk of several metres diameter. It is sensitive to drought and frost and requires specific conditions of exposed rock surfaces for recruitment, where young trees exploit cracks in the rocks to get their roots into the water but are protected from competition by the rock surface. These trees have been used as an indicator species for the state of a riparian zone in the Kruger National Park, particularly with regard to the rate of sedimentation, which prevents recruitment. Their presence in an area is tightly linked with the continuous availability of water.

There are quite a number of large specimens of these species on the banks of the Ga-Selati River and its tributaries in the lower parts of the Legalameetse Nature Reserve. They are particularly evident in the area known as Macheke Springs, indicating the constant presence of water close to the ground surface in the area, as well as the surface expression of this groundwater.

2.2 Invading alien plants

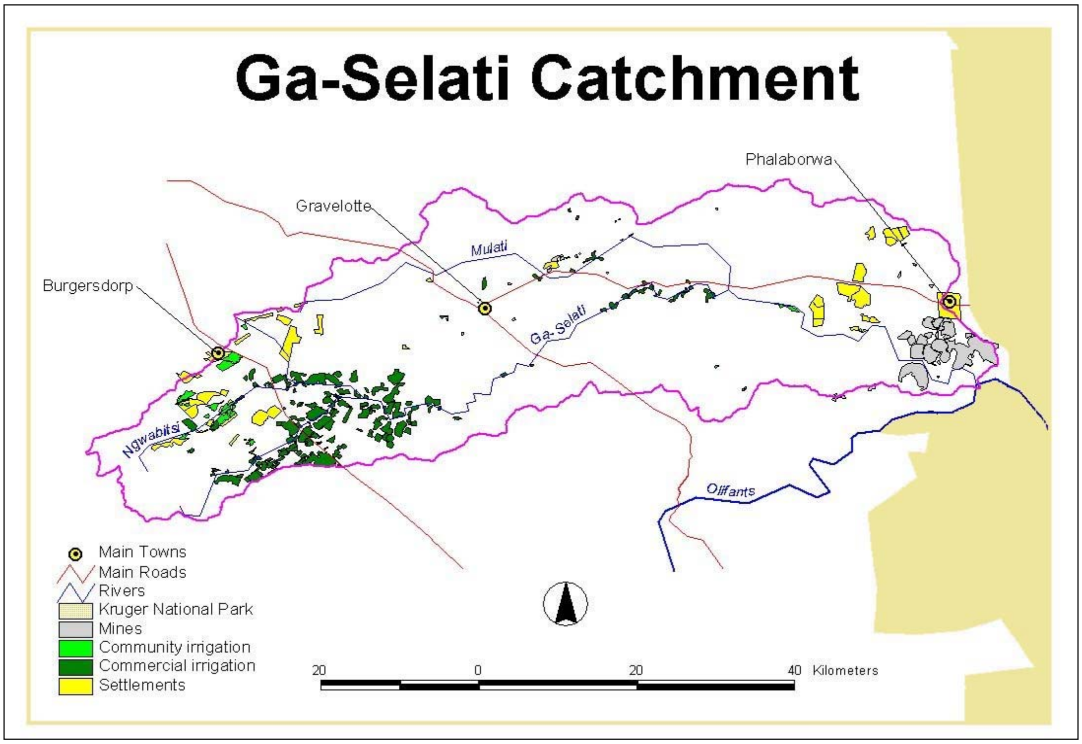
The existence of woody invading alien plants in the Ga-Selati River catchment has implications for local water resources. Exotic acacias and eucalypts are known as prolific water users in the South African context, and use greater amounts of water than those species that they replace (Bosch and Hewlett 1982; Scott et al. 2000).

Both grasslands and indigenous forests have been invaded by a variety of alien plants. The acacia and eucalyptus species are particularly prevalent and are spreading through the catchment headwater grasslands. The spread of invading alien trees in the upper montane grasslands poses a particular threat to the water resources of the whole catchment. Aliens in the Legalameetse Nature Reserve include:

Table 2: Invading alien plants in the Legalameetse Nature Reserve (Source: Working for Water Programme, South Africa)

Tall trees	Medium trees	Shrubs, vines, grasses and reeds
Acacia dealbata, *Acacia decurrens,* *Acacia mearnsii* *Acacia melanoxylon* *Eucalyptus spp.* *Grevillea robusta* *Pinus spp.*	*Cassia didymobotria* *Jacaranda mimosofolia* *Melia azederach* *Psidium guajava*	*Agave americana* *A. sisalana* *Ageratina adenophora* *Arundo donax* *Bambusa fulgaris* *Bauhinia variegate* *Caesalpinia decapetala* *Cardiospermum grandiflorum* *Cereus jamacaru* *Cestrum laevigatum* *Chromolaena odorata* *Lantana camara* *Macfadyena unguiscati* *Passiflora spp* *Ricinus communis* *Rubus cuneifolius* *Solanum mauritanium* *Tithonia diversifolia*

Figure 1: The Ga-Selati River catchment, with towns, settlements, rivers and farming operations utilising irrigation



2.3 Climate and hydrology

The climate of the Ga-Selati River catchment is subtropical, with hot summers during which most of the rainfall occurs. Winters are mild and dry (see Table 3). Rainfall is very variable however, given the area's proximity to the Tropic of Capricorn and the nature of global convection systems over the tropics. 'Natural vegetation has adapted to the extended droughts that are a feature of this region. Successful and sustainable agriculture therefore requires irrigation. Although rain-fed agriculture is practised, farming is particularly difficult without a sustainable supply of water.

