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Urbanisation, climate change and its impact on water quality and economic risks in a water scarce and rapidly urbanising catchment: case study of the Berg River Catchment

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Abstract

By 2050 it is predicted that 67% of the world population is expected to be living in urban areas, with the most rapid levels of urbanisation taking place in developing countries. Urbanisation is often directly linked to the degradation of environmental quality, including quality of water, air and noise. Concurrently, the climate is changing. Together, the negative impacts of climate change and urbanisation pose significant challenges, especially in developing countries where resources to mitigate these impacts are limited. Focusing on the Berg River Catchment in South Africa, which is experiencing increasing levels of urbanisation, the impacts of climate change, the 'wicked problem' of service delivery to the historically disadvantaged within a developing country, persistent infrastructure backlogs, and where high unemployment is prevalent, this paper explores the increasing water quality risks due to climate change and rapid urban development and the likely direct and indirect economic impacts that this will have on the agriculture sector, which is a key contributor to the regional and national economy. The results give support to the need to invest in risk mitigation measures including the provision of basic services, the upgrading and maintenance of wastewater treatment plants and investing in ecological infrastructure.

Key words: agricultural water, climate change, pollution, South Africa, urban development, water quality

INTRODUCTION

Countries around the world are increasingly faced with the challenge of managing the increasing risks and negative environmental impacts of climate change and urbanisation. By 2050 it is predicted that 67% of the world population is expected to be living in urban areas (UN 2011), with the most rapid levels of urbanisation taking place in developing countries (Zhang 2016). It is also likely, that despite our best efforts, the majority of future urban growth will be in informal areas as governments struggle to keep up with the increasing demand for basic services including water supply, sanitation and formal housing. Urbanisation is often directly linked to the degradation of environmental quality,

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including quality of water, air and noise (Cullis *et al*. 2005, 2018; Liang 2011; Bobylev *et al*. 2016; Zhang 2016).

Concurrently, it is now widely accepted that globally temperatures will increase and rainfall will become more variable, thereby affecting local climates across the world and that this can be largely attributed to human impacts (IPCC 2014a). Within urban areas, it is generally predicted that the increase in global temperatures associated with climate change will be exacerbated as a result of the urban heat island effect due to the modification of natural surfaces, where vegetation would have reduced heat (IPCC 2014b). Climate change is likely to also impact on water quantity and quality through a combination of higher temperatures and reduced freshwater flows (Cullis *et al*. 2015). Increasing demand for water from upstream users also results in reduced fresh water flows which is further increasing the concentration of key pollutants and deteriorating water quality in rivers and associated economic risks for downstream users.

Both climate change and increasing urbanisation, particularly informal development, are likely to negatively impact on water quality of rivers which, in turn, could have significant economic impacts for the communities dependent on these rivers both for direct use, but also indirectly in terms of the water-dependent economic activities such as agriculture. Better understanding of the link between increasing water quality risks due to urban development and climate change and the associated economic impact that this has, is therefore, critical in terms of identifying the need for interventions, improved management and investments in ecological infrastructure to ensure sustainable development and to mitigate against the increasing risks associated with rapid urbanisation and climate change.

Here, we investigate these critical links by way of a case study of the Berg River Catchment in South Africa. The results of this study not only have relevance for decision-making in the Berg River Catchment, but also at a regional and national level for South Africa. The lessons learnt are also equally applicable in other developing world cities, and even in some regions of the developed world facing similar challenges of declining water quality due to increasing urbanisation and climate change.

We investigate the increasing water quality risks from urbanisation and climate change using water quality data obtained during a current three-year drought period that is the worst on record, but potentially an indicator of the future conditions under a drying climate. These data are also compared with the results of earlier studies to identify potential for long-term trends and possible cause of declining water quality. In order to investigate the economic risks associated with the observed increasing water quality risk, we investigate the impact of different water quality scenarios, including the net present value (NPV) of alternative mitigation measures at the level of individual representative farms found within the Berg River Catchment, and the overall impact that this might have on the economy both locally and nationally as a significant contributor to gross domestic product and foreign export earnings.

The Berg River Catchment, located in the Western Cape Province of South Africa provides a rare opportunity to study the potential environmental impacts/risks and their relationship to water quality and economic risks for both the urban and rural economies within a developing country context. The Berg River falls within a catchment that is experiencing increasing levels of urbanisation, the complex problems of service delivery to the historically disadvantaged informal sector, infrastructure backlogs and the prevalence of high unemployment. In this regard, the Berg River is not unique, in that many catchments face similar challenges, particularly in the developing world. As a result, the lesson learnt from this study and, in general, the lessons learnt from the Cape Town drought crisis, are globally relevant.

OVERVIEW OF THE STUDY AREA

The Berg River in the Western Cape, South Africa, is an important water system as its upper reaches supply the City of Cape Town with a large proportion of its freshwater (two of the largest water supply dams are found in its upper reaches), while the middle reaches provide water for irrigation supporting a diversity of agriculture, as well as supporting the water needs of regional towns (Görgens & de Clercq 2005). The Berg River rises in the Groot Drakenstein Mountains near the town of Franschhoek, and discharges into the Atlantic Ocean on the West Coast of South Africa near Velddrift. The Berg River is approximately 300 km in length, with the main stem approximately 160 km in length, and drains a catchment of roughly 9,000 km^2, while traversing six local municipalities. The catchment lies in a Mediterranean climate, winter rainfall region with the average annual rainfall ranging from over 1,000 mm in the mountains in the east to 200 mm or less at the west coast. The land use in the Berg River Catchment falls primarily into four categories: agricultural (±60%), forestry (<1%), urban (±2.5%) and natural (±36%). Agricultural land use is further divided into irrigated (±7%) and dry land farming activities (±53%) (DWAF 2004). While the catchment remains largely rural, it has seen an increase in population throughout the catchment (1996–2011) and an associated substantial increase in buildings (2006–2013), particularly in the middle-upper catchment around the major centres of Tulbagh, Wellington and Paarl (Figure 1). Such trends are not surprising and align with the trend of increased urbanisation throughout South Africa. While the catchment has 18 waste water treatment works which treat domestic waste water, many of these are not operating optimally. In addition, the rapid rate of urbanisation and the growth of informal settlements has resulted in significant concerns in terms of the water quality impact of urban water runoff.

