An assessment of the channel morphological changes in the Lourens River, Western Cape

LB Smith-Adao[1]* and ACT Scheepers[2]

[1] *CSIR, Natural Resources and the Environment, PO Box 320, Stellenbosch 7599, South Africa*

[2] *Department of Earth Sciences, University of the Western Cape, Private Bag X17, Bellville 7535, South Africa*

Abstract

The Lourens River in the Western Cape Province of South Africa has been degraded to a great extent by forestry, agricultural activities, and a mixture of residential, industrial, urban and recreational developments that replaced the natural vegetation. The river has shown recent signs of localised channel morphological changes in the form of bed and bank erosion, channel widening and narrowing, in-channel deposition, bar formation and channel migration. This paper examines the extent to which channel discharge changes and riparian alien invasion contributed to the observed channel instability in the Lourens River. Data collected from a 90 m stretch of channel included cross-sectional profiles, riparian vegetation composition and channel discharge velocities. The riparian zone consisted mainly of herbaceous ground-storey alien plants and alien tree species that were unable to withstand flood flows and was associated with bank erosion. However, channel change occurred primarily in the upper section of the study reach. Analysis of the discharge velocity indicated that the cumulative effect of a wide range of intermediate discharges experienced in the winter of 2001 created high velocities that resulted in channel process and channel form changes. It is concluded that channel instability in the Lourens River was in part controlled by channel discharge and riparian vegetation changes.

Keywords: Lourens River, channel discharge, flooding effects, riparian vegetation, alien invasion, channel form changes

Introduction

Rivers and their fluvial processes are considered to be one of the most important geomorphic systems of the earth's surface (Dardis et al., 1988). In most landscapes these systems are primary agents of erosion, transportation and deposition and are products of their catchments (Summerfield, 1991). Channel morphology is a major variable in fluvial systems (Rowntree and Wadeson, 1999). Two sets of control mechanisms or factors are important in controlling channel form: catchment controls (e.g. climate and hydrology, geology and soils, vegetation cover and human factors) and site or channel controls (e.g. flow discharge, sediment load, channel gradient, etc.). Catchment controls determine the runoff and sediment regime of rivers while channel controls determine the stability of rivers (Rowntree, 1991). Together these two sets of control mechanisms determine channel form and process. Any disturbance (natural and anthropogenic) would be reflected in the channel morphology and the channel would adjust in the long, medium and short term to compensate for the disturbance (Richards, 1982; Rowntree, 1991; Rowntree and Dollar 1996b; Rowntree and Wadeson, 1999).

Rowntree and Wadeson (1999) revealed that fluctuations in channel discharge are for example either due to changing climate and hydrology, basin morphometry or as a result of human activities. Floods are the direct response to heavy or prolonged storm events. They are very important in geomorphological processes as medium to high discharges are needed for significant fluvial system morphological changes (Rowntree and Wadeson, 1999; Rowntree, 2000). Baker (1977) and Kochel (1988) argue that both catchment controls and channel controls are important variables influencing the role of floods of differing magnitude and frequency. The literature pertaining to the geomorphic effects of large flooding events is sparse (Eaton and Lapointe, 2001). However, site-specific instances of short-term river channel adjustments are well represented in the international literature. Most of these studies involved direct observation of the channel changes taking place, at best with some attempt to indicate the causative character of the changes (Thornes, 1977; Downs, 1995).

However, very little is known about the general nature of the different types of adjustments (Downs, 1995). Geomorphological effects on the river channel system include increased flood magnitude and frequency and sediment storage and sediment transport competency changes. Ultimately, the result is local erosion or deposition due to increased discharges; downstream channel width changes associated with decreased or increased channel depth (Knox, 1977; Magilligan, 1985; Ruhlman and Nutter, 1999; Wohl, 2000b; Knox, 2001) and, possibly, sinuosity changes may result as the channel adjusts to the new flow and sedimentary regimes (Patrick et al., 1982; Wohl, 2000b; Knox, 2001). Scour and fill are localised processes that occur over periods of hours to days in response to flooding events (Simon, 1995; Wohl, 2000c). In South Africa Beaumont (1981) was able to link instability in the Hout Bay River, Western Cape, to land- use changes in the catchment. Beaumont (1981) reported that the removal of catchment and channel vegetation increased large floods which resulted in significant channel erosion and enlargement, with the previously meandering channel shifting to a straighter channel.