Table 3: Climate parameters of the Ga-Selati River catchment

Station	Climate variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tours	Rainfall (mm)	94	125	112	31	13	13	11	15	26	77	100	137
	T. max (°C)	36.1	35.0	35.0	33.4	31.8	29.2	29.0	32.7	35.7	35.1	34.9	36.0
	T. mean (°C)	23.9	23.9	23.0	21.1	18.6	15.9	16.0	17.4	19.4	20.5	21.8	23.3
	T. min (°C)	14.9	14.4	13.2	10.1	6.7	4.0	3.6	4.9	6.7	9.5	11.7	13.2
	RH (minimum)	48	48	51	45	36	33	32	33	36	45	48	51
	A-pan (mm)	221	188	183	145	130	106	121	158	196	211	216	221
Phalaborwa	Rainfall (mm)	97	83	60	30	11	7	7	7	19	42	65	99
	T. max (°C)	38.4	36.8	36.4	35.0	33.3	31.0	30.7	33.7	37.3	38.3	38.1	38.3
	T. mean (°C)	26.3	25.7	24.9	22.7	20.1	17.4	17.4	19.3	21.7	23.1	24.4	25.4
	T. min (°C)	16.8	16.7	15.7	12.1	8.6	6.2	5.7	7.2	9.7	12.0	13.7	15.6
	RH (minimum)	51	52	50	49	42	39	39	41	42	46	50	51
	A-pan (mm)	224	192	187	142	127	102	119	155	194	204	218	218

A consequence of the highly variable rainfall is the equally variable runoff. The Ga-Selati River has two main tributaries, the Ngwabitsi and the Mutali Rivers (see Figure 2). This paper concentrates on the water resources of the Ga-Selati River proper and does not extend to these tributaries. There are several weirs positioned throughout the catchment, with varying periods of flow measurement and quality of data. Graphs of the flow through these weirs are presented in the Figures 3-6. The key feature of the data displayed below is the apparent decline in runoff, with the exception of flow below the Tours Dam (weir B7H010). (This is to be expected because water is released from this dam under a "maintenance-of-flow" policy.) Exceptions occur when there are regional floods ─ flooding occurred in 1958, while a more damaging regional flood occurred in 2000. These flood events are shown at several weirs (B7H002, B7H008, B7H010 and B7H014 – see Figures 3, 4, 5 and 6 below). Extensive damage was caused to infrastructure and property in South Africa and Mozambique during the 2000 event. Apart from these infrequent events, the general trend of flow in the rivers appears to show a strong declining trend.

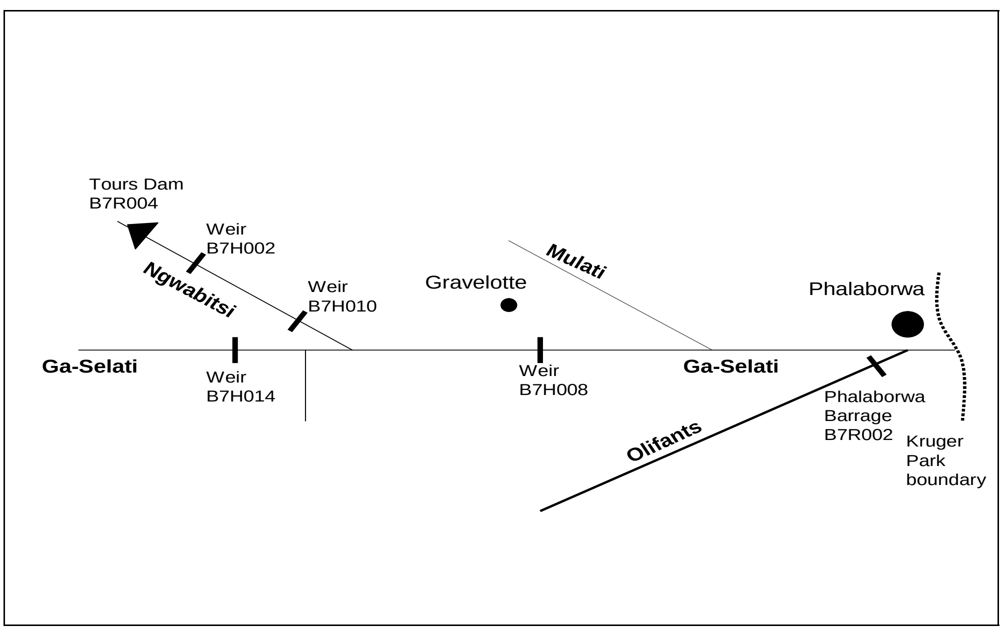


Figure 2: A systems diagram showing the rivers, weirs and towns in the Ga-Selati River catchment