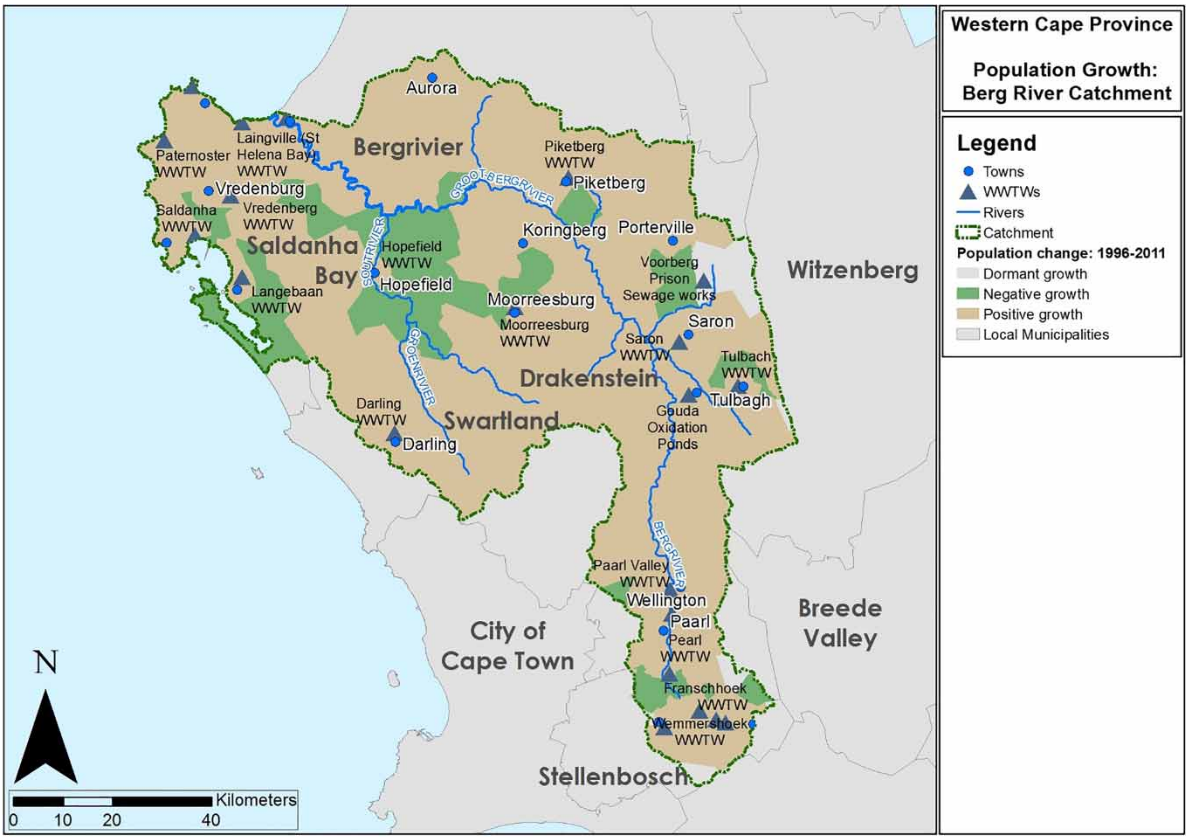

Figure 1 | Population growth areas and the location of wastewater treatment works (WWTW) in the Berg River Catchment and water quality monitoring sites along the Berg River main stem used for analysis.

Poor water quality in the Berg River, resulting from poor sanitation service provision, agricultural and other practices, could have a significant impact on the regional economy. It is difficult to link economic findings to specific water quality levels, although if water quality continues to deteriorate to the point where international exports are affected, the economic consequences would be considerable. Similar challenges have been identified in neighbouring catchments such as the Breede River (Cullis *et al.* 2018).

The concern, therefore, with the current trends of urbanisation, is that increasing populations will result in an increased impact on the river system, and because of its focus in the upper catchment the impacts will affect the entire river system. This could have an influence on the large number of agricultural users in the middle and middle-lower reaches of the Berg River who are an important component of the regional economy, in part due to the income generated from exporting produce.

The Berg River is a major water supply source to the City of Cape Town and other local and district municipalities in the region. Due to the seasonal nature of rainfall, water supply to these urban areas as well as to the farmers in the Berg River Catchment is dependent on several large dams and smaller farm dams, many of which are supplied from the Berg River itself using the river as a conveyance system for releases from the upstream dams, particularly during the summer months. The three largest dams in the catchment are the Berg River Dam, Wemmershoek Dam and Vöelvlei Dam which form part of the Western Cape Water Supply System (WCWSS). Maintaining minimum environmental flows to the Berg River estuary is also critical given the ecological importance of this estuary as well as its contribution to the sustainability of fish stocks that support the fishing industry in the region. Competition for water will affect the cost of irrigation water significantly in the future. The expectations that water availability and/or water quality can be influenced will ripple through to farm-level profitability.

APPROACH

Review of historical water quality and flow data for the Berg River

The water quality in the Berg River Catchment has been monitored since, at least, 1967 (De Villiers 2007). Since 2005 there have been a number of studies (Görgens & de Clercq 2005; Clark & Ractliffe 2007; Jackson *et al.* 2007; Paulse *et al.* 2007; Struyf *et al.* 2012) that have considered different aspects of water quality in the Berg River and other rivers in the region (Cullis *et al.* 2018). These studies have utilised data sets dating back as far as 1985. Unfortunately, the available data sets have been collected by a variety of stakeholders and, as such, do not always represent the same points along the water course – which limits comparison – and are not always located near a flow gauging station – limiting the assessment of the total flux (load) of pollutants in the river system. Interestingly, there does not appear to be a single study, to date, that has considered all the different water quality parameters that have been monitored, namely, water chemistry, microbiology and metals, and yet there are similarities in trends in the conclusions reached in the different studies.

Analysis of water quality data from the Berg River Improvement Project

In addition to the review of data from previous water quality studies, water quality data obtained from the Berg River Improvement Project (BRIP) and the National Department of Water and Sanitation (DWS) were also analysed in terms of the impact of urbanisation and drought on water quality, particularly for the last three years during which the region has experienced a severe drought that almost resulted in the City of Cape Town becoming the first global city to run out of water. The BRIP was started by the Department of Environmental Affairs & Economic Development (DEA&DP) of the Western Cape Government in October 2013. Water quality samples were collected mostly at a monthly frequency. Data for the period October 2013 to October 2017 were provided for this assessment. The location of the sampling points in relation to key features along the Berg River are given in Table 1 and in Figure 2.

Table 1 | List of Berg River Improvement Project (BRIP) sampling points on the Berg River

BRIP ID#	Site description	Lat	Long
B10	1 km downstream of Klein Berg confluence	−33.207516	18.943699
B11	Berg River downstream of Wellington WWTW	−33.656089	18.9666
B12	Berg River downstream of the Mbekweni storm water channels	−33.66682	18.974746
B13	Berg River downstream of Paarl	−33.690659	18.97549
B14	Berg River at Arboretum	−33.755504	18.972971
B15	Drakenstein stream Wemmershoek Dam	−33.807679	19.076892
B17	Franschhoek River at Rickety bridge	−33.898961	19.093116
B18	Berg River Dam bridge	−33.882484	19.047197
B20	Bienne Donne/Downstream of Berg Dam Pump scheme	−33.841534	18.9875
B21	Stiebeuels River 50 m d/s of Main Road	−33.896256	19.098658
B22	Klein Berg River at Tulbagh Nursery	−33.319134	19.095975

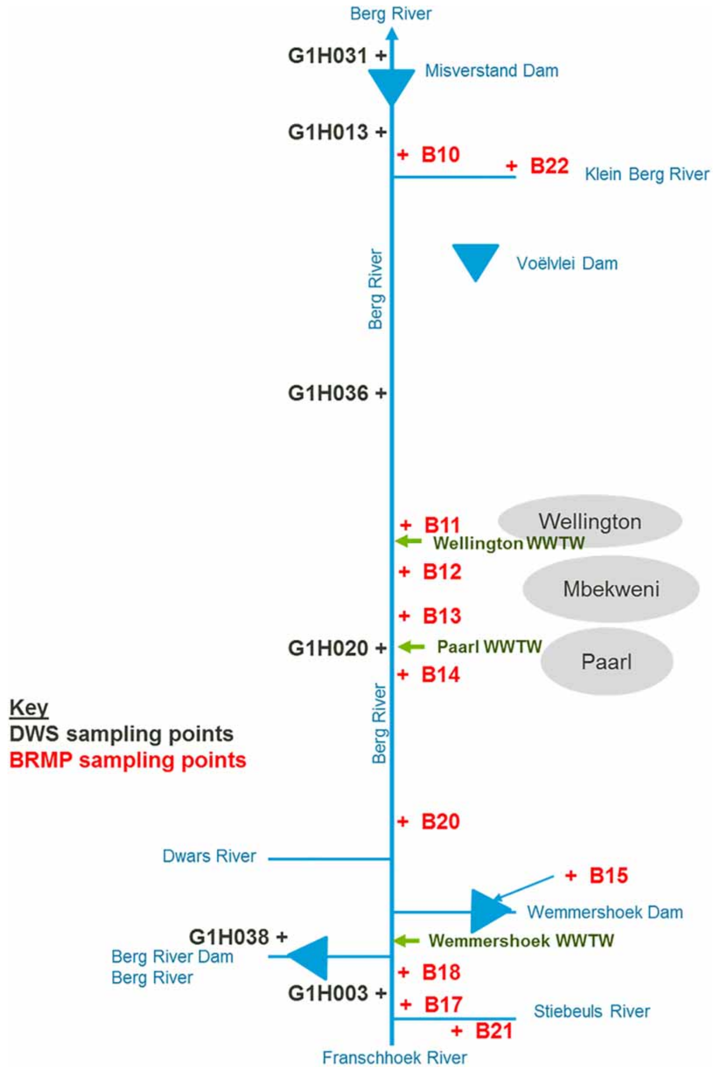

Figure 2 | Schematic diagram of the upper and middle Berg River showing the location of BRIP and DWS sampling points and key WWTW.

