Streamflow responses to the clearing of alien invasive trees from riparian zones at three sites in the Western Cape Province

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The changes in streamflow following the removal of invasive wattle (*Acacia mearnsii* and *A. longifolia*) from riparian zones during the dry summer months in three small catchments in the Western Cape Province are described. Portable steel box weirs, with a 30° compound V-notch and equipped with Belfort water level recorders, were used to measure streamflow. Each of the three streams had a control catchment against which it was correlated during a pre-treatment period. The riparian zones of the treatment catchments were cleared after this period of calibration, and the response of streamflow after treatment was recorded.

In the three catchments there was a marked increase in streamflow after clearing of the riparian invasive vegetation. The streamflow increases in the three catchments were 8,8, 10,4 and 12 m^3/day per ha cleared. The responses measured in these experiments are the result of changing from tall vegetation to minimal cover and represent a maximum response. Streamflow is expected to decrease again as vegetation regrows, but not to the levels that characterised the invaded site. The riparian areas should be kept under short indigenous vegetation, such as grass or fynbos, to sustain the long-term increases in streamflow.

Introduction

Many streams and rivers in the Western Cape have been invaded by alien wattle species. Teams from the Working for Water Programme of the Department of Water Affairs and Forestry have systematically been clearing the mountain catchment areas in the Western Cape of these and other alien invaders. The main motivation for this work is the predicted increase in streamflow of between 350 and 500 mm rainfall equivalent, based on studies of catchments afforested with pines (Van Wyk 1987; Le Maitre *et al.* 1996). There is, however, little information and no direct measurements of the effects of invasive black wattle (*Acacia mearnsii*), longleaf wattle (*Acacia longifolia*) and cluster pine (*Pinus pinaster*) on the streams in the Western Cape. The objective of this

Table 1: Salient features of the catchments at Knorhoek, Du Toitskloof and Oaklands. Biomass estimates are from Prinsloo (1998)

Site	Position	Experimental design	Catchment area (ha)		Mean annual rainfall (mm)	Geology	Altitude (m)	Slope (°)	Aspect
			Control	Treated					
Knorhoek	34°06'18"S 18°56'06"E	Nested catchment	85 (total catchment)		1 200	Sand-stone granite mixtures	340	7	W
Oaklands	33°43'28"S 19°04'05"E	Paired catchment	33	29	1 050	Sand-stone granite mixtures	410	29	E
Du Toits-kloof	33°36'18"S 19°04'44"E	Paired catchment	31	17	1 050	Sand-stone granite mixtures	560	17	SW

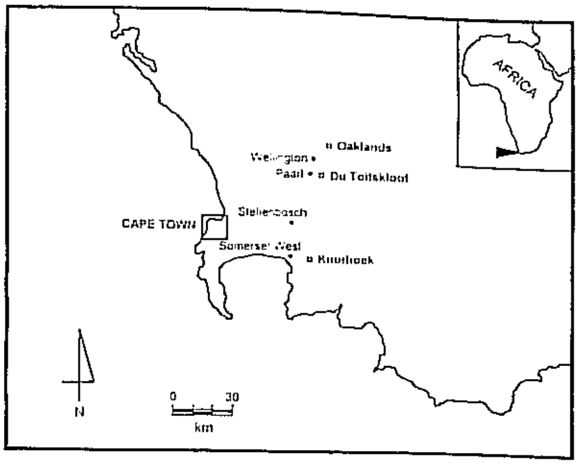

Figure 1: Location of the three experimental sites at Knorhoek, Oaklands and Du Toitskloof

study was to get more information on the influence (if any) that these invasive trees may have on streamflow, especially during the dry summer periods of the Western Cape region.

Methods

Study sites

Streamflow in three small mountain fynbos catchments in the Western Cape (Figure 1), each with a control catchment, was measured for a short period. Salient features of the sites are given in Table 1.