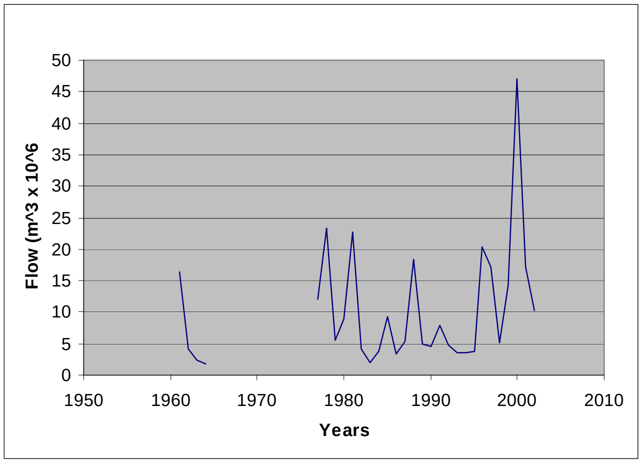


Figure 3: Flows ($m^3 x 10^6$/ yr) in the Ngwabitsi River (weir B7H002) below the Tours Dam

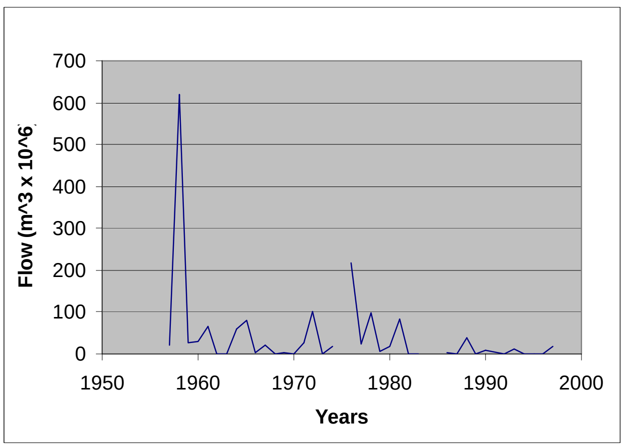


Figure 4: Flows ($m^3 x 10^6$/ yr) at the Mazunga weir (weir B7H008) near the town of Gravelotte

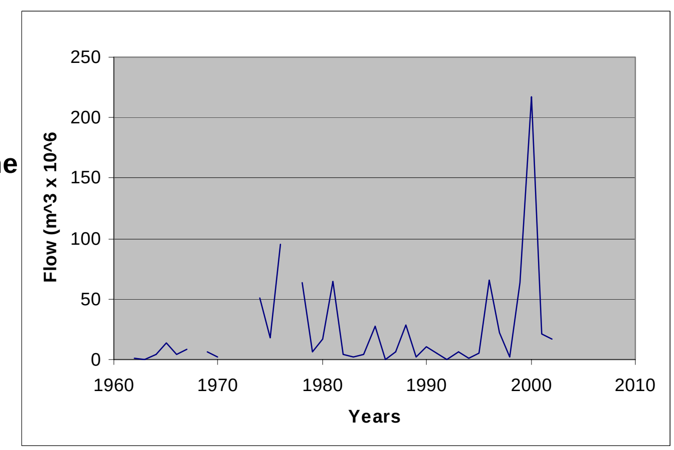


Figure 5: Flows ($m^3 x 10^6$/ yr) in the Ngwabitsi River tributary (weir B7H010) before its confluence with the Ga-Selati

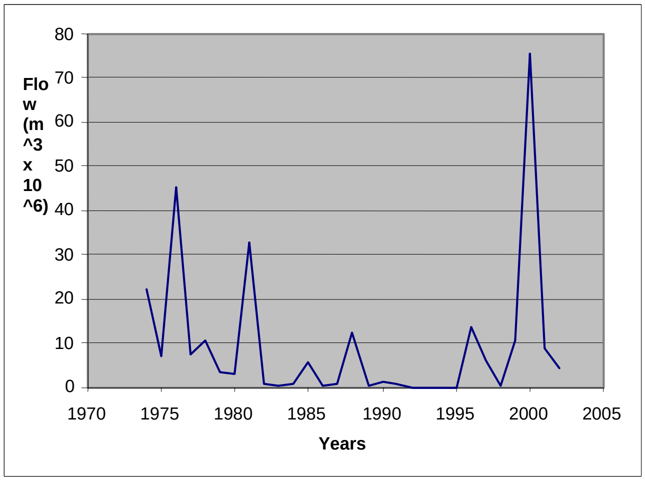


Figure 6: Flows (m^3x 10^6/ yr) in the Ga-Selati River near Calais in the upper Ga-Selati catchment (weir B7H014)

