A comparative assessment of water use by *Acacia longifolia* invasions occurring on hillslopes and riparian zones in the Cape Agulhas region of South Africa.

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Abstract

The detrimental impacts of invasive alien plants on ecosystems and water resources have raised concerns in dry countries like South Africa where the average precipitation is approximately 500 mm/y~~ea~~r, which is below the world average of around 860 mm/y~~ea~~r. Several studies have examined the effects of invasive alien plants such as the Australian Acacias on the~~South Africa's~~ water resources. However, no ~~There has however not been a~~ study has ~~investigat~~quantif~~ing~~ied the differences in water use~~ rates~~ between hillslope and riparian *Acacia longifolia* invasions~~ in South Africa~~. *A*.~~*cacia*~~ *longifolia* is one of the ~~problematic~~aggressive inva~~sive alien plants~~der species in South Africa and yet~~.~~ ~~H~~hillslopes contribute substantially to runoff ~~generation, and therefore~~generation. Therefore, the encroachment of~~ hillslopes by~~ invasive alien plants ~~occurring on these areas have the~~can ~~potential to reduce~~potentially reduce runoff~~,~~ thereby~~and thus~~ adversely affecting the available water ~~resources at the catchment scale~~downstream. This paper aims to:~~;~~ 1) ~~determin~~compare transpiration rates of~~by~~ *A. longifolia* growing on hillslopes and along riparian areas;~~,~~ 2) establish the key drivers for ~~transpiration rates~~water use by this species,~~,~~ and; 3) estimate the hydrological impacts of the invasions at the catchment scale in the Heuningnes catchment ~~which is~~ in the Western Cape Province of South Africa. T~~he water use rates~~ranspiration by the trees~~A. longifolia~~ was~~ere~~ measur~~determin~~ed using the h~~H~~eat ratio~~Pulse Velocity (HPV)~~ sap flow method~~technique~~. A~~n a~~utomatic weather stations and soil moisture sensors were used to monitor weather and soil water content variations at each site. The results showed that, at the stand level the riparian *A. longifolia* transpired two times more water (~596 mm/yr) than on the hillslope (~242 mm/yr). During years with above average ~~above the average ~~rainfall~~ above the average~~, the ~~the ~~water use rates by ~~A. longifolia~~the invasions was estimated to be ~579 mm/yr on the hillslope and could be as much as ~1 348 mm/yr at the

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riparian site. Thus, the hypothesis that riparian trees use more water than invasions on non-riparian areas was accepted in this study. ~~At the~~At the catchment scale, the estimated water use by the invasions~~ve alien plants~~ was 20.5 Mm^3/year. Clearing of all the invasions in the study catchment ~~is~~would likely ~~to~~ make 17 Mm^3/year of water available. Hence the clearing of *A. longifolia* along riparian corridors should be prioritised ~~in the riparian areas~~ as this will lead to water savings at the catchment scale.

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Most parts of sub-Saharan Africa are semi-arid to arid with actual evapotranspiration dominating the terrestrial hydrological cycle. Water resources assessments such as the WR2012 for South Africa (Bailey and Pitman, 2017) show that the mean annual runoff is generally less than 10% of the mean annual rainfall. Thus, evapotranspiration is greater than 90% of the annual rainfall in most parts of South Africa and elsewhere in the arid regions. Several studies in South Africa have demonstrated that land use and land cover changes often increase evapotranspiration rates which adversely affect the available water resources in a region that is already water scarce (Scott *et al.*, 2006; Bullock and Acreman, 2003). The invasion of indigenous vegetation by Invasive Alien Plants (IAPs) has been shown to reduce the available water resources due to their higher water use rates. Studies by Enright (2000), Le Maitre *et al.* (2002), Chamier *et al.* (2012), Dzikiti *et al.* (2013), and Meijninger and Jarmain (2014) showed that the Australian *Acacia*, *Eucalyptus* and *Pinus* genera have the largest impact on South Africa’s water resources. The increase in evapotranspiration rates reduce stream flows (Prinsloo and Scott, 1999), and lowers groundwater levels (Scott *et al.*, 2008; Dzikiti *et al.*, 2013b~~;~~). Besides their hydrological impacts, invasive alien plants threaten the biological diversity by ~~eroding gene pools,~~ outcompeting the indigenous species which consequently result~~ing~~ in the extinction of endemic species, especially in freshwater ecosystems (Bonanno, 2016). They also ~~occupy~~ invade and occupy grazing land thereby threatening the livelihoods of farmers (Ndhlovu *et al.*, 2011).

The water use rates of o~~O~~ne of the problematic invasive alien plants (IAP) in South Africa, ~~is~~ *Acacia longifolia*, ~~with water use rates that~~ have never been investigated. *Acacia longifolia*, which is commonly known as the “long-leaved wattle”, is an evergreen shrub/tree with bright yellow flowers that sprout from August to October in South Africa. This plant can grow between 2 to 8 meters in height (Morais *et al.*, 2015). The species was primarily introduced in South Africa around 1864 for ornamental purposes and for sand dune stabilization (Richardson *et al.,* 1997). However, this species has now spread beyond the initially planted area and ~~has~~ beca~~o~~me highly invasive. *Acacia longifolia* is highly problematic in the wetter parts of the Western Cape, Eastern Cape, Kwa-Zulu Natal and parts of Mpumalanga Province (Henderson, 2001). Consequently, *A. longifolia* is considered as ~~a~~ Category 1b invader, according to the South African National Environment Management: Biodiversity Act (DEA, 2014). This means that 1) importing into the country, 2) growing, breeding or any other form of propagation, and 3) selling or trading in any specimen of the species are prohibited to reduce the spread and impacts of these invasions.