The farm Knorhoek is situated midway up the slopes of the Hottentots-Holland mountains near Somerset West. The vegetation at Knorhoek was almost entirely long-leaf wattle (*Acacia longifolia*) within the riparian zone, with an average canopy height of 6 m. Along the outer edge were 10 to 13-year old cluster pines (*Pinus pinaster*), with a height of between 13 and 18 m. Cover was made up of approximately 75% long-leaf wattle, and 25% cluster pine, and the stand was almost impenetrable, with no gaps in the canopy (Prinsloo,1996). The biomass of the 4 ha cleared was estimated from *A. saligna* and *A. cyclops* biomass tables in Milton & Siegfried (1981) to be about 414 t (104 t/ha).

The farm Oaklands is in the Groenberg area near Wellington. Two adjacent catchments on the lower slopes of the Groenberg, were selected. The control catchment was not as densely invaded as the treated catchment, particularly in the lower part. Prior to clearing in the treatment catchment, a full survey of the vegetation was done (Prinsloo, 1998). The whole catchment was infested with self-sown black wattle (*Acacia mearnsii*) and eucalypts (*Eucalyptus grandis*) with the black wattle occurring mostly within the riparian zone, which is the area that was cleared. The eucalypts occupied the outer edges of the riparian zone and the ridges. The black wattle trees at Oaklands formed a closed canopy, and had a crown height of between 10 and 15 m. The stand was of mixed age and diameter, with some very large black wattle trees (breast height diameter >400 mm) within the riparian zone. The biomass for the 4,7 ha that was cleared, was estimated at 1081 tonnes (230t/ha) (Prinsloo, 1998).

The Du Toitskloof site is on the farm Floraleae, just below the Du Toitskloof Pass, where two adjacent catchments were selected. The pass (old National road) cuts through the upper section of the catchments. The invaded riparian zone in the treatment catchment varied in width from 10 m either side of the stream at the bottom of the catchment to about 50 m at the top. The catchment area above the road is covered in uninvaded fynbos. About 88% of the canopy cover in the riparian strip was self-sown black wattle (*Acacia mearnsii*) with about 4% hakea (*Hakea sericea*), 1% long-leaf wattle (*Acacia longifolia*) and the remaining 7% being indigenous species. The adjacent slopes supported a sparse stand (<5% cover) of invading cluster pine (*P. pinaster*) of varying ages, while there were a few medium to large (200

Table 2: Measurement periods of the Knorhoek, Oaklands and Du Toitskloof experiments

Site	Calibration measurement period	Treatment date	Post-treatment monitoring
Knorhoek	23/02/1996 – 24/03/1996 (30 days)	25/03/1996 – 04/04/1996 (11 days)	05/04/1996 – 23/04/1996 (19 days)
Oaklands	23/01/1997 – 11/03/1997 (47 days)	12/03/1997 – 20/05/1997 (69 days)	21/05/1997 – 31/03/1998 (315 days)
Du Toitskloof	10/01/1997 – 09/02/1997 (30 days)	10/02/1997 – 27/02/1997 (18 days)	28/02/1997 – 21/04/1997 18/11/1997 – 31/03/ 1998(185 days)

mm to 350 mm) pines within the riparian zone. However, smaller black wattle trees (<25 mm diameter) made up 76% of the vegetation in the riparian zone. The mean biomass of the cleared area was estimated to be 160 t/ha or 240 tonnes over the 1,5 ha (Prinsloo, 1998).

Experimental design

Two experimental designs were used in this study. At Knorhoek, a nested catchment approach was used due to the lack of a suitable control catchment. In this design, two weirs were placed in series down a single stream and weed clearing was confined to the area between the weirs. The upper station therefore provided a control for the lower station. The flow at the upper and lower stations was measured for a calibration period (Table 2), before an area of about 37 m on either side of the stream was cleared. At the Oaklands and Du Toitskloof sites, a paired catchment approach was used. In this approach, two catchments are gauged for a calibration period to establish a relationship between the two. Once this is done, one of the catchments is treated by clearfelling the alien plants, while the other is not and serves as a control.