Riparian landscapes are one of the most diverse and dynamic components of the fluvial system that may also trigger channel instability (Rowntree, 2000; Steiger et al., 2001). A complex

* To whom all correspondence should be addressed.
☎ +27 21 888-2475; fax: +27 21 888-2684;
e-mail: lsmithadao@csir.co.za

Received 24 March 2006; accepted in revised form 16 March 2007.

relationship between channel morphology, riparian plant communities and channel processes exists which remains poorly understood (Rowntree, 2000; Tabacchi et al., 2000). Rowntree (1991) reported that riparian corridors are generally more prone to alien invasion. Hence, alien species make strong competitors for available resources in riparian zones. From the invasive species that have been introduced from all over the world, a few have become abundant, even to pest proportions (Bromilow, 1995; Tickner et al., 2001). These species have the ability to disperse effectively and they have a wide tolerance of variation in the environment (Hill 1977; Tickner et al., 2001). According to Wohl (2000a) alien species may out-compete native species and become dominant in an area in the absence of co-evolved parasites or predators.

In South African literature the significant impact of alien vegetation on river morphology has been noted as one of the major concerns in river management (Rowntree, 1991; 2000). Alien species may alter channel bank resistance and stability, overbank hydraulic roughness and sedimentation (Rowntree and Dollar 1996a, 1999, Wohl, 2000b), channel width and channel pattern (Wohl, 2000b). Graf (1978) showed that along the Green River, Utah, USA, the invasion of tamarisk (*Tamarix chinensis*) on the channel banks and bars between 1925 and 1931 resulted in channel morphological changes. The dense tamarisk thickets trapped and stabilised sediment, resulting in an average channel reduction of 27% along the 60 to 140 m wide channel. Versfeld (1995) described how severe erosion problems along the Disa River in Cape Town, South Africa, resulted from the establishment of black wattle. Black wattle (*Acacia mearnsii)* caused severe bank erosion, which in turn led to channel widening (Versfeld, 1995).

A primary focus of fluvial geomorphology in recent years has been studies on river channel changes related to either climatic changes (Erskine, 1986) or anthropogenic influence (Knox, 1977; Park, 1981; Wohl, 2000c). However, much of the research has been carried out abroad (Rowntree and du Plessis, 2003). Therefore, knowledge of the physical functioning and processes operating in South African fluvial systems is fragmentary (Dollar, 2000; Dollar and Rowntree, 2003). The aim of this study was to determine the extent to which channel discharge changes and riparian alien invasion contributed towards the channel morphological changes of the Lourens River in the Western Cape of South Africa. It is hypothesised that the observed river channel changes at the Lourens River in 2001 were the result of channel discharge and riparian vegetation changes due to a winter of high rainfall and alien invasion in the riparian zone of the Lourens River catchment.