Invasive alien plants occurring within riparian zones tend to have access to multiple sources of water resulting in very high transpiration rates (Le Maitre *et al.*, 2000; 2004). Invasive alien plants are also spreading into hillslopes in mountainous areas of countries like South Africa. The mountain areas are regarded globally as strategic water source areas or water towers that require high levels of conservation to ensure sustainable water supply (Messerli *et al.,* 2004). In South Africa, 50% of the runoff is generated from 8% of the land area comprising mostly mountain catchments (Nel, 2013). The spread of IAPs onto hillslopes is therefore a major threat to the availability of water resources. However, few studies have compared the water use rates of IAPs growing along riparian zones and on hillslopes.

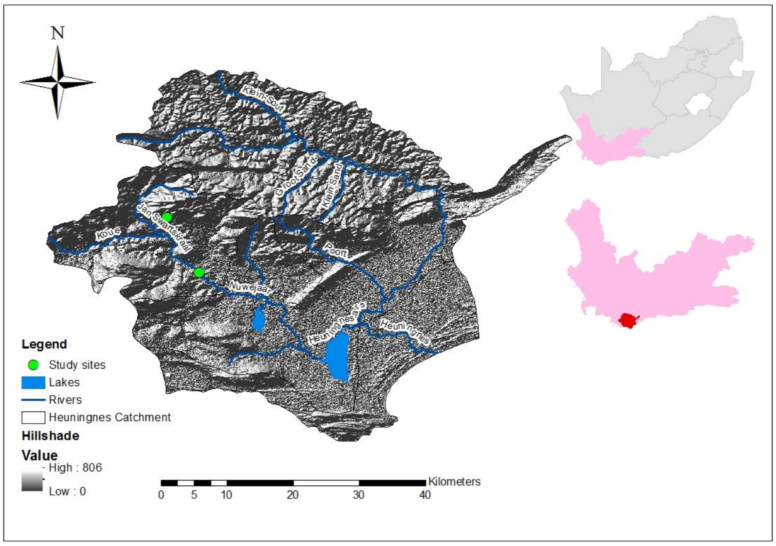
Catchments in the Cape Agulhas region are experiencing rapid expansion of areas affected by IAPs along both riparian zones and hillslopes (Kotze *et al.*, 2010). These catchments have headwaters in mountains and low gradient coastal lowlands. Organizations involved with alien plant clearing, such as South Africa's Working for Water Programme, prioritise their operations based on the assumption that riparian invasions use twice as much water as those growing in non-riparian settings. Detailed scientific evidence based on actual measurements of plant water use and its drivers are needed for accurate decision making and for resource allocation in alien plant clearing programmes. The catchment scale impacts of water use by IAPs on hillslope and riparian zones are also unknown. The objectives of this study were to; 1) quantify and compare the transpiration rates of *A. longifolia* growing on hillslopes and riparian zones, 2) investigate and document key drivers of water use by ~~invasions~~ IAPs in the different topographical settings, and 3) estimate the hydrological impacts of the invasions at the catchment scale.

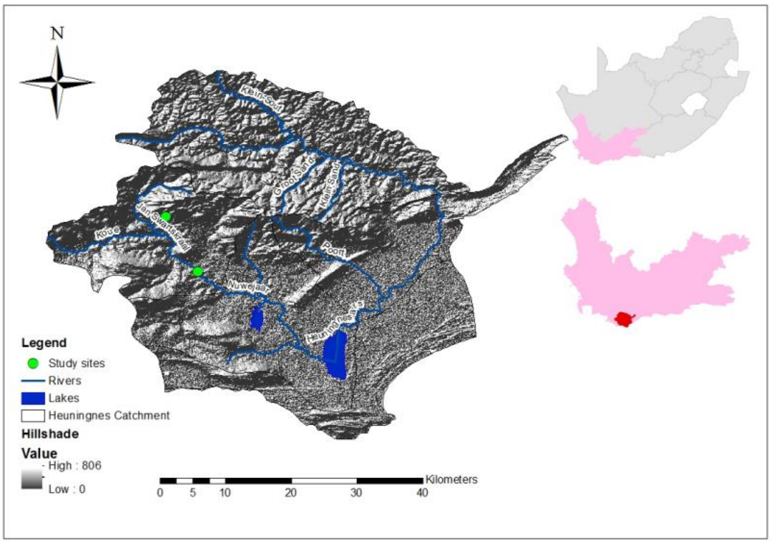
~~4.~~2. Materials and methods

This study was undertaken in the Nuwejaars Catchment from June 2016 to June 2017 ~~which enabled covering~~during the wet season (June – September 2016) and the dry season (November 2016 – March 2017).

2.1 Study area

The Nuwejaars Catchment covers an area of 740 km^2 in the Cape Agulhas region, which is the southern-most part of Africa~~.~~ (Figure 1). Mountainous areas cover the north-west, northern, and northern eastern parts of the catchment with altitude ~~varying~~ ranging from 200 to 600 m above sea level. Altitude decreases sharply to less than 100 m after about 10 km along the main river, followed by lowlands that are 10 – 60 m above sea level. Numerous wetlands in the form of pans, floodplain wetlands, and lakes occur within the lowland area. The Nuwejaars River passes through a floodplain wetland with the width reaching up to 0.8 km. This river discharges into a lake, Soetendalsvlei, which is 3 km wide and 8 km long. Soetendalsvlei discharges into the Heuningnes River that flows into the Indian Ocean.