Instrumentation

Measurement was done using portable weirs and clock-driven water level recorders. Teams from the Working for Water Programme then cleared the invasive vegetation within the riparian zone, and the streamflow was monitored to see if there was an increase after clearing.

Water at all the sites was piped out of the stream into portable weirs. The portable weirs were box-shaped, manufactured from 3 mm steel, 1,7 m (long), 0,80 m (wide), and 0,80 m (high), with a compound 30° V-notch on the one side. The 30° V-notch was used to give a high resolution measurement, especially during low flows. A similarly constructed portable weir is described in detail by Nänni (1972). The clock-driven Belfort FW1 model water level recorder was used in all experiments as they have proved to be reliable and are easy to operate. A stilling well inside the weir contained the float, and was used to dampen turbulence of the water level during windy days. A sieve suspended before the V-notch prevented twigs and leaves from clogging the notch. The weekly charts were digitised to convert data into electronic format.

Treatment and data collection

The experiments ran from 24 February 1996 to 31 March 1998. Calibration periods ranged from one month to 2,5 months, while the treatments were applied over periods of 10 days to 2,5 months. Post-treatment monitoring continued for between 18 days and 10 months (Table 2). During this time, charts recording streamflow levels were collected weekly and captured on computer for further analysis.

Data Analysis

The flow data from the catchments before clearing started were used to calculate the relationship between the flow in the control and the treated catchments. If adequate, this so-called calibration model allows the prediction of flow in the treatment catchment assuming no treatment had occurred. The differences between predicted and observed flows during and after clearing provide an estimate of the size and direction of the change in streamflow resulting from clearing. The statistical test for the significance of treatment is by means of the dummy variable regression technique (Draper and Smith, 1981) and described in full in its application to streamflow analysis by Hewlett and Bosch (1984). Essentially it involves fitting a separate regression model to the post clearing data, and testing for a significant change in the model co-efficients from those of the calibration model.

The trials reported here were originally intended as single-year experiments to measure the response to alien weed clearing. As most interest was expressed in dry season flow the portable box weirs were seen as the appropriate tool, and measurements were aimed primarily at summer and autumn low flows. Consequently, relatively short pre-treatment periods were available on which to develop predictive, calibration models.

Results

Streamflow at Knorhoek was more at the lower weir than at the top weir. This indicated that the stream was being fed by groundwater discharges. The mean daily flow during the whole gauging period was 160 m^3 at the upper weir, and 260 m^3 at the lower weir. Daily flow volumes at the lower station were regressed against those at the upper station. Data from the first two weeks of the calibration period were discarded, as flow at the upper and lower weirs did not correspond. Clearing had started on 19 March 1996, but it was only from