2.4 Geology

The catchment headwaters arise in the Black Reef Quartzites of the 2.2 billion year Wolkberg Group, characterized by its volcano-sedimentary series of rocks. Further east and north of the Ga-Selati River, the area is underlain by the Murchison greenstone belt which contains deposits of antimony and associated gold mineralization. Pegmatites in the adjacent granitoid terrain to the south of the greenstone belt contain a number of commercially important minerals and gemstones, particularly emeralds which are mined at Gravelotte. The central region of the catchment is therefore dotted with small mining operations, many of which are now inactive. The lowest part of the catchment is dominated by the mine at Phalaborwa, situated on a large carbonatite intrusive known as the Phalaborwa Complex, which is mined for its copper, iron, phosphate, uranium and vermiculite. The runoff from this mining operation impacts on the water quality in the lower part of the Ga-Selati River and the Olifants River beyond that point where the Ga-Selati joins it.

2.5 Water quality

Water quality in the upper Ga-Selati River, where it emerges from the steep and afforested escarpment, is high (Palmer et al. 2004). These catchments serve a useful biodiversity conservation purpose by acting as refugia for a number of riverine species that have been severely affected by the heavy water use and decreasing water quality in the lower parts of the catchment. For example, small fish could be observed in the Macheke Springs area, as well as in the sump on the farm on Dindinnie.

Irrigation water is therefore of a high standard. However, where villages and farm lands occur adjacent to the Ga-Selati River, water quality declines. The water becomes more turbid as a result of bank disturbance, nutrient enriched runoff, and possible irrigation return flows. Water quality deteriorates further down the catchment because of the influence of farming operations and settlements. At Phalaborwa, the quality of the water in the Ga-Selati River is poor (Ashton et al. 2001).

2.6 Archaeological and historical background

Early Stone Age (Acheulian) artefacts have been found along the Selati River below the Legalameetse Nature Reserve ─ evidence of both *Homo habilis* and *Homo erectus* presence in the region. San peoples (Bushmen) lived in the area before the arrival of the Bantu in the region about 2,000 years ago (van Wyk-Rowe 1993). The Bantu brought with them smelting technologies, as well as agriculture and pastoralism. They mined iron and copper at present-day Phalaborwa throughout these millennia (van Wyk-Rowe 1993). Population densities in the eastern region remained particularly low and ephemeral as the low and highly variable rainfall (averaging 450 mm per annum) made crop farming particularly difficult. The upper catchments consistently had greater population densities as a result of the better water resources and plant growth. The word 'Selati' comes from the name 'Shalati' ─ she was a female chief of the Tebula people who lived in the region more than 100 years ago.

Europeans first arrived in the area in the late 1830s, hunting for ivory and rhino horn in the lowveld region. They also searched for a trade route from the high plateau (the goldfields of present-day Johannesburg and the administrative town of Pretoria) to the coast at Delgoa Bay (now Maputo) in Mozambique. They did not colonise the area because of malaria, sleeping sickness, blackwater fever, dangerous animals, and the presence of hostile people. Gold was rediscovered near Leydsdorp (prospectors reworked prehistoric diggings) and as a result of the consequent rush of diggers in the 1880s, speculators established the Selati Railway Company in 1890 to move goods and gold. The gold strike soon proved unsustainable and the Selati Railway Company collapsed. Evidence of prospecting pits can still be seen along the Selati River in the Legalameetse Nature Reserve.

The grassland watershed at the top of the escarpment was settled by Europeans around 1905 or shortly thereafter. A farm there was named 'The Downs' and Orrie Baragwanath settled there during that time, giving his name to the pass that now traverses the escarpment through the Legalameetse Nature Reserve. During the 1920s, irrigation began in earnest in the region. The early stages of the Selati Irrigation Scheme were developed then, including some of the irrigation channels used to this day.

2.7 Groundwater

Groundwater is a crucial resource throughout the catchment. Beginning near the source of the Ga-Selati, the enterprise on the farm Dindinnie is fed largely by groundwater which surfaces at what is known as Macheke Springs, just below the entrance to the Legalameetse Nature Reserve. Here, water emerges from several adjacent springs and is immediately diverted via an unlined canal to the farming operations. The occurrence of these springs, along with others nearby, suggests an important local unconfined aquifer, possibly made up of local riverine sedimentary deposits (Macheke Springs are only about 100 m from the Ga-Selati). At the time of the author's visit to the area (September 2005), at the end of the dry period and within the third year of a regional drought, good quality water was still flowing and it is this water on which some farming operations depend entirely.