The study area has a Mediterranean climate characterised by wet winters from mid-May to late August, and dry summers, November to March. Annual rainfall varies from 400 to 600 mm/yr, with a mean annual of 650 mm/yr on the hills that form the northern watershed

(Herdien *et al.*, 1995; Kraaij *et al.*, 2009). Maximum temperatures (27 °C) occur in January and the minimum temperatures (8 °C) occur in July and August (Hanekom, Russell and Randall, 2009; Herdien *et al.*, 2010; Hoekstra and Waller, 2014). Most streams draining from the mountainous headwaters are perennial due to springs that maintain their flows throughout the year. However, the main river, Nuwejaars River, is non-perennial and mostly flows from May to December, and then dries up for the rest of the year. This river has numerous pools that have water throughout the year. The water table is quite shallow, generally less than 3.0 m in the riparian zone and floodplain of the Nuwejaars River. On the hillslopes the depth to the water table is variable, 3 – 10 m.

The indigenous vegetation is mainly fynbos, which is a sclerophyllous scrub dominated by species of the *Proteaceae*, *Ericaceae* and *Restionaceae* that are typical of the Cape Floral region (Scott, 1999; Mucina and Rutherford, 2006). In the floodplains, sedges, reeds, restios and grass on drier land are dominant. About 41% of the catchment is under agriculture involving commercial dryland crop production (wheat, barley, etc.), sheep and cattle production, irrigated vine yards and orchards, and commercial forestry (Herdien *et al.*, 2010). According to the National Invasive Alien Plant Survey done by Kotze *et al.* (2010), the invasive alien plants ~~affected~~ cover 265.1 km^2 or 35% of the Nuwejaars Catchment. The dense bushes in the catchments are ~~dominated~~ mostly formed by ~~invasive alien plants~~IAPs (Figure 2). IAPs occur in riparian zones and all the hillslopes in this catchment, and ~~have on some locations~~often form dense and impenetrable stands. Landowners formed a Nuwejaars Wetland Special Management Area forum that aims to improve biodiversity of water-related ecosystems. Coordinated clearing of invasive alien plants is one of the major activities they are undertaking. This complements the Working for Water Programme.

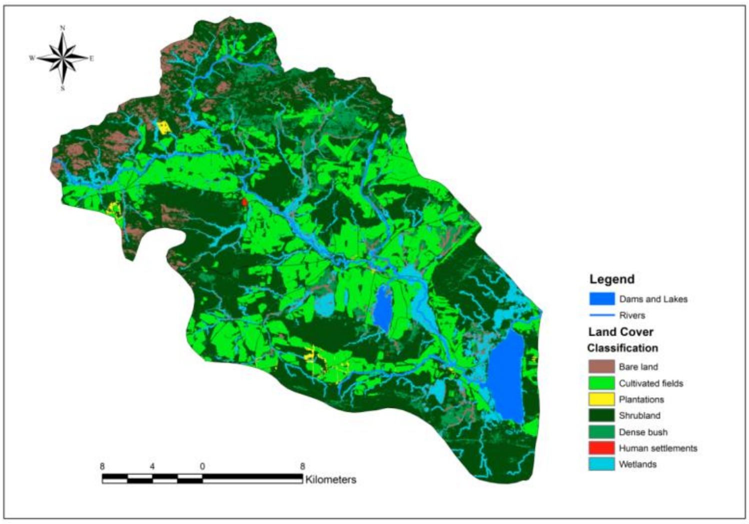


Figure 2: The land cover map of the Nuwejaars catchment

2.2 Study sites

The study required two sites, a hillslope and a riparian site with actively growing stands of *Acacia longifolia*. Several sites were evaluated with the assistance of the coordinator of the IAP clearing programme run by the Nuwejaars Wetland Special Management Area forum. Since all the land in this catchment is privately owned, permission was sought from the respective landowner to install and regularly monitor the sites. The hillslope site ~~is~~ was located on the northern part of the catchment and on the southern slopes of the Bredasdorp Hills. The area is locally known as Spanjaardskloof (34° 31’ 45.7’’ S, 19° 45’ 9.2’’ E), and the selected site ~~is~~ was at an altitude of 125 m and 1.7 km from the hilltop which has an altitude of 430 m. ~~Baboons which can damage monitoring equipment used in this study,~~This site was selected to minimise damage to monitoring equipment from baboons that frequently roam ~~locations with~~at altitude ranging from 200 to 450 m on this hill. ~~Therefore this hillslope site below 200 m altitude was selected in order to minimize damage of equipment by baboons.~~ Also, t~~T~~he presence of suitable trees sizes for transpiration monitoring also influenced the exact site chosen on the hillslope. The riparian site was located less than 20 m from the Nuwejaars River channel which had a 0.8 km wide floodplain ~~in~~ at the Zoetendals

Farm (34° 36’ 15.8’’ S, 19° 47’ 46.7’’ E). This floodplain is locally referred to as the Moddervlei, and has an elevation of 25 m above sea level. *A. longifolia* occurred as a dense stand 120 m wide along the right bank of the Nuwejaars River. The hillslope and riparian sites were 9.5 km apart. Soils at the riparian site varied from deep sandy alluvial soils close to the river channel to dark red clayey loam soils further from the stream channel. At the hillslope site, the soils were shallow loamy soils dominated by boulders and rocks.

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The invasions at the riparian site comprised tall trees with thick stems and an average height between~~,~~ 7, 0 - 10 m. There was dense undergrowth ~~which~~ that was a mixture of *A. longifolia* trees and the indigenous ~~shrubby~~ ~~tree,~~ *Kiggelaria africana* (wild peach) trees. Most of the undergrowth was in a poor state and dying either due to the drought ~~during~~ which persisted through ~~the~~ 2016/17 ~~season~~ or due to lack of light as a result of shading by the taller trees. ~~The root system of the riparian trees was fairly shallow, approximately less than 80 cm deep, presumably due to soil water abundance during wet years.~~ The stand characteristics at the hillslope site were somewhat different from those at the riparian site, which ~~reflecting differences in the~~influenced the growing conditions. Trees at the hillslope site had thinner stems, and they were shorter with the height varying from 3.0 - 6.0 m. The forest floor was mostly clear of vegetation although dense grass occurred in open spaces. ~~The trees had shallow root systems.~~