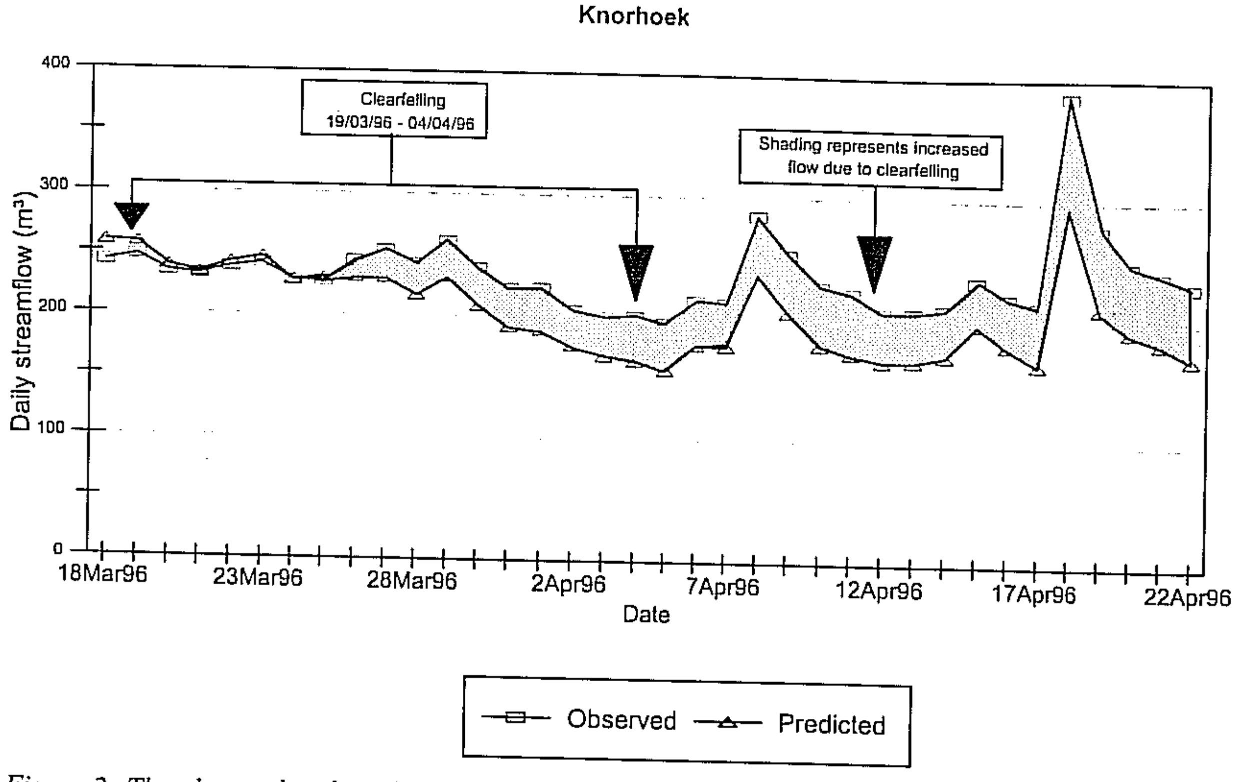

Figure 2: The observed and predicted flow at the lower Knorhoek weir, showing the clear increase in flow after clearfelling

Monday 25 March that the teams started to make real progress in clearing the trees. We therefore used all data until 25th of March as part of the calibration period.

A good calibration relationship was obtained at Knorhoek (log T = 2,99 + 0,484 log C; Adjusted R^2 = 0,83; 13 df, where T and C are the daily volumes in m^3 in the treated and control catchments respectively). This allowed us to show that increases were statistically significant and to predict what the flow would have been had the riparian trees not been cleared (Figure 2). By comparing the observed with the predicted flow at the lower weir, we calculate that there was an additional flow of 12 m^3/day/ha cleared over the late dry season. This equates to a 13% increase in flow after clearing.

At the next two sites, streamflow data from days on which major storms occurred were removed from our analysis, as was the main winter rainfall period of June to August (Table 3), because our interest was in the base flow from the catchments.

The calibration relationship at Oaklands was good (T = 54,94 + 0,54 C; Adjusted R^2 = 0,96; 34 df). Figure 3 illustrates the marked increase in flow during base flow periods after

Table 3: Number of base flow days per month used in the analysis of the Oaklands and Du Toitskloof experiments

Month	Oaklands	Du Toitskloof
January 1997	7 (starting 23/01/97)	20 (starting 10/01/1997)
February 1997	21	28
March 1997	27	31
April 1997	20	18
May 1997	18	station closed
June 1997	no base flow	"
July 1997	"	"
August 1997	"	"
September 1997	16	"
October 1997	30	"
November 1997	14	5
December 1997	23	29
January 1998	27	31
February 1998	8 (flow ceased on 09 Feb.)	28
March 1998	no flow	28