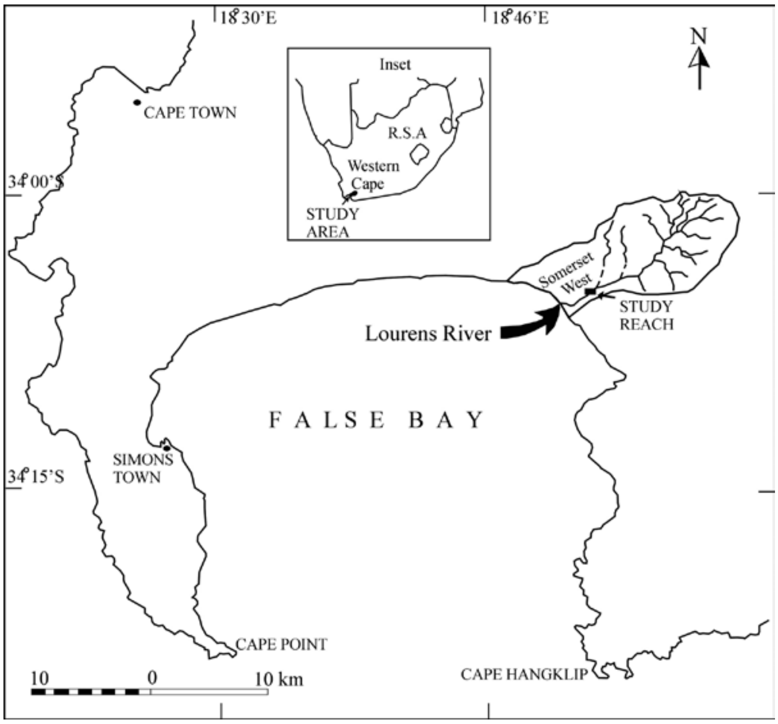

Figure 1
Location of the Lourens River catchment area within the Western Cape and South Africa (modified from Cliff and Grindley, 1982)

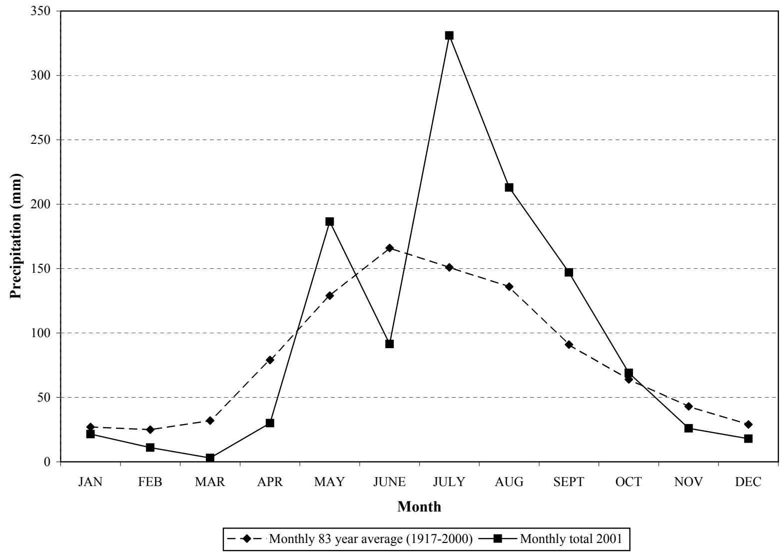

Figure 2
Rainfall data for the study area (Lynn Taute, 2001)

Study area and study site

The Lourens River rises in the Hottentots Holland Mountains at an altitude of about 1 080 m. The river flows in a south-westerly direction for 20 km through Somerset West before discharging into the ocean at False Bay (Fig. 1). Its catchment (approximately 140 km^2) lies entirely within the winter rainfall area of South Africa (Cliff and Grindley, 1982; Tharme et al., 1997). Yearly rainfall ranges from 1 500 mm on the mountains to around 600 mm on the coastal plain (Midgley et al., 1994). The study area received very high precipitation during the winter months of 2001 (Fig. 2). Estimates of naturalised mean annual runoff (MAR) for the catchment are in the order of 122 x 10^6 m^3 of which 87% occurs in winter while only 13% occurs in summer (Tharme et al., 1997).

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ISSN 0378-4738 = Water SA Vol. 33 No. 4 July 2007
ISSN 1816-7950 = Water SA (on-line)

The upper slopes and higher lying regions are underlain by Table Mountain Group sandstones whereas the middle slopes are underlain by Pre-Cape granites and Malmesbury Group shales and greywacke. Tertiary/quaternary alluvial clays and Aeolian sands dominate the foot-slopes and coastal plain (Cliff and Grindley 1982; Tharme et al., 1997). The Lourens River catchment area falls within the Fynbos Biome (Davies and Day, 1998). The natural vegetation in the downstream foothill and coastal plain has been replaced by mixed forestry, agricultural crops, pasturelands and a mixture of residential, industrial, urban and recreational developments. Invasions by woody and herbaceous plant species such as wandering jew (*Commelina benghalensis*), grey poplar (*Populus x canescens*), kikuyu grass (*Pennisetum clandestinum*, etc. have also resulted in the reduction of indigenous species particularly within riparian zones (Tharme et al., 1997) (Plate 1).