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2.3 Climate data

The microclimate at each site was monitored using an automatic weather station measuring solar irradiance, ambient temperature, relative humidity, wind speed, wind direction, and rainfall. The sensors were installed 2.0 m above the ground and the stations were on a short grass surface. This data was used to calculate the reference evapotranspiration (ETo) according to the FAO 56 guidelines (Allen *et al.*, 1998). All the sensors were connected to a data logger that was programmed to ~~store~~ record data at 15 minutes intervals throughout the duration of the study. Solar panels were used to charge batteries that powered the stations. The hillslope weather station was located at 81 m altitude approximately 1.5 km from the invaded hillslope site, this station was installed for an on-going monitoring project in the catchment . The riparian weather station was located 90 m from the invaded site at an altitude of 25 m above sea level.

2.4 Transpiration, growth, and soil water measurements

Water use rates by *Acacia longifolia* trees at each site were determined from sap flow measurements using the heat ratio method of the Heat Pulse Velocity (HPV) sap flow technique (Burgess *et al.*, 2001). At the hillslope site, data were collected from three neighbouring trees with stem diameters of 15, 29, and 40 cm at breast height, and representative of the stem size distribution at this site. Similarly, three trees with stem diameters of 19, 53, and 58 cm were instrumented at the riparian site. The HPV method has been found to be appropriate and cost-effective for transpiration measurement of various tree species (Clulow *et al.*, 2013; Dzikiti *et al.*, 2013, 2016, 2017; Everson *et al*~~;~~., 2014; Ntshidi *et al.*,2018; Scott-Shaw *et al.*, 2017). A metal template with three holes spaced 5 mm apart was used to drill the holes in the stems to minimize probe misalignment. The HPV system comprised heaters implanted into the stems and connected to custom-made relay control modules which controlled the heat application. Two T-type thermocouple pairs which measure the sapwood temperature were installed ~0.5 cm above and below each heater probe. The thermocouples were connected to multiplexers (Model: AM16/32B Campbell Scientific, Logan UT, USA), which were in turn connected to CR1000 data loggers. Four sets of sensors were installed in the four cardinal directions around the stem on each of the six trees. The sensors were inserted at different depths into the sapwood to account for the radial variation in sap velocity (Wullschleger and King, 2000).

Each system was powered using one 105Ah battery. Methylene blue dye was injected in the stems to determine the extent of the active xylem vessels (sapwood depth) into which the thermocouples were inserted into. The average bark thickness was about 3 and 5 mm whilst the wood density averaged 0.7 g/cm^3, and the moisture fraction was 55 % and 63% on the hillslope and riparian site, respectively. The thermocouples were inserted into the sapwood at depths ranging from 12 – 40 mm on the hillslope, and 10 – 50 mm at the riparian site. The volumes of water transpired by the instrumented trees were estimated by converting the HPV signals into sap velocities. This was done by correcting for moisture fraction of the wood, wood density, and wounding due to sensor implantation (Swanson and Whitfield, 1981). Total sap flow of the individual trees was calculated by summing the product of the mean sap velocity and sap wood areas corresponding to the sampled areas (Dzikiti *et al.*, 2013; 2016).

Tree density at each site was estimated by counting the number of trees in four 10 m x 10 m quadrants. The number of trees per quadrant was then used to estimate the average density of trees per hectare. The stem size distributions were estimated by measuring diameters of forty randomly selected trees at breast height at each site. This information was used to establish stem size classes for each site. Stand level transpiration (T in mm/day) was then determined as the weighted sum of transpiration by trees in the respective stem size class as:

$$T = \sum SAI_i \times U_i \qquad (1)$$

~~where~~Where U_i is the average sap flux density in each size class, and SAI_i is the stand sapwood area index (SAI: m^2 of sapwood per m^2 of ground area).

To estimate the extent of the transpiring leaf area, the leaf area index (LAI) was measured once in July (wet) and November (dry) using a leaf area meter (Model: LAI 2000, LICOR, Inc., Lincoln NE, USA). These data were collected on 5 transects at each site at sunset when diffuse radiation conditions prevailed and the leaves approximated black bodies. Each transect was about 200 to 300 m long.

2.5 Monitoring soil water content

To investigate the influence of the soil moisture variations on tree water use, soil water content was measured in the root zone of the trees at 10, 30, 50, 70, and 90 cm depth at the hillslope and riparian site. Soil water content monitoring was done using 5TE decagon sensors (Decagon Devices, Inc., NE, USA) connected to a data logger (Em50) and programmed to collect data at hourly intervals throughout the study at each site.

~~5.~~3. Results and Discussion

3.1 Microclimate and soil water content

There were no major differences in the weather elements between the two sites except for wind speed (Figure 3, Table 1). ~~During the~~From October 2016 to February 2017, the hillslope site received slightly higher radiation, often 1 – 4 MJ/m^2/day greater than the riparian site. The riparian site had generally higher wind speed than the hillslope site. The riparian site is located at the centre of a 0.8 km wide U-shaped valley with no windbreaks, and therefore winds moving in a SE-NW direction tend to be funnelled through this valley.~~, hence the high wind speed~~. These conditions resulted in differences in the atmospheric evaporative demand between the two sites.