Further down the catchment, the Ga-Selati appeared to by completely dry, yet close to Calais a local farmer was pumping water from a small weir, via a petrol pump, to his drip-irrigated bean fields. This implies that the river is intermittent and that there is a substantial groundwater resource within the vicinity of the river.

Nearby, the village community of Calais is supplied with water from a borehole. This is close enough to the Ga-Selati River to have a hydrological connection to the river. An implication for expanded farming and human settlements in the area that rely on borehole water will be a reduction in the resource. A database held by the government department responsible for water resource issues (the Department of Water Affairs and Forestry) shows a surge of borehole installations in the late 1980s and early 1990s. The installation of boreholes is continuing. This implies a switch from abstraction of surface water resources to one of groundwater. This has serious implications for achieving reliable water supplies in the region. If the local groundwater resource is tightly linked to flows of water in the Ga-Selati River, increasing the abstraction of groundwater will have a significant impact on flows in the river. In the upper Ga-Selati River catchment, close to the Legalameetse Nature Reserve, groundwater and flow in the river is definitely tightly linked. The Macheke Springs and other nearby springs are evidence of this.

2.8 Institutional arrangements for water management

In the old *Water Act* (54 of 1956), access to, and distribution of, water was determined by ownership of land. Based on Roman Dutch legal principles, access to water was determined by riparian ownership. Farms with unique access to water were developed along rivers where an irrigation area could be proclaimed and surveyed by the granting authority. Areas of land were allocated an irrigation “duty”, which was an allotment of water over time determined by what was available for abstraction from the river, and the irrigation requirement. The effect of this legislation was to allow for development of irrigation schemes and extraction of water from rivers such as now exists on the Ga-Selati River. People living in areas outside that riparian land had no right to extra water apart from that which arose on the underlying property. The effect of the legislation was to create a distinctive pattern of land use on the landscape.

The new *National Water Act* (NWA) (36 of 1998) has shifted rights away from private access to a public rights system of water allocation. The new Act also prioritises supply by introducing the concept of the “Reserve” which specifies superior rights of use to humans and the environment. It also specifies the licensing of water use and contrasts general use licences (which are granted for most reasonable uses when supplies are plentiful) to those of compulsory licences. The general thrust of compulsory licensing is to regulate the demand for water when there is insufficient supply to meet demand.

Finally, the NWA specifies how water should be managed and sets up rules for the development of a Catchment Management Authority (CMA), in which different stakeholders cooperate in the management of the water under its jurisdiction. The Ga-Selati and its tributaries fall under the Olifants CMA which incorporates a region much larger than the Ga-Selati River catchment.

CMAs are still putative bodies and none as yet has legal force. Groups of users can represent themselves as stakeholders. The commercial irrigators on the Ga-Selati (as opposed to subsistence irrigators, or those without legally allocated water) have constituted themselves as a Water Users Association (WUA), known as the Ga-Selati Irrigation Scheme. Other stakeholders include the Lepelle Water Board (a body which ensures water supply to the major urban areas in the region, e.g. Phalaborwa and Tzaneen, and some of the community settlements).

In the meantime, other pieces of legislation that affect the ways that water resources and the natural environment are managed, and that are relevant to the Ga-Selati catchment, are already in effect. These include:

- The *National Water Services Act*. This provides for access to basic water supply, and basic sanitation, for water services development plans as well as regulating water services institutions. The implementation of the Act is primarily through the Water Boards. The primary activity of a Water Board is to provide water services to other water service institutions within its service area, for example municipalities and rural water supply schemes.

- The *Integrated Waste Pollution Act*. This Act aims to prevent pollution at its source and to avoid environmental degradation.

- The *National Forest Act*. This Act provides for the protection of the environment for the benefit of the present and future generations, with particular respect to conservation of forests and woodlands.

- The *National Environmental Management Act*. This Act strives to achieve environmentally sustainable development. It addresses the relationship between economic activity, human population and the environment.

Any change in the way water and other natural resources in the Ga-Selati River catchment are used will require that these laws be taken into account.

3. Land use in the upper catchment

A broad breakdown of the land use is given in the following table.

Table 4: Broad land uses and land types in the Ga-Selati River catchment with percentages of total land area (data from the South African National Land-Cover Project – unpublished data)

Land use type	Area (ha)	%
Indigenous forest	3,799	2
Savanna	176,288	75
Degraded	28,536	12
Irrigated	7,407	3
Dry land	3,467	1
Other	14,334	7
Total	**233,831**	100

The dominant land cover is the lowveld savanna. A substantial proportion of the catchment has been classified as degraded. Agriculture covers only 4% of the total land area, with irrigated agriculture at 3%. This land use therefore has an impact on the water resources of the region out of proportion to its relative size. The reader needs to refer to associated studies on the resource economics of the region to understand the economic value added by irrigated agriculture.