The study reach is located in the foothill zone and comprised 90 m of the Louerens River (Fig. 3). Salient features of the study area in this zone include a stony substratum, small to medium-sized gravels/cobbles with a few large cobbles and small boulders. Reach morphology could be classified as short riffle/pool/run transitional hydraulic biotopes. The study reach was chosen due to its accessibility, diverse array of geomorphological and physical characteristics and degree of disturbance (King et al., 2003). It lacked major channel modifications such as canalisation or impoundments. However, gabion mattresses did form part of the right bank while at the most downstream section of the reach, the river was constrained by a concrete wall on the left bank, designed as a flood protection measure (Plate 1a) (King et al., 2003).

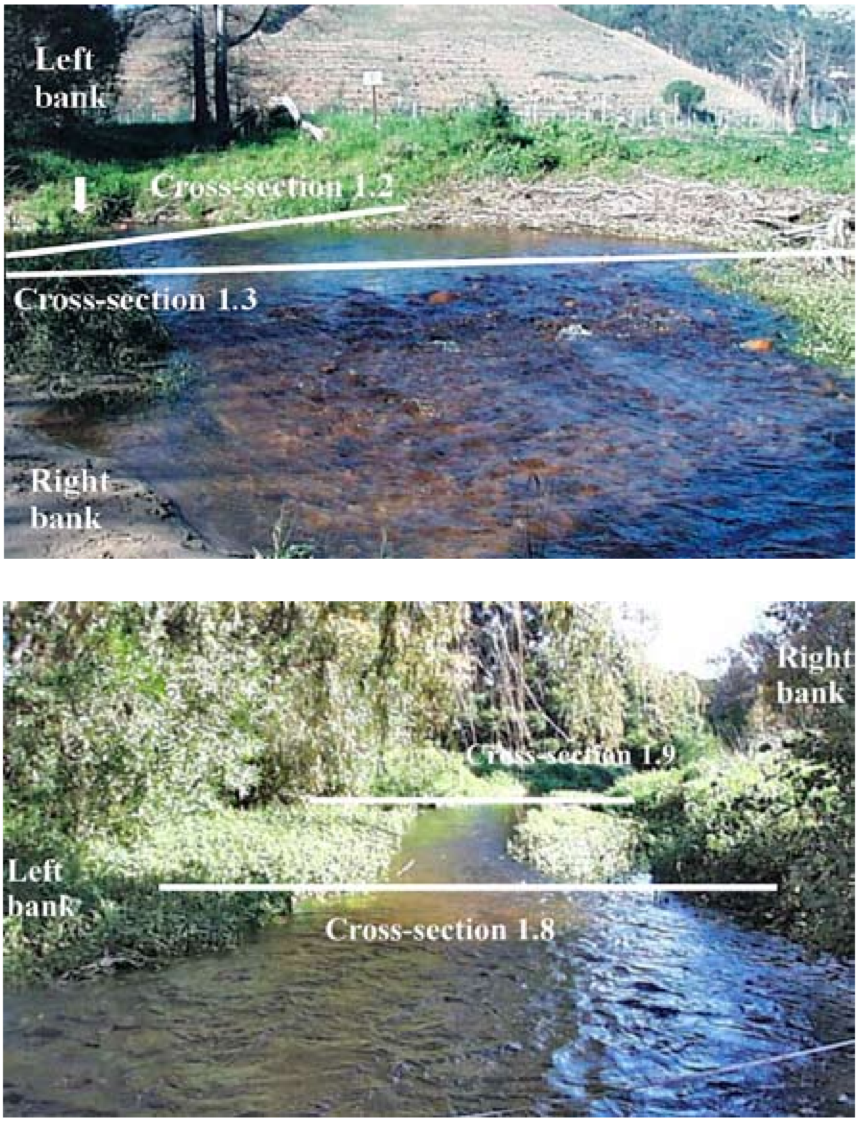

Plate 1
Photographic comparison between the (a) upper section and (b) lower section of the study reach at the beginning of the study period (May 2001). (a) Note the wide channel, the natural predominance of smaller cobbles in a foothill river, the gravel/cobble lateral bar at the foreground bottom left and the presence of cobble gabions (white arrow indicates the end of gabions). (b) Note the narrow channel and alien-infested river banks.