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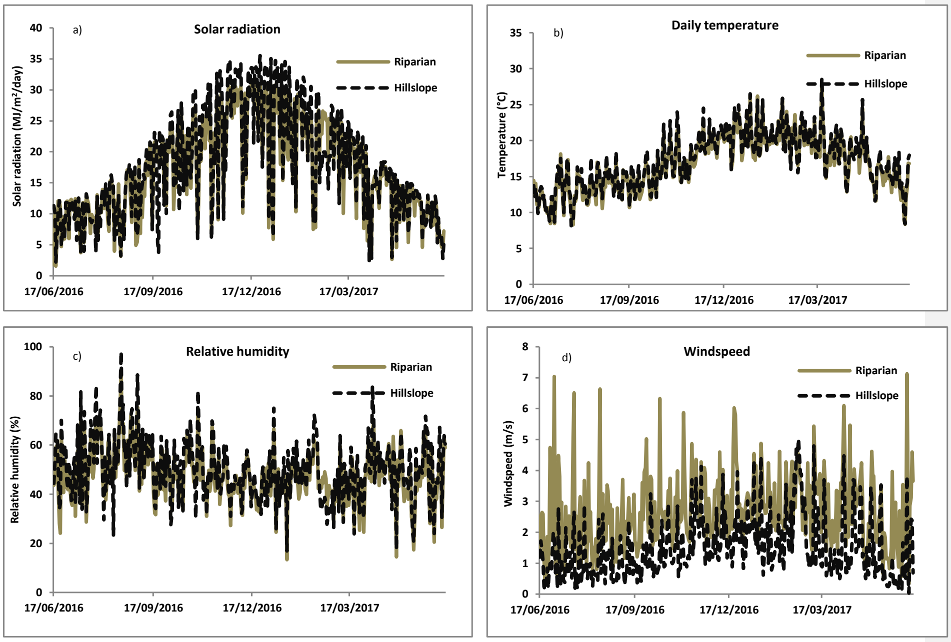

Table 1: Weather conditions at the riparian and hillslope sites ~~during the~~ from June 2016 to June 2017 period. Total rainfall row shows the sum of the rainfall received and the rest maximum.

	June – August 2016				November 2016 – February 2017			
	Riparian		Hillslope		Riparian		Hillslope	
	Min	Max	Min	Max	Min	Max	Min	Max

Solar Radiation, MJ/m^2/day	1.6	17.3	3.2	18.7	5.9	31.0	6.0	35.5
Daily temperature (°C)	7.5	18.1	8.1	18.5	14.1	26.3	14.5	26.5
Relative humidity (%)	57.6	92.7	61.0	99.0	50.5	79.2	54.8	86.0
Wind Speed (m/s)	0.3	7.1	0.0	3.8	1.6	6.0	0.6	5.0
Eto (mm/day)	0.8	4.8	0.7	5.3	2.1	10.5	1.8	9.1
Total Rainfall (mm)		277.9		211.0		58.9		111.4

***Total rainfall shows the sum of the rainfall received and not maximum**

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The reference evapotranspiration (ETo) estimated using the Penman-Monteith Equation with an albedo of 0.23 ~~appropriate for deciduous trees~~ was 1243 mm/year and 1306 mm/year at the hillslope and riparian site, respectively. The 5% difference in the reference evapotranspiration between the two sites is due to higher wind speeds at the riparian site. The daily evapotranspiration rates were similar throughout the monitoring period ranging from 0.8 to 10.5 mm/day at the riparian site compared to 0.7 to 9.1 mm/day at the hillslope site. February 2017 was the exception when the hillslope site had generally higher ETo rates than the riparian site (Figure 4a).

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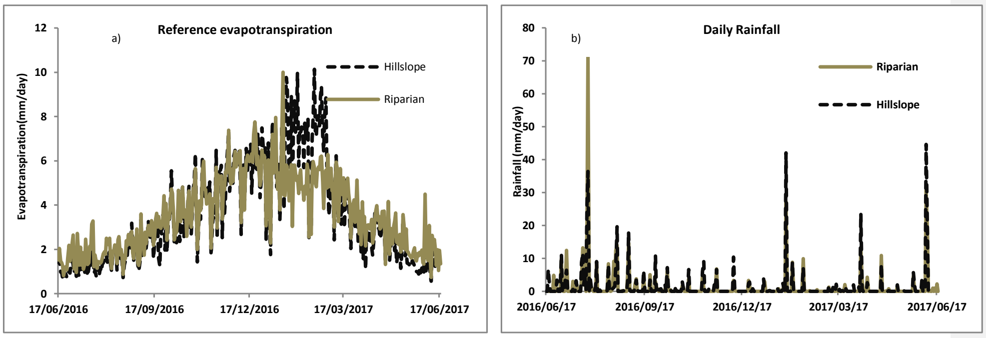

Figure 4: Daily evapotranspiration rates and rainfall at the riparian and hillslopes ~~during the~~from June 2016 – June 2017~~ period~~.

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Daily rainfall was generally less than 10 mm/day and only exceeded 20 mm/day on 4~~5~~ occasions during the study period (Figure 4b). The hillslope site received 497 mm/year of rainfall while the riparian site had 438 mm/year. These rainfall totals are rather low, and are consistent with the drought that occurred in the entire Western Cape Province during

2016/17. The study period was relatively drier in comparison to long-term average rainfall of 629 mm/year in 2015 (Mazvimavi *et al.*, 2018).

The hillslope and riparian study sites had similar soil characteristics (Table 2). At both sites sandy clay loam occurred from 0 to 30 cm depth.

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Table 2 Soil textures at various depths on the hillslope and riparian study sites

Depths (cm)	**Hillslope**	**Riparian**
0 - 30	Sandy clay loam	Sandy clay loam
31 - 60	Sandy loam	Sandy clay loam
61 - 90	Loamy fine sand	Loamy fine sand

The Soil Water Content (SWC) in the root zone at both sites showed clear seasonal variations. The soil water content at both sites responded to major rainfall events. On 26 July 2016 the riparian site received 72 mm/day of rainfall compared to 36 mm/day at the hillslope site (Figure 5). The water content of the top soil (0.1 m) increased to 0.55 and 0.25 m^3/m^3 at the riparian and hillslopes sites respectively ~~as a~~in response to this rainfall event. The soil water content at 0.9 m depth increased to 0.2 – 0.3 m^3/m^3 at both sites. As from July 2016, soil water content generally decreased at both sites and was 0.03 – 0.09 m^3/m^3 by December 2016 (Figure 5). The 42 mm/day of rainfall received at the hillslope site on 27 January 2017 caused some increase of soil water content to 0.10 – 0.20 m^3/m^3 at this site. The riparian site received 27 mm/day of rainfall on the same day which caused no significant changes in soil water content (Figure 5).