3.1 Water use by invading alien trees

Surveys of the area of invading alien woody plants in the Legalameetse Nature Reserve and upper Ga-Selati give the results shown in Table 5. The invading plants have a mixture of forms, ranging from shrubs to medium trees to large trees (See Section 2.2). Roughly 3-5% of the upper Ga-Selati River catchment has been invaded, about 20% is covered by indigenous forests and bare rock, leaving the remaining 75% as sourveld grassland (about 15,000 ha).

Table 5: Area of invading alien woody plants in the upper Ga-Selati River catchment and the Legalameetse Nature Reserve (Data source: Working for Water Programme, Department of Water Affairs and Forestry, South Africa)

Area of invaders in density class categories (ha)							
Closed (>75%)	Dense (50-75%)	Medium (25>-49%)	Scattered (5-24%)	Very scattered (1-5%)	Occasional (0.02-1%)	Rare (<0.02%)	Condensed area
196	410	1,095	750	62	5	40	853

In Table 5, reference is made to the condensed area of invasion (last column). This is done in order to make estimates of water use tractable. Invasions of landscapes feature a variety of plant densities per unit area. This makes it difficult to estimate the incremental water loss due to invading trees because there is no technique for accommodating the differences in canopy cover of the invading plants. The solution adopted by le Maitre et al. (1996) was to develop a model for an invaded landscape in which 100% of the ground surface was covered by alien tree canopy, in the same way that a plantation is. Therefore, each of the areas of density class category has been scaled (see le Maitre et al. 2000 for the methods and scaling factors).

Estimates of water use by the invading alien plants have been made by following the approach of le Maitre et al. (1996). Firstly, I have assumed that there is more or less an even distribution of plant forms across the categories of shrubs, medium-sized trees and large trees. This makes the selection of the le Maitre et al. (1996) 'medium tree model' seem appropriate for the estimation of biomass. Secondly, I have assumed that their average age is about 8 years. Current water use by the invading alien plants was calculated as follows:

Biomass (g/m^{-2}) $= 9{,}610 \times \log_{10}$ (age in years) - 636
= 8,042

Streamflow reduction (mm/yr) = 0.02 x biomass + 37
= 198

Given a condensed area of alien invaders at 853 ha then results in a water use of = 1,637,760 m^3/yr, or 52 l/s

If no action is taken in removing these alien plants, particularly the acacias and eucalypts invading the sourveld grassland, water loss can be expected to increase. After 10 years, the areas of invasion canopy of the dense and medium density categories can be expected to reach the closed category and the area of this density class would increase by eight times. Runoff reduction would then be of the order of:

= 3,688,000 m^3/yr, or 117 l/s

Abandoned agricultural fields on the top of the escarpment in the Orrie Baragwanath Pass have left a disturbed landscape that is vulnerable to invasion. *Acacia mearnsii* and *A. dealbata* as well as some eucalypt species (probably *Eucalyptus grandis*) readily invade temperate moist grasslands in South Africa. Both genera are difficult to control, seeds of the acacia species being long-lived in soil stores while eucalypts re-sprout vigorously if stems are cut. Unless the alien invasion on the topmost areas of the Ga-Selati catchment are not controlled early enough, the impacts will be an increased loss of runoff as well as rapidly rising costs for future control.

3.2 Water losses from irrigation systems

The major irrigated crop types in the Ga-Selati Irrigation Scheme are mangos, avocados, and various types of annual crops such as tomatoes, chillies and beans. The breakdown of the relative size of each crop type for the catchment is unavailable at present. Many of these crops are irrigated by drip line. This is an efficient method of irrigation. However, as stated earlier, a key aspect of the irrigation practices in this region is the use of unlined channels to transport water to individual farms. These farms have night dams – temporary storage structures, filling during the night and drawn down during the day as the water is used for irrigation. These structures are generally poorly maintained and are also unlined. Water is lost from them via infiltration. To make matters worse, overflows are usually let out into the farm lands where the flows serve no useful purpose. See Table 6 in Section 3.3 for a summary breakdown of water uses within the upper Ga-Selati River catchment area.

The other irrigated areas of concern include those of Ofcolaco Farmers' Union and the Harmony Farmers Union. Individual farmers from these communities pump their water directly from the river and are not bound to an irrigation scheme, albeit they work together. Water use licences are applied for directly from the Department of Water Affairs and Forestry, and not through an irrigation scheme.

3.2.1 The Legalameetse Nature Reserve 'Avocado Orchard'

The avocado orchard in the middle of the Legalameetse Nature Reserve is irrigated with water abstracted from the surface river flow in the upper reaches of the Ga-Selati River (a small stream at this point), and by partial abstraction from a tributary stream. Water is drawn off from the streams on a continuous basis and run down unlined channels to sumps from which overhead sprinklers are operated. Overflows from these sumps, for example when the sprinklers are not in use, are run out onto the soil and therefore go to waste.