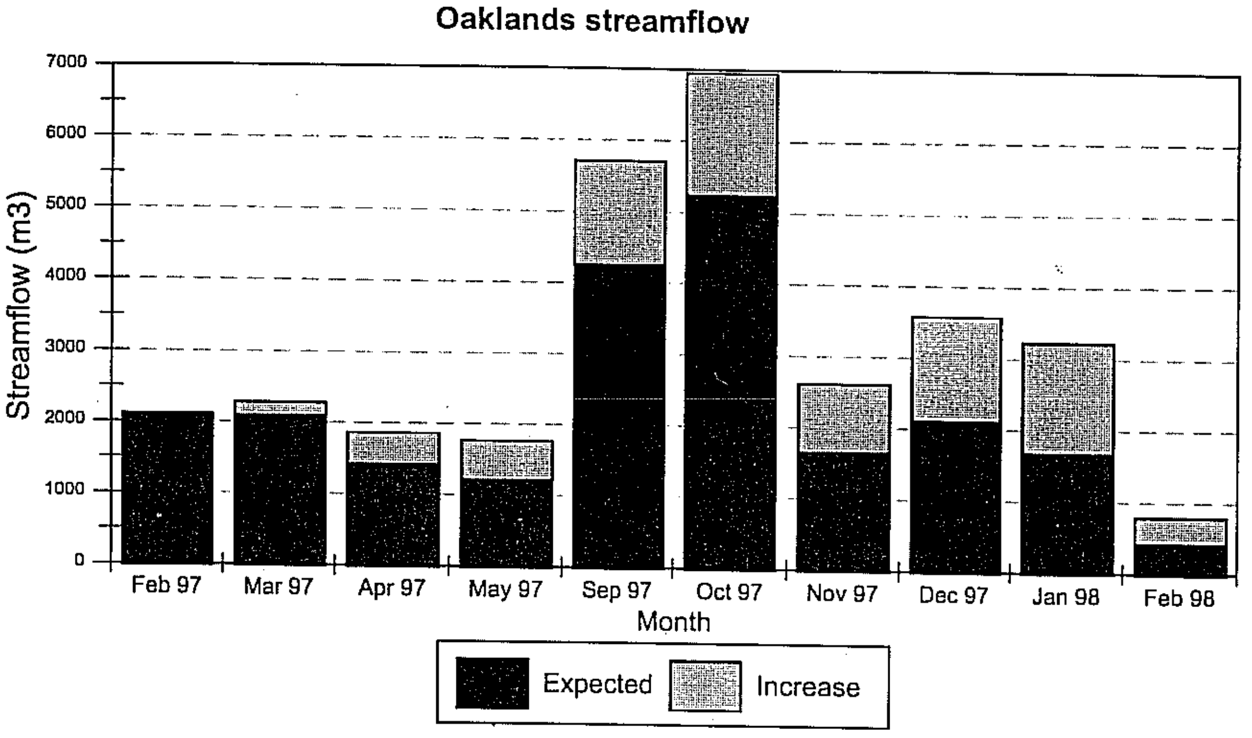

Figure 3: Expected streamflow and the increase in flow after clearing of riparian vegetation at Oaklands near Wellington, Western Cape Province