The National Chemical Monitoring Programme (NCMP) of the DWS also collects water quality data along the Berg River. Data for the period January 2013 to May 2017 were obtained from the DWS for the monitoring points (Figure 2) listed in Table 2. The sampling frequency at the NCMP points vary although samples are mostly collected at a monthly frequency.

Table 2 | Department of Water and Sanitation (DWS) National Chemical Monitoring Programme sampling points selected for this study to complement the BRIP water quality data set

DWS code	Name	Latitude	Longitude
G1H003	G1H003Q01 At Le Mouillage La Motte on Franschhoekrivier	−33.8906	19.07889
G1H020	G1H020Q01 At Dal Josafat Noorder Paarl on Berg River	−33.7075	18.97444
G1H036	G1H036Q01 At Vleesbank Hermon Bridge on Berg River	−33.435	18.95694
G1H013	G1H013Q01 At Drieheuvels on Berg River	−33.1308	18.86278
G1H031	G1H031Q01 At Misverstand Die Brug on Berg River	−32.9969	18.77889

The BRIP water quality data, which included parameters listed in Table 3, were combined with the DWS data (Table 2) for analysis. DWS does not routinely monitor dissolved organic carbon (DOC) and chemical oxygen demand (COD), and no *Escherichia coli* samples have been collected by DWS since about June 2013. The data were then analysed in terms of both spatial and temporal variation to investigate the impact of changing land use, as well as the impact of wet and dry seasons as an indication of conditions under a possible drier future climate.

Table 3 | Parameters analysed for in the BRIP

BRIP parameter names	Units	NCMP parameter names	Units
Ammonium (NH_4-N)	mg/L	NH_4-N-Diss-Water (ammonium nitrogen)	mg/L
Alkalinity (Alk) as $CaCO_3$	mg/L	TAL-Diss-Water (total alkalinity as calcium carbonate)	mg/L
Nitrate plus nitrite nitrogen ($NO_3 + NO_2$-N)	mg/L	$NO_3 + NO_2$-N-Diss-Water (nitrate + nitrite nitrogen)	mg/L
Ortho-phosphate (PO_4-P)	mg/l	PO_4-P-Diss-Water (ortho phosphate as phosphorus)	mg/L
Dissolved organic carbon (DOC)	mg/L C	–	–
Electrical conductivity (EC)	mS/m (25 °C)	EC-Phys-Water (electrical conductivity)	mS/m (25 °C)
pH	pH units (20 °C)	pH-Diss-Water (PH)	(pH units)
Chemical oxygen demand (COD)	mg/L	–	–
Escherichia coli	per 100 mL	–	–

Determining the financial and economic impacts of declining water quality for agriculture

Farmers operate at the interface between physical-biological and financial-economic dimensions, which means that various physical quantities and environmental parameters will be important drivers. Farm management is defined as the process by which resources and situations are manipulated by the farm manager in trying, with less than full information, to achieve his goals (Dillon 1980). This definition, in essence, relates to a decision-making process involving the identification and evaluation of alternatives. It would therefore be reasonable to expect that if the water quality in the Berg River continues to deteriorate, the agricultural sector will try to adapt. Adaption

– such as treatment of river water – would incur additional costs which would likely be passed onto the consumer and affect the competitiveness of farmers in the international market.

Concerns around the effect of the water quality of irrigation water in 2008 strongly motivated the need to prevent further degradation of water quality in the Berg River, failing which there could be significant economic consequences if the international export market were to limit their acceptance of produce from the region. While there would be benefit to all stakeholders in managing the water quality in the river, in order to protect their livelihoods the agricultural sector could, potentially, treat water prior to use for irrigation to ensure it meets international standards. In order to assess the scale of the decision to treat irrigation water a set of 'whole-farm budget models' were developed for the different types of agriculture currently taking place in the Berg River Catchment.

'Whole-farm budget models' are simulation models that simply express how a farm operates and the financial and economic consequences of its operation. By manipulating the parameters and inputs of the model, research questions of a descriptive, causal and predictive nature can be addressed (Steward 1993; Brenner & Werker 2007; Jakku & Thornburn 2010; Douthwaite & Hoffecker 2017). A high level overview of the models used in this study is provided in Figure 3, and described in more detail in Hoffmann (2011).

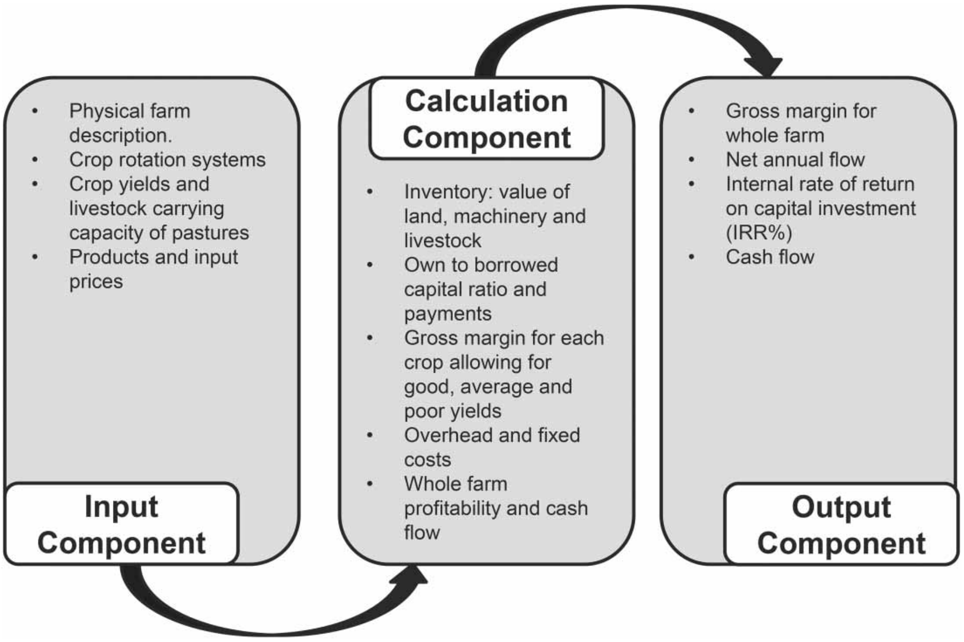

Figure 3 | A graphical representation of the components of the whole-farm, multi-period budget model.

Financial modelling is typically used in studies that aim at developing and validating accurate representations of the real world, in this instance a farm using river water for irrigation, and allow for the evaluation of possible alternative outcomes (Pannell 1996; Dorward *et al.* 1997; Kuehne *et al.* 2017). Budgeting is perhaps the most widely used method of financial planning. Budgeting, as a non-optimising method evaluates plans in physical and financial terms (Nance & Sargent 2002; Daellenbach & McNickle 2005). The models provide an indication of a farm's gross margin, the net annual cash flow, the internal rate of return (IRR) on capital investment and NPV. Farm systems are complex, more because of the interrelationships within the farm structure than by the different tangible components. Assessing the risk involved with irrigation availability is therefore dependent on the integration of the various components of farming and assessment of these factors at the whole-farm level.

The impact of trends, strategies and policy options on whole-farm profitability can be assessed by using a typical, or representative farm. In essence, it is a synthetically constructed model farm based on the expected structure of a farm in a particular area (Ash *et al*. 2017). The farm sizes and land distribution identification for the typical farms was done according to statistics obtained from industry organisations (Hortgro 2016; SAWIS 2016; SATI 2017). The farm description for each area was presented to a study group of industry role-players for validation of the assumptions.

The various enterprises are integrated into the whole-farm gross margin level. Expected income and production cost as well as the calculated gross margin per hectare level are based on information provided by the study group of industry role-players. Fixed and overhead costs are subtracted to calculate a figure that would resemble net farm income. From this annual figure, the capital replacement is subtracted to give the net annual flow after capital replacement.

The model is structured to show the impact of changes in inputs or output quantities, input and output prices, fixed costs' levels, changes in land utilisation, crop replacements schedules and movable asset replacement costs. The profitability indicators, IRR and NPV are calculated on a capital budget format and thus already include capital replacements for aspects such as machinery and orchards and vineyards in normal farming cycles. The normal increase in land values is ignored. It is important to note that the IRR in this case is a real return, in other words, one should still add inflation to calculate the nominal rate of return. The discount rate that was used for the calculation of the NPV is 2.4% which is a real rate based on the Repo rate.