The soil profile at the hillslope site was dry during summer with all the sensors measuring between 0 and 0.06 m^3/m^3 of soil water content. In contrast the soil profile at the riparian site was relatively wet. At the riparian site, the soil water content at 0.1 and 0.3 m depth decreased to almost zero by March 2017 which indicates severe water stress for plants accessing water at these depths. However, the riparian trees had access to water during the dry season at relatively deeper soil from 0.5 to 0.9 m ~~depths~~ depths, which had about 0.1 m^3/m^3 of soil water. ~~which~~ This was slightly higher than observed at the hillslope site at these depths. ~~This suggests that the riparian trees had access to some limited soil water at 0.5 – 0.9 m depths during the dry season.~~

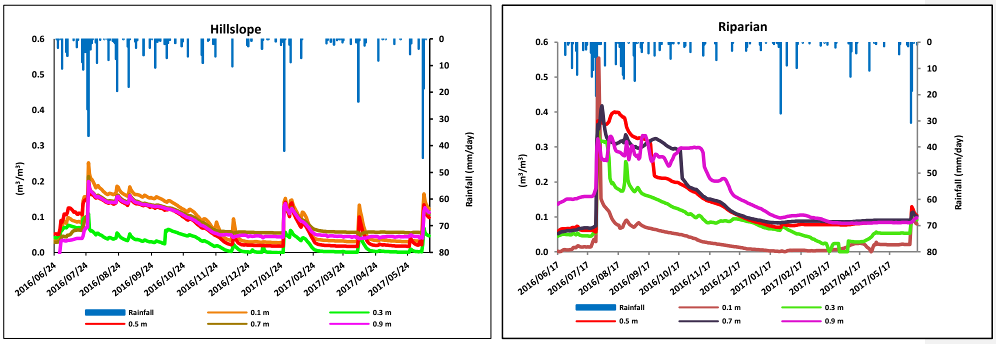

Figure 5: Variations of soil water content at 0.1 to 0.9 meters depth on the hillslope and riparian sites.

3.2 Characterization of A. longifolia invasions

Tree heights on the hillslope ranged between 3 – 6 m, whereas they were 7 - 10 m at the riparian site. The average trees counted in 100 m^2 quadrants were 18 and 25 on the hillslope and riparian site respectively. Therefore, the average tree density was approximately 1 800 and 2 500 tree per hectare at the hillslope and riparian site, respectively. There was not much changes over time in canopy cover as *A. longifolia* is evergreen, and the leaf area index was 2.1 -.2.2 on the hillslope and 3.3 – 3.4 at the riparian site. The distribution of stem sizes at the sites show that 63% of the stem sizes on the hillslope belonged to the small class size (1 – 10 cm) (Figure 6), whereas at the riparian site, most trees (70%) had large stem sizes (> 20 cm).

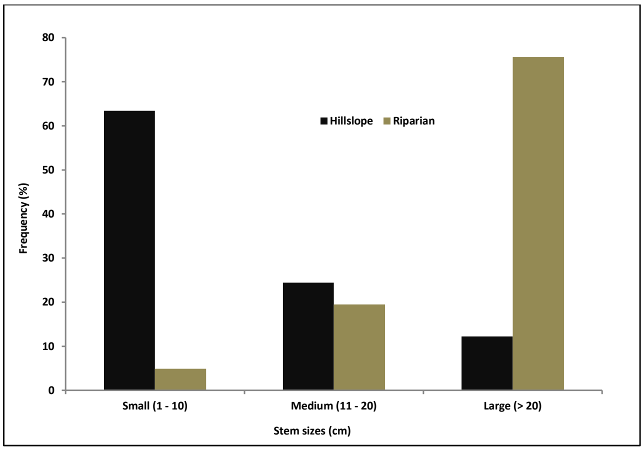

Figure 6: Distribution of stem sizes determined from measurements of stem diameters at breast height of 40 trees on the hillslope and riparian site.

3.3 Transpiration dynamics

Transpiration rates of *Acacia longifolia* occurring at the riparian site were greater than those on the hillslope throughout the June 2016 to June 2017 period (Figure 7). ~~During the~~From August to December 2016~~ period~~, transpiration rates were generally high 2.0 - 3.5 mm/day at the riparian site, and 1.0 – 1.4 mm/day at the hillslope site. From December 2016 to May 2017, transpiration rates generally decreased at both sites (Figure 7). The total water use by *A. longifolia* during the period of the study on the hillslope was 242 mm/year and 596 mm/year at the riparian site. The riparian tree water use was 146 % greater than the hillslope invasions. The 146% difference in water use rates was explained by high tree density dominated by larger stem sizes in the riparian site. The differences in stem diameters and tree density between riparian and hillslope sites have also been observed in other studies by Scott (1999), Dye and Jarmain (2004), Clulow *et al.* (2011), and Dzikiti *et al.* (2013). Schachtschneider and Reinecke (2014) noted that plants growing under different conditions of water availability can adapt their physiology to maximize their chances of survival. Therefore, the availability of water in the riparian zones caused trees to have large stem diameters than those growing in non - riparian zones and thus increasing the detrimental effects of riparian trees to water resources.