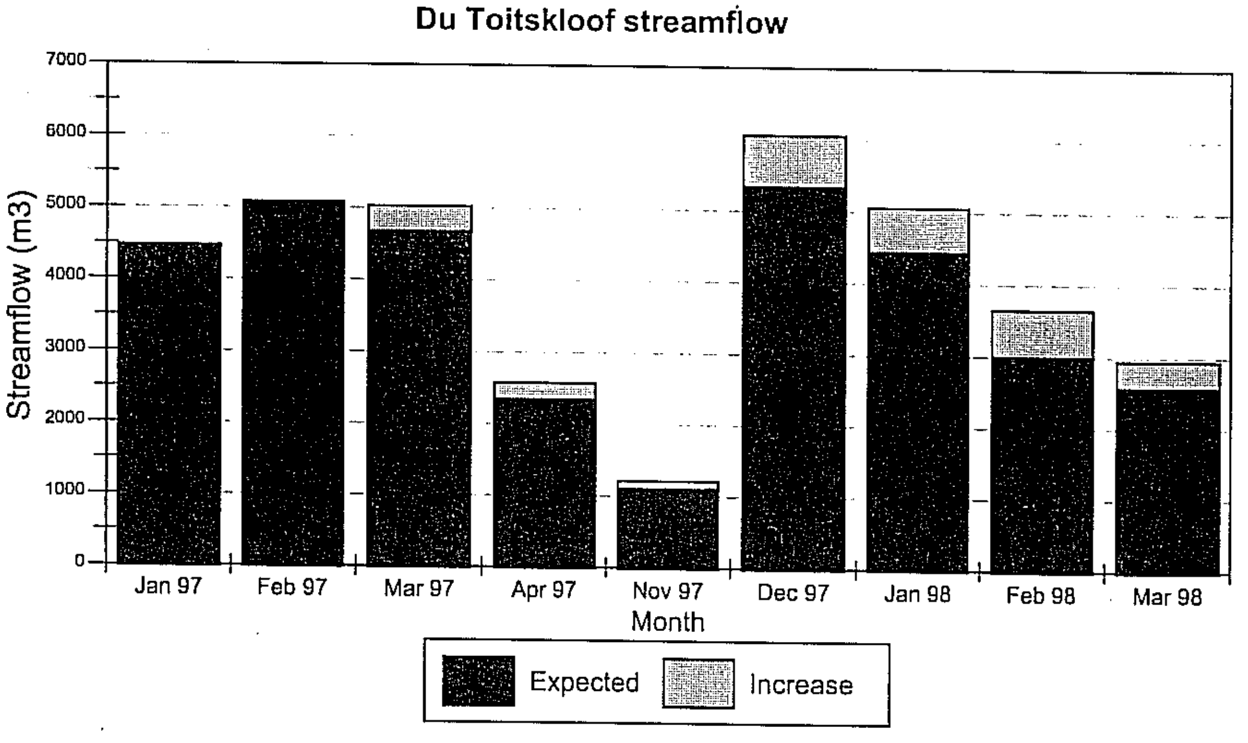

Figure 4: Expected streamflow and the increase in flow after clearing of riparian vegetation at Floraleae near Du Toitskloof Pass, Western Cape Province

riparian clearing. Before treatment, both streams at Oaklands had an initial flow rate of about 1,3 l/s (112m^3/day). Post clearing flows were significantly higher than predicted. As the control catchment had dried up during February 1998, which, according to the foreman at Oaklands, was normal for these catchments this time of the year, there was no way to be sure what flow would have been

Table 4: Summary table of base flow increases resulting from clearing of invading alien plants on Western Cape streams

Site	Area treated (ha)	Percentage of total catchment (%)	Base flow increase	
			m^3/day/ha	%
Knorhoek	3,98	4,7	12	13
Oaklands	4,7	16,2	10,4	6,5
Du Toitskloof	1,5	8,8	8,8	4,7

in the treated catchment during March. However on the basis of local knowledge as well as the calibration model, all measured flow was essentially an increment during this period.

The clearing of 4,7 ha alien invaders (wattle and eucalypts) in the treated catchment at Oaklands resulted in an additional 8 525 m^3 of water over 173 base flow days. This translates to 10,4 m^3/day/ha cleared (base flow days only).

Storm flow response at the Du Toitskloof site caused the weirs to overflow as the streams serve as drainage for the tarred road of the Du Toitskloof Pass. The initial flow of both catchments during calibration was fairly high, relative to the flow at Oaklands (control = 5,15 l/s (445 m^3/day), treated = 2,69 l/s (232 m^3/day)).