In this reach, the river forms a boundary to Radloff Park, a recreational area. During the dry season the active channel was between 2 to 10 m wide. The single thread channel was sinuous and confined, with the right bank steep and eroded and the left bank gently sloping (Fig. 4) (King et al., 2003). The tree canopy was largely closed, opening in a few areas only and comprising primarily of alien trees such as grey poplars and weeping willows. Marginal vegetation such as kikuyu grass and wandering jew were also observed at the study reach. No aquatic vegetation was present.

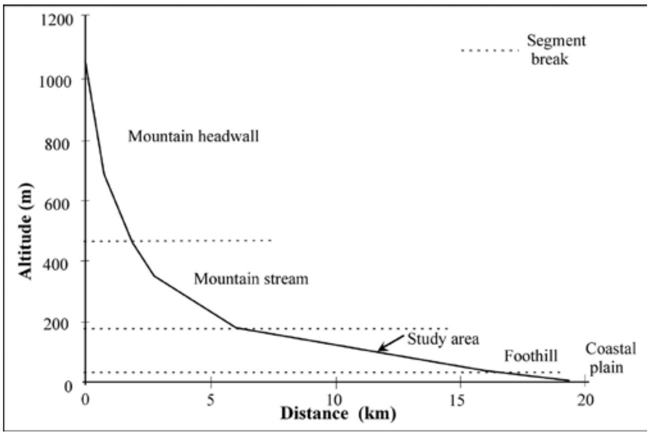

Figure 3
Zonation of the long profile of the Lourens River (after King et al., 2003)

Methods

Channel morphological changes were assessed over one year by comparing pre-flooding data with the post flooding data. Three parameters were sampled or measured. Cross-sectional