Hydraulic calculations based on measurements of water depths at inlets, the inlet dimensions, slope and wetted perimeter roughness of the pipes and channel off-takes from the Ga-Selati and its tributaries, give an abstraction of 0.0135 m^3/s. This translates in to 48 m^3/hr and 1,166 m^3/day.

3.2.2 The Ga-Selati Irrigation Scheme

In South Africa, before abstractions can be taken from a river for irrigation farming, a scheduled irrigation area needs to be proclaimed and licensed. This is done by surveying the land identified for irrigation and calculating how much water can be reasonably abstracted from a river to water it. The amount abstracted must leave enough for maintenance of river function, but also maximise production from the available land.

The scheduled area for irrigation in the Selati Irrigation Scheme is 997 ha and the scheduled or licensed theoretical abstraction from the river is 127.5 l/s or 0.1275 m^3/sec. At the first abstraction point for the Selati Irrigation Scheme, 100% of flow in the river was directed into the scheme's canal system. Just below the entrance to the Legalameetse Nature Reserve, the flows to the Ga-Selati River from the Macheke Springs were captured entirely and redirected into farming projects along a small canal system, most of which is unlined (Macheke Springs to Dindinnie).

The Ga-Selati River Irrigation Scheme: a multi-use system (Photograph: R.A. Chapman)

At the main abstraction point for the Selati Irrigation Scheme, the flows in the stream are directed into a large pipe and lead into a concrete-lined canal. At various stages along the canal, water is directed into so-called "night dams", the purpose of which is to store water overnight ready for use during the day. Canals to these night dams are mostly unlined and there is a very substantial loss of water as a result. The night dams are also unlined and in some cases so weed-infested that it was not possible to see the water surface. Significant further losses take place through them. Furthermore, overflows from the night dams are directed into open fields and this water is lost to the system entirely.

Just above Calais, water in the river system was being pumped, by a portable petrol pump, onto fields. These fields were also being cleared of large trees and it appeared that the cultivated area was spreading upstream towards the Legalameetse Nature Reserve. Water is directed into the irrigation scheme on a continuous basis and any water not used directly in irrigation is lost. Little provision has been made for reducing losses transporting water to field edges, and surplus water in the irrigation system is entirely lost from the Ga-Selati system.

3.2.3 Evaporation losses from the Ga-Selati River surface

The lowveld savanna is a warm, dry place and evaporative demand is high. At the time of writing, the dry condition of the river bed of the Ga-Selati River, from the bridge at Calais all the way to Phalaborwa, is indicative of the need to supply water to meet evaporative demand from the river surface and associated riparian ecosystem. It is important to note that any water delivered at the bottom of the catchment (at Phalaborwa) must first supply evaporative demand of the river system before it becomes additionally useful for other purposes such as effluent dilution.

The distance from the confluence of the Ga-Selati and the Ngwabitsi rivers to Phalaborwa is 70km. With a water loss from an open water surface of 4-7 mm/day (summer and winter values), and an average river width of 5m (a conservative estimate that includes water use by riparian vegetation), the catchments need to deliver 1,400 - 2,450 m^3/day or 16-28 litres/s to the river before any additional water will reach Phalaborwa to be used for dilution and any other purposes.

From the beginning of the Selati Irrigation area to the confluence of the Ga-Selati and Ngwabitsi rivers is 15km. Evaporation losses over this length will require 300-525 m^3/day or 3-6 litres/s. The Ngwabitsi River will also be required to deliver a similar amount. The effect is that water savings created by any change in the way water is used in the catchment, or by changing catchment land-use practices, must deliver 2,000 - 3,500 m^3/day or 23-41 litres/s before any additional water can be used for beneficial purposes in the downstream locations.

3.3 Summary of water losses

The impacts of the above inefficiencies have been estimated and are given in Table 6. These values illustrate current use and possible water savings that could be achieved in the Selati Irrigation Scheme. Note that these quantities do not include other independent and unregulated irrigators below the scheme, such as those in the Harmony Block and the Ofcolaco Block, for whom no data exists at present.

Table 6: Baseline water use and potential savings after intervention for the upper Selati Irrigation Scheme

	Baseline current use (m^3/yr)	**New practice savings (m^3/yr)**
Aliens [1] - current - after 10 years	-1,637,760	1,637,760 3,688,000
Legalameetse Avocado Orchard [2]	-279,840	279,840
Irrigation [3]	-7,144,000	0
Evaporation [4]	-492,750	- 985,500
Wetlands [5]	0	0
Total	**-9,554,350**	**932,100** **2,982,340**

Notes:

1. A simple spread model indicates the effects of the progressive invasion of the Ga-Selati uplands by alien trees. If nothing is done now to prevent further invasion, and assuming a lack of control for the next 10 years, the water loss would increase to a higher amount, which would translate into potential savings of the same value if they were controlled.