The water use rates established in this study were similar to those determined in other studies for Acacia species in the Western Cape. Dye and Jarmain (2004) estimated 171 mm/year, and 585 mm/year was estimated by Scott-Shaw *et al.* (2017). Other riparian invasions, such as pines and eucalyptus used ~ 980 mm/year and ~ 833 mm/year respectively as reported by Dzikiti *et al.*, (2013; 2016).

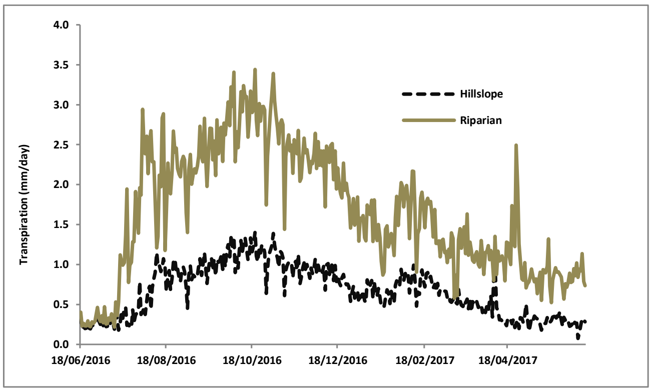

Figure 7: Seasonal variation of transpiration rates of *Acacia longifolia* at the hillslope and riparian sites.

Temporal variations of transpiration rates of *A. longifolia* invasions had similar patterns to the atmospheric evaporative demand (represented by ETo), which was the major driver of transpiration ~~during~~ from winter to late spring when the trees accessed residual soil moisture from rainfall at both sites (R^2 = 0.6 and 0.5) (Figure 8a&b).

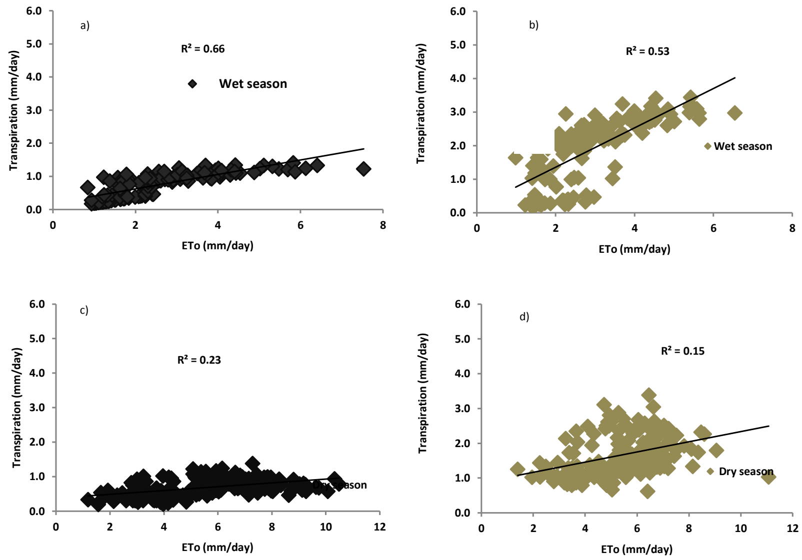

Figure 8: The relationship between transpiration rates of *Acacia longifolia* during the wet season (June – September 2016) and dry season (October 2016 – March 2017) at the hillslope (a & c) and riparian site (b & d).

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During the dry periods soil water content declined from November 2016 to May 2017 causing transpiration rates of *Acacia longifolia* at both sites to decrease (Figure 9).

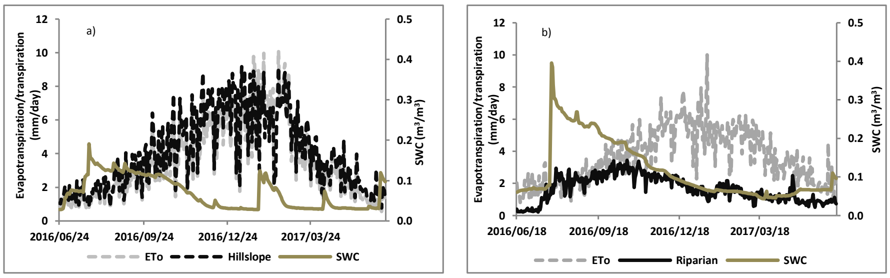

Figure 9: Seasonal variations of *Acacia longifolia* transpiration rates (Hillslope, Riparian), reference evapotranspiration (ETo), and soil water content (SWC) at the study sites.

Figure 9 shows that while the reference evapotranspiration (ETo) rate was increasing from October to December 2016, the transpiration rates of *Acacia longifolia* decreased as the soil water content decreased. The decrease of the transpiration rate at the riparian site was rather unexpected as it had been assumed that trees at this site would have access to groundwater occurring at depths greater than the monitored soil depth range (1.0 m). Five monitoring boreholes developed in July 2017 for another related but separate study just outside the *Acacia longifolia* stand at the riparian site had water tables at 2.4 to 2.9 depths below the surface. These findings therefore contradicted the previous literature (Scott, 1999; Doody *et al.*, 2011; and Nowell, 2011) ~~which~~ that suggested ~~that~~ riparian trees tend to strongly depend on groundwater although different species from the one reported here were investigated in these studies. Snyder and Williams (2000) suggested that not all woody species in the forest use groundwater and not all riparian trees benefit from seepage of water from the adjacent river (Dawson & Ehleringer, 1991). The results of this study are in agreement with the findings of Dzikiti *et al.* (2016) who concluded that water use by riparian *Eucalyptus* declined with increasing soil water deficit in the upper soil horizons although the atmospheric evaporative demand was high. Thus rain water stored in the shallow soil layers was an important source of water for the riparian eucalyptus trees which seem to be the case for the *Acacia longifolia* monitored in this study. The *A.longifolia* trees at the riparian site had very shallow root system (less than 60 cm) measured on trees uprooted by strong winds.~~which was evident from a number of trees that were uprooted by strong winds, due to poor anchorage.~~ The prevailing drought during the study period led to the substantial drying of the top soil where most roots were concentrated.