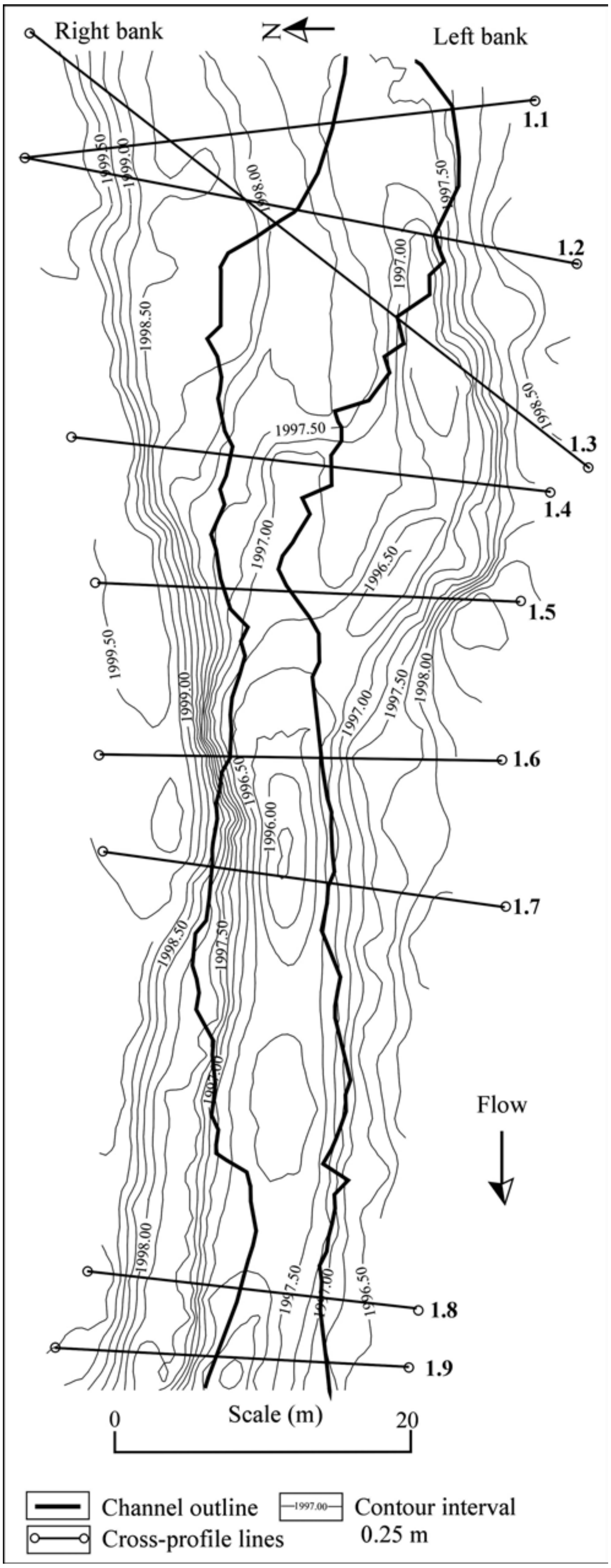

Figure 4
Plan view of the study reach at the beginning of the study period

data were obtained through surveying, discharge data were collected and lastly, vegetation composition was assessed along several of the same cross-profiles (Transect 1.3, 1.7 and 1.9).

Cross-sectional data

Nine cross-sections were established at the study site during baseflow conditions (Fig. 4). The channel cross-profiles were surveyed with an electronic theodolite or total station, a Leica TC307 model, with a reflecting Standard Leica prism fixed onto a staff. The tachometry method of optical distance measurement was used to survey these cross-sections (Gordon et al., 1992). The calculated survey error was in the order of 2 cm, making the survey point data measured for the cross-profiles very accurate. Cross-sections were chosen on the basis of representivity of mainly run-and-riffle hydraulic biotopes, bank vegetation characteristics, to best capture any possible channel changes, to give an accurate representation of geomorphological features of the reach and to measure characteristic flow hydraulics at observed discharges. Hence, repeat surveys of these cross-sections provided point-by-point data on breaks in bank and bed slope, wetted area, substrata, cover, water depth and so on. Since no two runs or riffle hydraulic biotopes are identical, multiple hydraulic biotope cross-sections were chosen (Rowntree and Wadeson, 1999). The total station was also used to map the channel outline, thalweg and plan or contour maps when the site was surveyed in 2001 and 2002. Computer aided design (CAD) programs Autocad and Allycad were used to generate the above-mentioned variables.

Discharge data

Discharge measurements were taken at the study reach on six occasions during the winter months of 2001. Pool hydraulic biotopes were avoided because of the difficulty of accessibility during peak discharges (cross-sections 1.6 and 1.9). An average of ten measurements of water velocity and depth ranging from 0.5 m to 1 m intervals were made along certain cross-sections at fixed points. The velocity readings were taken at 0.6 depth from the water surface with a top-setting wading rod and Price AA or pygmy current meter. Discharge was calculated from the velocity area method described by Gordon et al. (1992) and Rowntree and Wadeson (1999). Field observations and photographs recorded the channel changes that had occurred at the study reach.

Riparian vegetation data

Quantitative data on the riparian vegetation was collected by means of belt transects. Kent and Coker (1992) described belt transects as quadrats (sampling plots) laid along the transect line or next to each other. Therefore, vegetation data were collected along the whole length of selected transects (Table 1). The Braun-Blanquet cover-abundance scale methodology was used to determine species cover and abundance values in 1 m^2 grids (Gordon et al., 1992). We estimated percentage cover (e.g., 50% cover), type (e.g. herb, shrub or tree), species (indigenous or exotic) and species position (bottom, middle or top of bank, or bar). Samples of the same species were collected from the surrounding areas, pressed in the field and sent to specialists for species identification.