In this study, three water quality and on farm response scenarios were considered. The first scenario assumed the water quality in the Berg River remained acceptable for agricultural use and met international export standards and farmers would continue to operate their farms, without any changes. The second scenario assumed that the water quality in the Berg River continued to decline, and as a result farmers began to see a decrease in productivity, but the water quality no longer met international export standards. The third scenario assumed that in order to protect their livelihoods farmers installed adequate water treatment facilities to ensure the quality of water utilised for irrigation was acceptable.

The first scenario for the purpose of this excercise is the control or status quo situation, or the prefered situation. The second scenario resembles a possible situation where all the export fruit would need to be sold domestically. That is, for example, a price decrease for table grapes to domestic prices, which would make table grapes unprofitable and structurally farmers would most likely change to wine grape production or other fruits with lower quality standards or higher yields. The third scenario entails the establishment of a water purification plant. A minimum cost of R1.5 m for the whole farm is assumed as this was the cost for a private producer who installed such a system in 2017. In this scenario, the added infrastucture cost and electricity cost is increased in the whole-farm budget model used for the analysis.

RESULTS AND DISCUSSION

Water quality trends in the Berg River Catchment

It is evident, as would be expected, that as the catchment has developed – principally through increased agriculture and urbanisation – the water quality in the Berg River has deteriorated (DWAF 2004). De Villiers (2007) noted that there has been a seasonal change in certain water nutrient levels, resulting from anthropogenic factors, that exceed national and internationally accepted levels. De Villiers (2007) indicates that the two most likely anthropogenic sources of nutrients along the Berg River are agricultural runoff, including pesticides and fertilisers, and also effluent from over-loaded municipal sewage works and runoff from informal settlements. These findings were made prior to the completion of the Berg River Dam, and were accompanied by a warning that if the dam resulted in the reduction of the downstream flushing effect, it would be very likely that nutrient levels in the Berg River would significantly increase above their already unacceptably high levels.

The importance of the Berg River Improvement Project is that it has investigated whether the pollution levels have continued to increase, and has the potential to show whether the Berg River Dam has had any impact. The Berg River Dam was designed to make environmental releases, however in the height of the current drought, these have been suspended. De Villiers (2007) investigated both the pollution concentrations in the river and also the flux or total mass of these pollutants.

In light of De Villiers (2007), it is of concern to note the findings of Struyf *et al.* (2012), who investigated the changes in riparian nutrient dynamics along the Berg River. They found that nutrient concentrations in the sediments within the riparian zone reflect the concentrations of nutrient in the Berg River. Significantly, they noted that sediments close to the river had more efficient recycling and export of nutrients into the river. Struyf *et al.* (2012) highlighted that their study indicated that if the changes in the hydrological cycle, in particular reduced flow, and water quality levels suggested in De Villiers (2007) were to come to fruition, it would be highly likely that a number of ecosystem goods and services would be impacted – including the natural filter function of the river system. Furthermore, Struyf *et al.* (2012) suggest that due to the impact of the high nutrient levels on the riparian zone, it may in future become a source of nutrients for the river, further compounding the challenges in managing the river.

Paulse *et al.* (2007) utilised a section of the Berg River to compare different enumeration techniques for the investigation of bacterial pollution. Incidentally their study highlighted that the majority of samples fell outside of the maximum acceptable levels. While the study is not representative of the whole river, it is an indication that the river is affected by anthropogenic pollution. Jackson *et al.* (2007) investigated the metal contamination of a section of the Berg River. Metals are typically only found as trace elements in the environment, as such when their concentrations increase significantly they may become toxic to the surrounding environment. The study found concentrations of several metals to be consistently above the available guidelines. The sources of these pollutants were, speculatively, linked back to informal settlements and agriculture, and highlighted the need for improved service provision in informal settlements and better management of pesticides, within agriculture.

Long term, the phosphate (PO_4^{3-}) levels in the Berg River indicate reason for concern. When the total at B10 (this study) is compared to the results of previous studies (B4 from De Villiers (2007)) there is a strong long-term trend (Figure 4) of increasing loads of phosphate. This trend is also present upstream of Paarl, to a lesser extent (B2 – De Villiers (2007); B14 – this study). If nothing is done to mitigate the increasing pollution risks, it is likely that by early 2020 (B10) and 2050 (B14), levels of

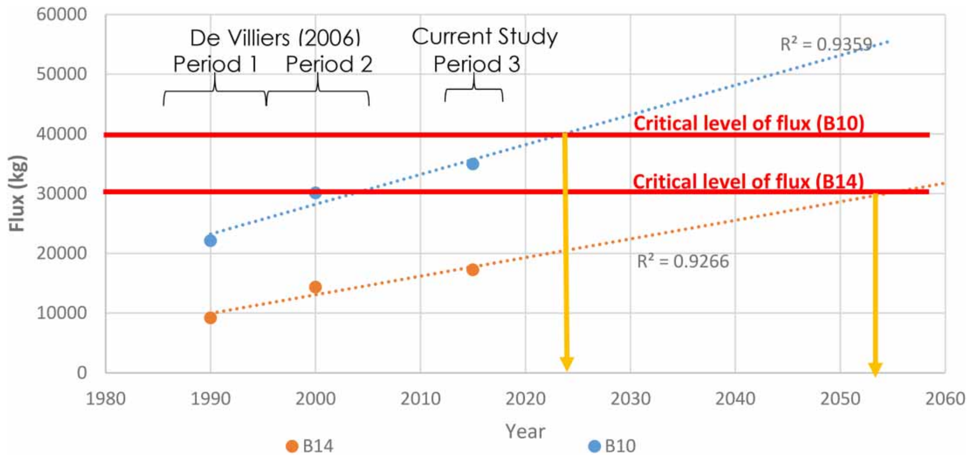

Figure 4 | Long-term prediction of total flux of phosphate (PO_4^{3-}).

phosphate will be unacceptable, while assuming the flow in the river remains constant. It is expected that there will be increasing periods where the level of phosphate will exceed the unacceptable levels. It is worth noting that B10 is lower down in the catchment and thus has a higher flow and, as such, the total acceptable flux (load) of pollutants that is acceptable would be higher. The increase in phosphate is more likely the result of urban development, rather than agriculture, as PO_4^{3-} does not easily leach from the soil, and evidence (discussed below) is that agriculture's impact on the nutrients in the river is decreasing, hence, addressing concerns around the compliance of wastewater treatment works (WWTWs) as well as the provision of basic sanitation services and improved stormwater management of the informal areas is critical in terms of reducing the pollution risk.

Unlike the flux of phosphate, the concentrations and flux of nitrate (NO_x) along the length of the river shows no consistent trends (data not shown) and does not result in a similar long-term increasing trend when compared to the results of De Villiers (2007). The nitrate concentration profiles do however peak during months with high runoff conditions. This is consistent with a diffuse source – which could be attributed to either agricultural runoff or diffuse urban pollution and the flushing out of the drainage systems servicing informal settlements at the start of the winter rainfall period. It is difficult to identify the specific source of nitrate pollution except to note that above Paarl (B14) there is a long-term trend indicating a reduction in the annual flux (load). The upper catchment for B14 includes a significant proportion of the agriculture, namely, vineyards and orchards, thus suggesting that agriculture in this region may be reducing their impact on the river through improved practices. It appears that downstream of B11, the flux of both phosphate and nitrate has increased since 2005. While agriculture in the catchment downstream of Paarl may be contributing to the increase, it is possible, if not likely, that the increase in pollution is due to urbanisation and its associated impacts on the catchment.

In summary, it is evident that there have been significant water quality impacts on the entire Berg River Catchment and that these have continued to deteriorate in the face of rapid urbanisation and that they need to be addressed as they present a significant economic risk to the region. If climate change (and increasing demands) results in further reduction in runoff, then the concentrations of nutrients in the river will increase with the reduced flows in the river and if the nutrient contribution to the river remains the same. This was observed during the last three years of the drought as described below.

Urban development and agricultural impacts on water quality

A vast amount of water quality data was collected as part of the study and analysed on behalf of the DEA&DP. This paper focuses on the results from only five water quality parameters, which together provide insight into the current levels of pollution in the catchment, possible causes, and potential risks and impacts of pollution. The analysis particularly compares trends along the river reach as well as the differences in the observed trends during wet and dry years which were both observed during the period.