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3.4 Transpiration dynamics under unstressed conditions

Rainfall data from the on-going monitoring in the catchment suggested that the total rainfall received in the catchment in 2017 was 50% of the long-term average for the catchment (Mazvimavi *et al.*, 2018). Therefore, total transpiration rates measured in 2016 and 2017 represented the water use rates when *A. longifolia* trees were water stressed. Unstressed transpiration coefficients (Allen *et al.*, 1998) were estimated using data from August to September 2016 when soil water content was not limited and the trees were transpiring optimally. It was assumed that the unstressed coefficients remained the same from September 2016 to June 2017. The unstressed coefficient on the hillslope trees was estimated to be 0.39

for the hillslope and 0.90 for the riparian trees. These coefficients were used to estimate unstressed transpiration rates (Figure 10).

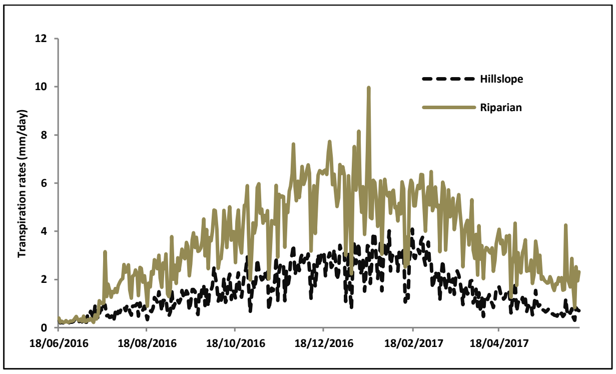

Figure 10: Seasonal variations of transpiration rates of *A. longifolia* under unstressed conditions.

Under conditions where soil water is available for plants, riparian *A. longifolia* trees can use up to 10 mm/day of water per day while the hillslope invasions can use up to 4 mm/day (Figure10). Under this scenario, water use on the hillslope can reach 579 mm/year and 1 348 mm/year at the riparian site. These results suggest that during years with rainfall above the average, *A. longifolia* invasions can use more than two times the estimated rates in this study.

Commented [Y10]: Why are these findings important?
Relate them to similar studies
Acknowledge the limitations
Make future recommendation

These results are important to inform water resurces managers in catchments that receive……..(WRC report)

3.5 The impacts of IAP's at a catchment scale

The effects on water resources was also estimated at catchment scale. This was based on the assumption that the area invaded by alien plants in the catchment is equivalent to 7 930 hectares at 100% density cover (Kotze *et al.*, 2010). It was also assumed that the riparian zone makes up 5% of the invaded area and 95% being the hillslope. If other alien species transpired at similar rates to *A. longifolia* trees, then the total water use by IAPs at a catchment scale would be 20.5 Mm^3 from June 2016 to June 2017, which was a dry year. The estimated water use by these plants is in close range with the estimated annual runoff (18.8 Mm^3/yr) of the catchment (Mazvimavi *et al.,* 2018). During years with rainfall above the average, total water use by IAP's can reach 49 Mm^3/yr. Transpiration rates of the natural shrub lands ~~were~~ was not investigated in this study. However, assuming that the fynbos shrubs transpired at similar rates to grasses, which use ~411 mm/year based on SAPWAT 4 estimates (van Heerden and Walker, 2016), ~~.~~ ~~Then,~~then transpiration rates by IAP's were 30% more than that of the fynbos shrubs. The hydrological benefits of clearing IAPs was estimated as the difference in transpiration rates between unstressed *A. longifolia* trees (579 mm/year) and the fynbos shrubs. Clearing IAPs and ~~being replaced~~restoring ~~by~~ with fynbos plantations has the potential to result in 17 Mm^3/yr of water being saved and available for other uses. These results are in agreement with the results by Nowell (2011) ~~which~~ that suggested ~~that~~ the potential water savings after clearing IAP's at the Agulhas Plain over the total area of 66 772 hectares was ~36 Mm^3/yr. There will also be a gain in groundwater recharge and/or stream flows if the alien trees are removed especially from the riparian zones (Holmes *et al.,* 2008; Scott-Shaw *et al.,* 2017).

This study becomes one of the few studies that demonstrates that the water use by riparian invasive species exceeds that by a similar species growing in non-riparian environment. However, most studies, such as the current one, made measurements over small temporal and spatial scales which makes it difficult to extrapolate findings (McConnachie et al., 2012). Also, the successes and failures of alien clearing programmes have not been well documented. This is why water resources managers have not consider alien clearing as the first option to acquire "new" water.

4 Conclusions

Water use rates of *A. longifolia* growing in a flat riparian zone ~~has been~~was found to be greater than when this species is growing on hillslopes. During the dry period, soil water content was the main limiting factor ~~for~~ to transpiration of *A. longifolia* at both the riparian and hillslope sites. This contradicts the common assumption that riparian trees have ready access to subsurface water. Generalizations about water use dynamics of riparian trees should therefore take into account the specific conditions or features of river water – riparian subsurface water interactions, and rooting systems of the concerned species. Clearing of invasive *A. longifolia* growing along the riparian zone should be prioritised due to the higher water use rates in comparison to hillslope sites. Clearing of IAPs will contribute to making "new" water available in the affected catchments.

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The study was funded by the South African Water Research Commission~~ of South Africa~~, and the National Research Foundation/Applied Centre for Climate and Earth Systems Science. Landowners and members of the Nuwejaars Special Management Area supported this study by granting us permission to install monitoring equipment.

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