Models were only fitted to the base flow data. A good calibration relationship was established ($\log T = -2{,}81 + 1{,}63 \log C$; Adj $R^2 = 0{,}94$; 28 df) which allowed us to predict what the expected flow in the treated catchment would have been had the riparian trees not been clearfelled. When we tested for a treatment effect, two models had to be used, one to predict flows higher than 200 m^3 per day, and another for flows below 200 m^3 per day. It is clear from Figure 4 that clearing caused an increase in streamflow during base flow periods.

Discussion

At all three sites, Knorhoek, Oaklands, and Du Toitskloof there were statistically significant and important increases in flow after clearing. Clearing of 3,98 ha of alien weeds, or 4,7% of the treated catchment at Knorhoek during base flow periods in late summer, increased streamflow by 12 m^3/day/ha (13%). The clearing of 4,7 ha alien weeds (wattle and eucalypts) at Oaklands resulted in an average increase of 10,4 m^3/day/ha (6,5%). Clearfelling of 1,5 ha of alien weeds within the treated catchment of Du Toitskloof in late summer increased base flow by an average of 8,8 m^3/day/ha (4,7%).

These results are similar to the water yield increases measured in other riparian clearing experiments around the country. Increases measured over a whole year after clearing of tall indigenous riparian forest at Westfalia near Tzaneen were 15 m^3/day/ha, 22 m^3/day/ha from clearing indigenous bush with some pine invasion at Witklip near Nelspruit, and 31 m^3/day/ha following the clearing of mature riparian pine in Jonkershoek, Stellenbosch (Scott and Lesch 1995). Dye and Poulter (1995) reported a base flow increase of 12,2 m^3/day/ha following the clearing of a dense stand of *Pinus patula* and *Acacia mearnsii* at Kalmoesfontein, southeast of Lydenburg, Mpumalanga.

The method of using portable box weirs, as in this experiment, carries a risk. The assumption implicit in the experiment layout is that riparian trees are drawing water from the stream channel and/or intercepting groundwater that would otherwise discharge to the streams. A response to treatment should indicate the magnitude of the water-use of the weeds which have been cleared. However, the water the riparian trees are using could be moving on other underground paths which are not being measured by the boxed weir method in the typically rubble-filled and porous channel bottom. Thus our method may be under-estimating the water use by alien plants.

The complexity of the flow-generating process is a primary reason that a good correlation may not be obtained between two adjacent streams, though apparently similar, or even between two points on one stream. Therefore, unless the full flow process within a catchment is measured, a non-response to a clearing treatment cannot be taken as evidence that there is no response; simply that a response has not been measured by the weir methodology.

It is important to realise that the streamflow response does not measure the whole water use of the invading weeds, but is rather an indication of their effect. Diurnal dips in streamflow are usually attributed to the draught of stream-side vegetation; in other words, the volume represented by diurnal dips has been equated to the transpiration of riparian zone vegetation (Wicht 1941; Rycroft 1955). Water on the sites where trees are cleared may also be contributing to groundwater recharge which does not contribute to streamflow at the point where measured. In addition the weirs may not be measuring the full catchment discharge. In other words, net yield benefits of weed clearing may not all be measured in short-term experiments where the full difference between rainfall and evaporation is not necessarily being measured.

It is also important to stress that the responses measured in these experiments are the result of changing from tall vegetation to minimal cover and would therefore tend to represent a maximum response. All riparian areas need to have a healthy vegetation cover, such as grass or fynbos, to assure that water quality is not negatively affected. It is expected that the vegetation in the catchment, if managed well, will revert to tall fynbos rather than becoming re-invaded with tall trees. The water use of such vegetation will be lower, and thus the overall impact of clearing will be an increase in streamflow.

The results of the experiments fully justify the working assumption behind the Working for Water Programme that clearing of woody alien invader plants, particularly in riparian zones, leads to a substantial increase in base flows. Management of riparian zones to maintain a healthy stable cover of short indigenous vegetation such as grassland, scrub or fynbos, should maintain a catchment's ability to continue to yield sustained flow.

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