Figures 5 and 6 provide a summary of the water quality data collected along the course of the Berg River Catchment for five key parameters that can then be used to investigate the likely consequences of urban developments, both formal and informal, along the length of the river as well as the potential impact due to the current state of the various WWTW.

The results show a clear spike in NH_4 and PO_4 concentrations at the location of sampling point B12 downstream of the Mbekweni informal settlement. There is a slight increase at B13, downstream of the Paarl WWTW and the spike persists at B11 downstream of the Wellington WWTW. After this point the river flows predominantly through an area of agricultural land use and by G1H036 the NH_4 and PO_4 concentrations are reduced to normal. This highlights the importance of natural river processes in terms of reducing the pollution load and the importance of maintaining ecologically

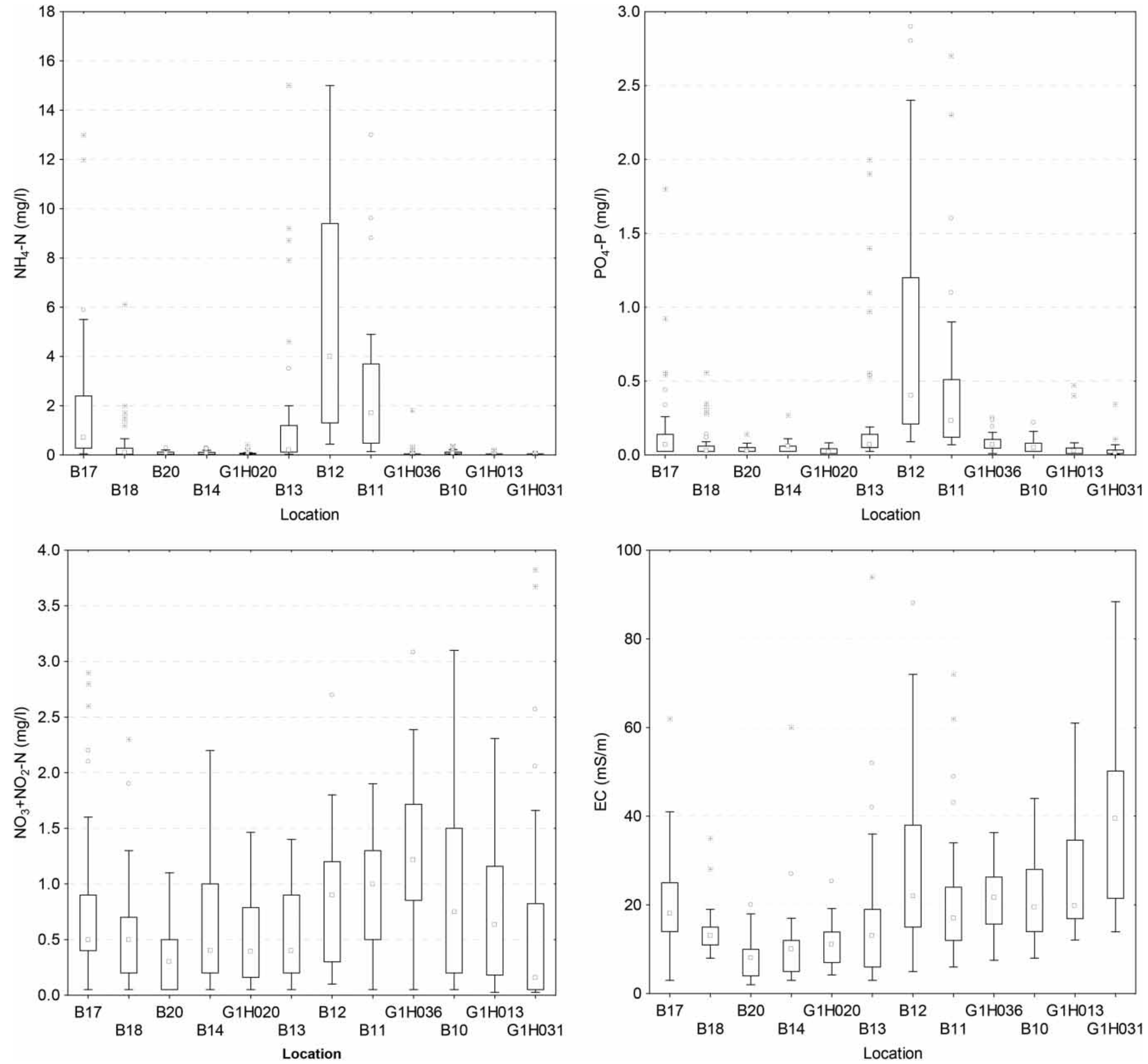

Figure 5 | Summary of water quality data for ammonia (NH$_4$), phosphates (PO$_4$), nitrates (NO$_3$ + NO$_2$) and salinity (EC) for the BRIP sampling locations from upstream (1) to downstream (12) for the period 2013 to 2017. The median values for each location are shown in the centre of the box which represents the upper and lower quartile. The whiskers represent the 5th and 95th percentile of the data and the other dots indicate extreme, or possible outlier results.

functioning river corridors. There is also a slight increase at B17 which is located downstream of an informal settlement in Franschoek.

A similar trend is not seen for nitrates, which peak at G1H036. This suggests that agricultural non-point source pollution is a greater contributor to nitrate pollution rather than urban water runoff or WWTWs. Interestingly, at B14, located upstream of Paarl, but also downstream of an area of intense agriculture, there is an indication of a long-term decrease in nitrate concentrations. This is consistent with the findings in De Villiers (2007) and could be due to improved agricultural practices including buffer strips.

Increasing salinity in the Berg River is a concern for agriculture. This is partially due to the underlying geology which consists of Malmesbury shale, which contributes significant levels of natural salinity to the catchment runoff, particularly in the lower sections of the river. It is thought that deep ploughing of these catchments has potentially resulted in additional salinity loads and there have also been concerns that the damming of the headwaters of the Berg River through the construction of the Berg River Dam in 2010 has further contributed to increasing salinity levels by reducing the

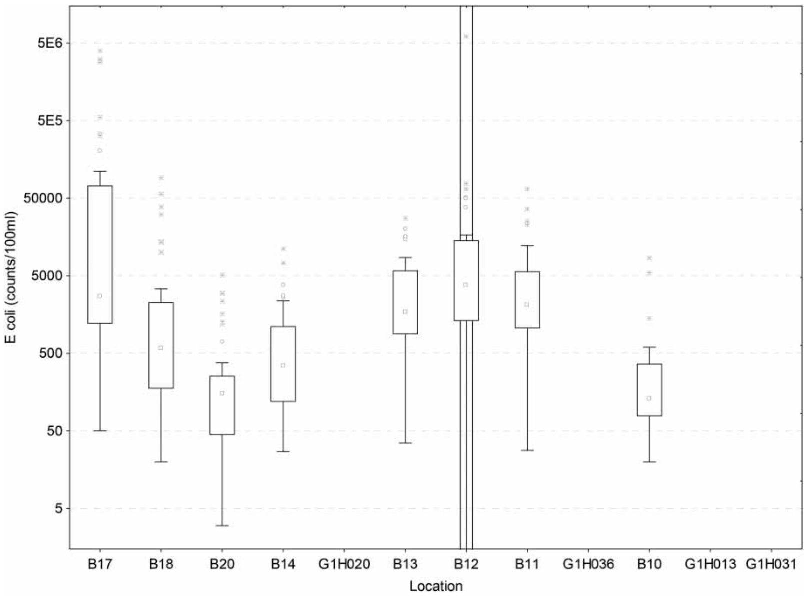

Figure 6 | Microbial water quality results for the Berg River from upstream (B17) to downstream (G1H031). The median values for each location are shown in the centre of the box which represents the upper and lower quartile. The whiskers represent the 5th and 95th percentile and the other dots indicate extreme, or possible outlier results.

amount of fresh water entering the system. However, due to the irrigation releases from the Berg River Dam during the summer months, the salinity is reduced. Towards the end of the growing season, as the irrigation releases decrease, there is an increase in the salinity concentrations The general downstream increase in salinity or electrical conductivity (EC), shown in Figure 5 and the seasonal trend is an indication that agriculture is having some impact on water quality, but as evidenced in the changes in EC through Wellington, Mbekweni and Paarl, it is highly likely that these urban and informal areas are also contributing to the increase in EC.