2. These figures represent water use by the avocado orchard within the Legalameetse Nature Reserve; irrigation water is drawn directly from the Ga-Selati River and its tributaries in the upper catchment.

3. These values represent the irrigation demand by the Selati Irrigation Board, being a “theoretical” allocation of water, e.g. what the Selati Irrigation Board has been licensed to use. Actual use varies greatly according to weather patterns. The savings are quantified as zero because:

   - All water coming into the irrigation scheme is consumed, and
   - Any savings brought about by improvements of efficiency are likely to be taken up by increasing the area under irrigation rather than being returned to the Ga-Selati River. That is, the full benefit of the licence will continue to be utilised given sufficient water.

   The values do not include abstractions by farmers belonging to the Ofcolaco Farmers’ Union and the Harmony Block Farmers Union. The current licensed use by irrigation includes all inefficiencies. New pattern use will result in a reduction of inefficiency, but will be unlikely to yield more water in the river. Water saved by increasing the efficiency of reticulation will be used to expand production through increased irrigated area.

4. Evaporation takes place from the river and riparian vegetation. This evaporative demand must be supplied before any additional water can reach its beneficiaries downstream. For current use (or the baseline), half of the demand is unmet, that is, the river goes dry for some of the time (this is a very crude estimate). After intervention in water use (new practice), more water is available for routing downstream, increasing the evaporated quantity just because there is more water available.

5. Wetlands are not considered as having a net effect on the quantity of water moving through the system.

4. Discussion and conclusions

There are a number of interventions that will make a difference to water resources in the region:

1. Reduce water losses in the irrigation schemes by using pipes to convey water from source to field edge.

2. Where night storage dams exist, clean these and line them with a more impervious material.

3. Return excess water to the Ga-Selati River, rather than letting it run to waste as at present.

4. Regulate water abstractions from both river and boreholes, particularly those close to the river.

5. Possibly remove the avocado orchard in the middle of the Legalameetse Nature Reserve – it uses water but is most likely uneconomic.

6. Remove the eucalypts and acacia species invading the upper watershed grasslands in the Drakensberg Mountains.

A primary principle that should be adhered to is that a solution must have all three of the following: ecological integrity, economic efficiency, and social equity. When these objectives are achieved, the solution is more likely to be sustainable than one where there is a deficiency in any of these entities.

4.1 Options for payments for environmental services

Payments for environmental services therefore include some means of addressing the interventions described above. Primarily these are to:

- Increase the efficiency of the irrigation schemes (Points 1-5 in the above discussion). This option will probably have the biggest impact on increasing water supply in the catchment.

- Prevent the use of the Legalameetse Nature Reserve as a source of non-renewable natural resources such as firewood, which is not replaced by planting of suitable species.

- Secure the future supply of environmental goods and services by enforcing conservation measures in the Legalameetse Nature Reserve.

- Protect the springs and their surrounds from degradation – Macheke Springs and others in the vicinity. They are already heavily invaded by *Chromolaena odorata* and *Lantana camara*.

- Remove the invading acacias and eucalypts in the Legalameetse Nature Reserve. The Working for Water Programme that is supposed to be undertaking this work does not appear to be targeting these species.

PES may not necessarily be in the direct transfer of cash, but might be an investment in better irrigation technology in the upper catchments, or by means of the training of farmers benefiting from the Land Restitution Programme. Or it may be the funding of a Catchment Resource Management Committee or similar body that endeavours to achieve certain objectives that meet certain water supply targets. This approach will only be successful when the economic, social and ecological needs of the whole catchment are met.

Threats to the process of improving the reliability of water supplies in the region are: the increasing population of rural poor in the upper catchments; their demand for land and other natural resources; failure to regulate water abstractions from the river and nearby groundwater resources; and failure to conserve the natural resources of the Legalameetse Nature Reserve.

An issue that needs to be strongly considered is that water released by efficiency gains might not reach the desired beneficiaries, i.e., those individuals and organisations downstream providing the money for upstream benefits. From Legalameetse to Phalaborwa, there is ninety kilometres of generally dry river bed with intense competition for water. The lowveld is also characterised by periodic droughts. It is therefore very unlikely that water released by payments for watershed services in the upper catchment will get to Phalaborwa. This issue needs to be considered before any implementation of PWS in the region.

A strong business case will need to be made to convince individuals such as downstream users of water to pay for the provision of environmental services upstream. The individual services, and their benefits and beneficiaries, will need to be identified clearly (Giorgieva et al*.* 2003). The manner in which these services are generated must also be understood. The type of service provided must be demand-driven, not supply-driven (Giorgieva et al. 2003).

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