The *E. coli* levels and distribution along the water course, shown in Figure 6, clearly highlights two-potential sources of faecal pollution – (1) WWTW that are not compliant and (2) drainage from informal settlements. This conclusion is based on the following observations:

1. There is evidence below monitoring point B21, where the Stiebeuels River draining Langrug informal settlement joins the Berg River, that the *E. coli* levels are elevated. Based on the data there appears to have been a seasonal trend during 2014–2015 with the peak concentrations found during winter. Interestingly, during 2016–2017 the seasonality has reversed, with winter concentrations remaining approximately the same as during the 2014–2015 period. This may be due to the build-up of faecal waste in the drainage system draining the Langrug informal settlement – which would normally have been washed out during the winter season but has not due to the drought (2015–2017).
2. The releases from the Berg River Dam as well as the relatively un-impacted flows in the Dwars River appear to dilute the *E. coli* concentrations and contribute to an improvement in water quality until the river reaches Paarl (B20). Also due to the benefits of natural river functioning.
3. The increase in *E. coli* levels between upstream (B14) and downstream (B12) of the Paarl WWTW and the Mbekweni informal settlement is a further indication of the impact of inadequately serviced settlements and struggling WWTW, on the water quality in the catchment.

The level of compliance with microbial pollutants is of concern as these have a direct link to international standards for crop exports. The financial flows from these exports form a significant part of the local and national economy and so the quality of irrigated water from the Berg River needs to be managed. *E. coli*, an indication of faecal pollution, is typically at 'tolerable' and 'unacceptable' levels throughout the upper reaches of the Berg River Catchment. *E. coli* only shows consistently acceptable levels in the vicinity of the Misverstand Dam – well downstream of most urban areas.

The compliance summary for the WWTW along the Berg River, shown in Table 4 indicates significant long-term compliance – especially microbiological and chemical – challenges for a number of the WWTW in the upper catchment. Addressing these deficiencies through the rehabilitation and upgrading of the relevant treatment plants is critical. Upgrading the treatment plants, however, will not entirely eliminate the risk of pollution without also addressing the concerns about the non-point source pollution impacts from informal settlements. The decrease in the *E. coli* concentrations further downstream, however, also indicates the importance of maintaining river functioning as these natural processes do assist in mitigating the downstream risks associated with upstream development and poorly functioning WWTW. The protection and rehabilitation of instream habitats and riparian banks is therefore critical and is a primary focus of the interventions of the Berg River Improvement Project.

Table 4 | State of compliance of WWTW in the Berg River Catchment

WWTW name	Capacity (ML/d)	Monitoring compliance (%)	Microbial compliance (%)	Physical compliance (%)	Chemical compliance (%)
Saron	1	98.58	75	94.06	73.91
Hermon	0.3	100	0	0	0
Pearl Valley	2	100	44.57	94.49	69.57
Paarl	35	97.67	80.43	91.06	39.53
Wellington (*Note:* Wellington has not discharged into the river since 2013. Sewage is pumped to Paarl WWTW during upgrade)	7 (currently being upgraded to 16)	100	62.5	92.67	76.81
Gouda	0.64	100	100	90.91	11.76
Wemmershoek	5	90.33	72.73	83.72	90.91
Pniel	1.315	97.5	91.67	82.22	60.42

Source: DWS Greendrop Drop Report (January 2018).

Drought impacts and climate change

While climate change is considered to have a major impact on the water resources of South Africa, there exists significant uncertainty regarding the specific impacts on the Berg River Catchment, particularly in terms of the potential for a decrease in runoff. Using a 10-year moving average (Figure 7), there appears to be little change in the annual runoff – this could in part be 'masked' by how the Berg

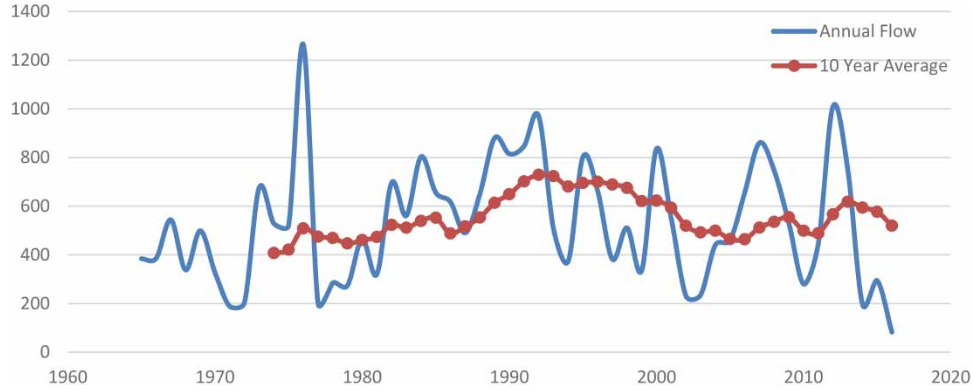

Figure 7 | Changes in the annual and 10-year moving average for flow (Mm^3/a) in the Berg River at G1H013.

River Dam is operated and the relatively short record since its construction. It is apparent that there is significant variability in rainfall between years, and that the period 1985–1995 had higher than average runoff, but based on the available flow data it is difficult to conclusively note any climate change impacts. While there appears to be little change in runoff since 1995, indications are that in the long term it is more likely that flows in the river will decrease (DEA 2013; Cullis *et al.* 2015).

More importantly, while the long-term averages may not change, extremes may become more frequent. This could prove significant as the flux of pollutants is not directly proportional to rainfall and flow – especially for point sources such as WWTW and drainage discharges from informal settlements. As such, the concentrations of pollutants from these sources will likely increase substantially during periods of drought. This is particularly evident in the increase in all pollution parameters between upstream (B14) and downstream (B12) of the Paarl WWTW and the Mbekweni informal settlement during 2016–2017 – as the region experienced drought conditions. A comparison of the water quality results from 2013 to 2014 (wet years) vs 2016 to 2017 (dry years) shows a significant difference in the water quality concentrations indicating the potential impact the more frequent dry years could have on the overall water quality of the Berg River (Figure 8). In addition, increasing

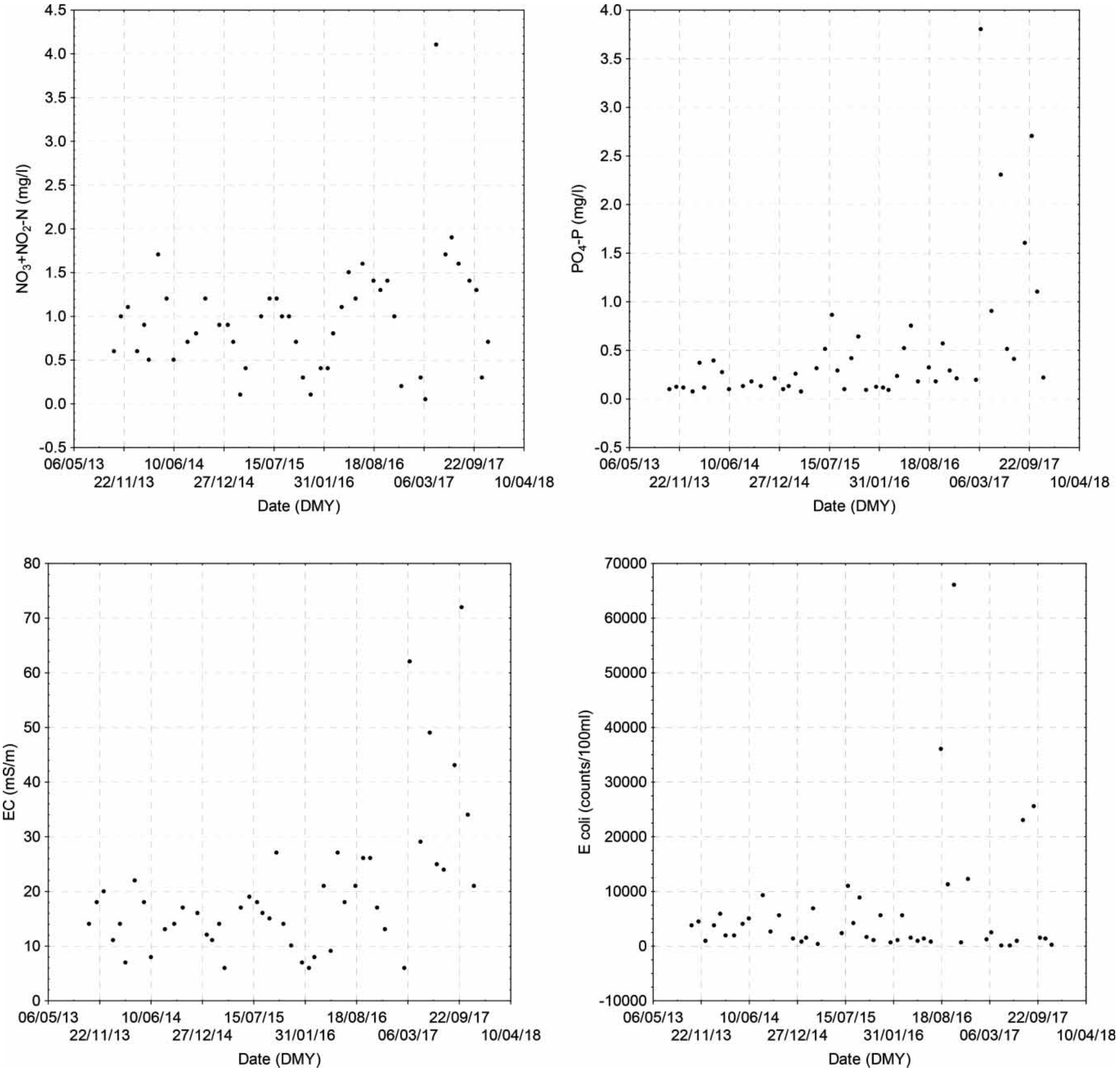

Figure 8 | Time series of selected water quality parameters at site B11, downstream of Wellington WWTW showing the impact of the drought, particularly the very low flows and high concentrations in 2017.

temperatures due to climate change are likely to result in higher demands for water, which would result in even less streamflow being maintained in the river to assist in the dilution of the pollution impacts due to both urban and agricultural development.

Economic impacts of declining water quality on the agricultural sector

The diversity of agricultural activity in the Berg River Catchment can be subdivided into a number of smaller homogeneous production areas. These include:

1. Franschhoek: Wine grapes, stone fruit and pome fruit
2. Paarl: Table grapes, wine grapes and stone fruit
3. Wellington: Wine grapes, table grapes and stone fruit
4. Swartland: Winter cereals, small stock and potatoes.

Table 5 indicates the actual and relative size of the different farming activities. The area is clearly an important producer of table grapes and wine grapes, as in this area, there are 120 out of a total of only 493 private wine cellars across the whole of South Africa. This shows the agricultural value adding that is produced within the Berg River irrigation area, particularly in terms of export earnings and tourism.

Table 5 | The actual and relative (to South Africa) contribution of table grape production, wine grape production and fruit production of the Berg River area

	Actual	**% of South African total**
Table grapes (4.5 kg carton equivalent)	15,426,175	23%
Wine grapes (number of vines)	45,876,435	16.17%
Fruit		
Nectarines (ha)	210	9.9%
Pears (ha)	132	1.1%

Sources: SATI (2017), SAWIS (2016) and Vinpro (2017).

The figures in Table 5 are calculated from the agricultural industry information that is published annually. It shows the importance of agricultural activity in an area where the economic activities in the area are further strongly linked to farming, such as agri-processing and tourism.

Table 6 shows the importance of agriculture as a contributor to employment and the money spent on labour, as a significant component of the expenditure on intermediaries. The potential farm-level financial impacts if irrigation water quality deteriorates would directly impact on the producers' income first of all, which would affect their ability to employ farm labour. If structural adaptations are made, such as a move towards wine grape production and away from table grape production, it will have a decreasing impact on all inputs, but especially direct employment on farm level. There

Table 6 | The economic contribution of the main farming activities as expressed in expenditure on intermediaries (inputs), the producers' income and expenditure on labour

	Expenditure on intermediaries	**Producers' income**	**Expenditure on labour**[a]
Table grapes	454,844,220	570,768,475	285,640,510
Wine grapes	575,658,720	813,351,000	205,042,320
Fruit			
Nectarines	30,624,510	47,411,100	4,393,200
Pears	26,182,068	35,128,632	3,119,556

[a] Expenditure on labour is included in total intermediaries.

would be a necessary time lag to put these physical changes into place. This is a likely scenario if water quality deteriorates to the extent that export phytosanitary standards for fruit and table grapes are not met.

Table 7 shows the farm size and cultivated area for the typical farm in each relatively homogenous area of the Berg River. Table 8 presents the land use pattern for the typical farm for each of the relatively homogeneous areas of the Berg River. The land use patterns were identified in the same way as the farm description. Franschhoek is mostly a wine grape production area with some fruit production, while table grapes and fruit predominate in Paarl and Wellington. The Swartland farm is in the Sandveld area closer to the Atlantic Ocean and some centre-pivot irrigation is used in combination with rain-fed winter cereal and pasture farming.

Table 7 | Farm size and land use for the typical farm of each relatively homogenous area

	Farm size	Cultivated land
Franschhoek	150 ha	69 ha
Paarl	200 ha	69 ha
Wellington	130 ha	60 ha
Swartland	850 ha	822 ha

Profitability is measured in IRR and NPV in capital budgeting, which means a figure is required on the investment value. This is expressed in capital requirement for each of the typical farms and is presented in Table 9. The land prices and farm size are the main contributors to capital requirement. The typical farm for Paarl and Wellington shows a relatively higher requirement for fixed improvements due to packing and cooling facilities. The structure of the Swartland farm is completely different with much less infrastructure, but an added livestock component.

Table 10 shows the expected IRR and NPV for the typical farm for each relatively homogenous area. This is for scenario 1 and thus assume normal export expectations based on sustained water availability and quality. An important consideration is that the profitability for the Franschhoek farm is calculated for grape production, in other words, for the farming side and not the cellar where wine making and value adding takes place. This value-added wine production is expected to have a much higher profitability.

Table 11 shows the expected profitability, namely, IRR and NPV, for the typical farms should water quantity or quality decrease to force producers to move from table grapes to wine grapes, and at lower yields. Quality will mostly affect market access and price. The price of red wine grapes at lower yields may increase for selected red wine cultivars (Louw 2015). For the Swartland, the potato area was simply decreased. The effect on the profitability of wine grape farming will possibly be worse as the infrastructure change for the setting up of additional cellars was not incorporated in the model. Producers will also need to take up shares in cellars to be able to deliver wine grapes.

The third scenario entails the establishment of a water purification plant to remedy the water quality deterioration. This comes at a minimum cost of R1.5 m to the private producer. In this scenario, the infrastructure cost is added and electricity cost is increased. Table 12 shows the expected IRR and NPV for the cost of water purification scenario. In all probability, the Swartland producer will either stop producing potatoes or would produce them with lower water quality.

The results of this analysis show the significant reduction in both IRR and NPV due to a decrease in either water quantity or water quantity. As has been explored earlier, this decrease in water quality (and quantity) is most likely as a result of the pressures of rapid urbanisation and possible climate change impacts. The impact of decreasing water quality is to reduce the expected NPV by between 25% and 60%, which would have a serious negative impact on the local economy, as well as the potential for job creation and foreign earnings due to the export nature of the agriculture sector in this region. The

Table 8 | Land use pattern (hectare) for each typical farm for the Berg River irrigation area

	Franschhoek Ha	Paarl Ha	Wellington Ha	Swartland Ha
Wine grapes				
Chenin blanc	9.1	4.3	5.3	
Colombard	2.9	5.6	1.7	
Sauvignon blanc	2.9	4.3	1.7	
Chardonnay	6.6	5.0	3.8	
Cabernet sauvignon	10.4	4.0	6.0	
Pinotage	3.7	3.4	2.2	
Shiraz	3.7	2.8	2.2	
Merlot	2.1	1.6	1.2	
Ruby cabernet	2.5	1.9	1.4	
Peaches				
Keisie	3.5	1.3	2.3	
Kakemas	3.5	1.3	2.3	
Oom Sarel	2.5	0.9	1.6	
Sandvliet	0.8	0.3	0.5	
Neethlings	0.6	0.2	0.4	
Malherbes	1.0	0.4	0.6	
Cascade	2.1	0.8	1.4	
Plums				
Souvenir	2.8	1.0	1.8	
Harry Pickstone	4.1	1.6	2.7	
Apricots	6.9	2.6	4.5	
Table grapes				
Crimson seedless		4.1	2.7	
Red globe		5.2	3.4	
Sugranineteen		4.1	2.7	
Thomson seedless		4.7	3.1	
Regal		3.9	2.5	
Dun-ben-hanna		2.2	1.4	
Autumn royal		1.7	1.1	
Sunred seedless		1.7	1.1	
Rain-fed crops				
Winter cereals				603
Pastures				149
Vegetables				
Potatoes				25

Table 9 | Capital investment requirement for the typical farm for each relatively homogeneous area in the Berg River area

	Franschhoek	Paarl	Wellington	Swartland
Land	R 33,201,000	R 33,251,000	R 28,774,200	R 51,000 000
Fixed improvements	R 10,531,583	R 14,398,250	R 14,317,250	R 2,895,000
Movables	R 7,284,456	R 7,753,456	R 8,254,592	R 5,487,641
Livestock				R 964,901
Total:	R 51,017,039	R 55,402,706	R 51,346,042	R 60,347,542

Table 10 | The expected IRR and NPV for the typical farm of each relatively homogeneous area under normal export expectations (scenario 1)

	Expected IRR %	Expected NPV (R/farm)
Franschhoek	3.16%	R 5,158,880
Paarl	9.17%	R 43,424,956
Wellington	7.46%	R 29,545,468
Swartland	5.01%	R 22,419,280

Table 11 | The effect of decreases in quantity or quality of irrigation water on the IRR and NPV for each relatively homogeneous area of the Berg River (scenario 2)

	Expected IRR %	Expected NPV (R/farm)
Franschhoek	2.08%	−R 2,184,242
Paarl	4.84%	R 16,616,521
Wellington	4.36%	R 11,909,278
Swartland	4.32%	R 16,612,664

Table 12 | The IRR and NPV for the typical farm for each relatively homogeneous area with a water purification system introduced to mitigate the impact of decreasing water quality in the Berg River (scenario 3)

	Expected IRR %	Expected NPV (R/farm)
Franschhoek	2.87%	R 3,360,167
Paarl	8.44%	R 40,463,301
Wellington	6.74%	R 26,583,814
Swartland	4.92%	R 26,963,101

fact that farms in the Franschoek area could experience a negative NPV due to declining water quality is particularly concerning as this would make agriculture essentially unviable in this region. This is significant not only for the agriculture sector, but also because the wine farms in this region are a significant contributor to the local (and international) tourism and are a significant source of job creation.

Under scenario 3, the NPV and IRR are returned to similar levels as for scenario 1. This would suggest that investing in on-farm water treatment to treat the irrigation water from the Berg River is a viable investment due to the threat of declining water quality. There are however alternative mitigation options that should also be considered as these could potentially be more cost-effective. These include piping water directly from the major dams to the indiviudal farms and not using the river as a conveyance channel, or alternatively finding solutions to the causes of the water quality risk. The latter solution, while preferable, has many challenges associated with the provision of basic services in a developing country context such as South Africa, which in itself is another wicked problem (Govender 2016). As has been shown in terms of the analysis of the water quality data along the length of the Berg River, the importance of maintaining functioning stream ecosystems to reduce the water quality risks is also critical.

RECOMMENDATIONS

The provision of water services in a developing country context

The provision and management of services in a developing country context is challenging, particularly in areas where there are historic infrastructure backlogs and high unemployment. Govender (2016) considers that service delivery has complexity, uncertainty and power inequalities among stakeholders. Addressing historic legacies of poor service provision and the associated backlogs is a significant challenge for any government and can create a moral dilemma. OECD (2017) highlights that while 'wicked problems', as first defined by Rittel & Webber (1973), may have a number of characteristics, they are particularly difficult for governments to manage as they cannot be '*solved only by partial or transactional solutions, but rather require concerted, adaptive and carefully stewarded approaches*'.

The management of water pollution in the Berg River is very complex and is considered to be a 'wicked problem' as it has multiple conflicting interests, affects multiple levels of government and impacts on the livelihoods of a significant number of people. Additionally, solutions for any one challenge are likely to impact or cause other challenges. Managing water quality is further complicated due to the Berg River crossing multiple administrative boundaries, a varied and diverse land use within the catchment, and not least, the complexities of water chemistry and the uncertainty of the sources of pollution once they reach the river. The results of this study however show that it is critical to address these challenges as the associated financial and economic impacts of a continued decline in water quality are significant.

Economic risks from declining water quality

Louw (2012) highlights the significant economic impact that poor water quality in the Berg River could have on the economy of the regional economy, resulting from poor sanitation service provision, agriculture and other practices. While Louw (2012) did not link their economic findings to specific water quality levels, he clearly demonstrated that if water quality continues to deteriorate to the point where international exports are affected, the economic consequences would be considerable. De Villiers (2007) indicates that from 1985 to 2005 there was a trend of increasing nutrient levels in the Berg River.

Managing current and future water quality risks

Up to a point, the receiving environment, such as a river, can provide ecosystem services by reducing the pollution loads through a combination of dilution and ecological processes. In the case of riparian systems, and in particular wetland areas, this can be significant (Turpie *et al.* 2010). However, as discussed above, the Berg River is not expected to benefit from increased runoff volumes but is expected to see an increase in total population and levels of urbanisation. This will further add to the risks around water quality, water security and economic sustainability and so the risks to the agricultural sector might therefore increase. The local (South African) context further adds to the risks of the complexities of service provision against an historical background whereby, since a system previously existed of limiting the access of indigenous people to the urban areas, there has been an influx of people since the early 1990s.

This urban population increase has created a backlog and added to the difficulties of delivering services to those who historically do not have them while concurrently meeting the demand for services from an increasing and urbanising population. The management of water quality in such a catchment is a complex, but important issue, owing to the diversity in types and sources of pollution. The management of pollution in a catchment where there are multiple municipalities involved, and pollution control measures have been set by a higher authority – such as the DWS – is particularly challenging. However, even within a single municipality where different departments have competing objectives, there can be significant challenges to implementation (Fisher-Jeffes *et al.* 2012).

CONCLUSION

Urbanisation and climate change are likely two of the most defining occurrences of the 20th and 21st centuries. The Berg River in South Africa, like many other catchments, particularly in the developing world, falls within a catchment that is experiencing increasing levels of urbanisation, the impacts of climate change, the 'wicked problem' of service delivery to the historically disadvantaged within a developing country, persistent infrastructure backlogs, and where high unemployment is prevalent. Building on the previous investigations looking at water quality in the Berg River, it is evident that the state of the river requires management, and at places along the river is potentially unsuitable for irrigation.

The results of this study indicate that while agriculture may, and it is not certain, be reducing its impact on the river, the impact of urbanisation is undoubtedly increasing. The impact of urbanisation is primarily from three sources: effluent discharges from WWTW, drainage stormwater from informal settlements, and stormwater from formal fully serviced settlements. Added to this is the threat of climate change. The whole-farm costing in this paper has shown that the economic consequences of deteriorating water quality in the Berg River is potentially quite severe. The alternative, considered in this paper, was for the agricultural sector to protect the industry by investing in treating the water prior to irrigation. This too would have significant, albeit not as severe, economic consequences for the agricultural sector and while it is a possible option for mitigation, it is critical to explore other options such as improved provision of basic services or the rehabilitation and protection of natural systems that have other potential benefits.

The Berg River is not unique in that many catchments face similar challenges, particularly in the developing world. As a result, the lesson learnt from this study, and in general, the lessons learnt from the Cape Town drought crisis, are globally relevant. The intention of this study was to indicate the importance of making investments into mitigating the significant impact of declining water quality, particularly in terms of investment in the upgrading of treatment plants and the protection of ecological infrastructure.

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