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ISSN 0378-4738 = Water SA Vol. 33 No. 4 July 2007
ISSN 1816-7950 = Water SA (on-line)

TABLE 1 Vegetation transects, number of plots and number of species recorded in 2001 and 2002				
Transect number	Transect length (m) and number of plots		Number of species	
	2001	2002	2001	2002
1.3	48	48	18	24
1.7	30	25	5	8
1.9	23	22	8	16

Results

Cross-section change

The cross-sections of the study site indicate that the channel was slightly sinuous and quite stable at the beginning of the study period, with an active channel incised into a bigger macro-channel. The macro-channel was more pronounced on the right bank (looking downstream) than on the left bank. In general, the upper section showed high variability in width, ranging from 4 m to 10 m, while the lower section displayed a less variable, narrower range of between 2 m and 4 m (Fig. 4).

It can be seen from Fig. 5, cross-sections 1.1 to 1.5, that major changes in channel morphology occurred within the upper section of the study reach. Cross-sections 1.6 and 1.9, located at the lower section, displayed very little variability in channel width and depth with increased discharge. The evidence presented indicated that the observed changes in the upper section represented the cumulative effect of a wide range of discharges experienced in 2001 and were not simply the result of a single high flow event (King et al., 2003). The channel expanded due to severe erosion and retreat of the active left bank channel as shown on combined cross-profiles 1.3, 1.4 and 1.5 (Figs. 5c, d and e). Sediment size analysis revealed that the active left bank consisted of a high percentage of medium to fine sand (91%), low silt (8%) and almost no clay (< 1%). Hence, the left bank was made up of material that could have led to bank instability especially in the absence of stabilising vegetation (King et al., 2003). The active right bank, a newly deposited lateral bar, consisted of coarse material (gravel and cobble). A detailed account of the sediment analysis data will be presented in a follow-up article.

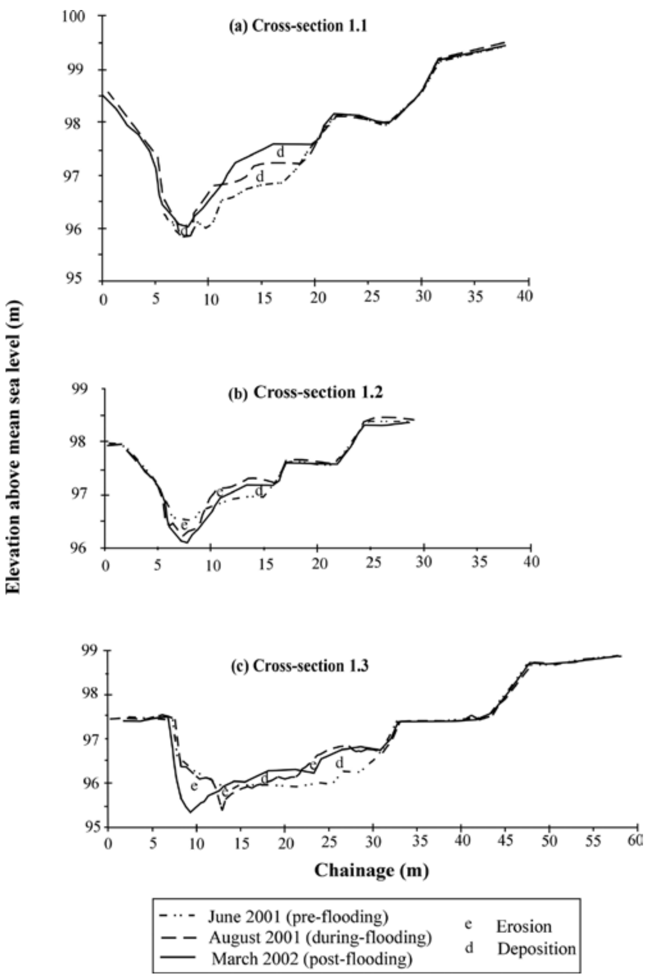

Figure 5a-c
Cross-section surveys at the study site before, during and after the flooding events in 2001

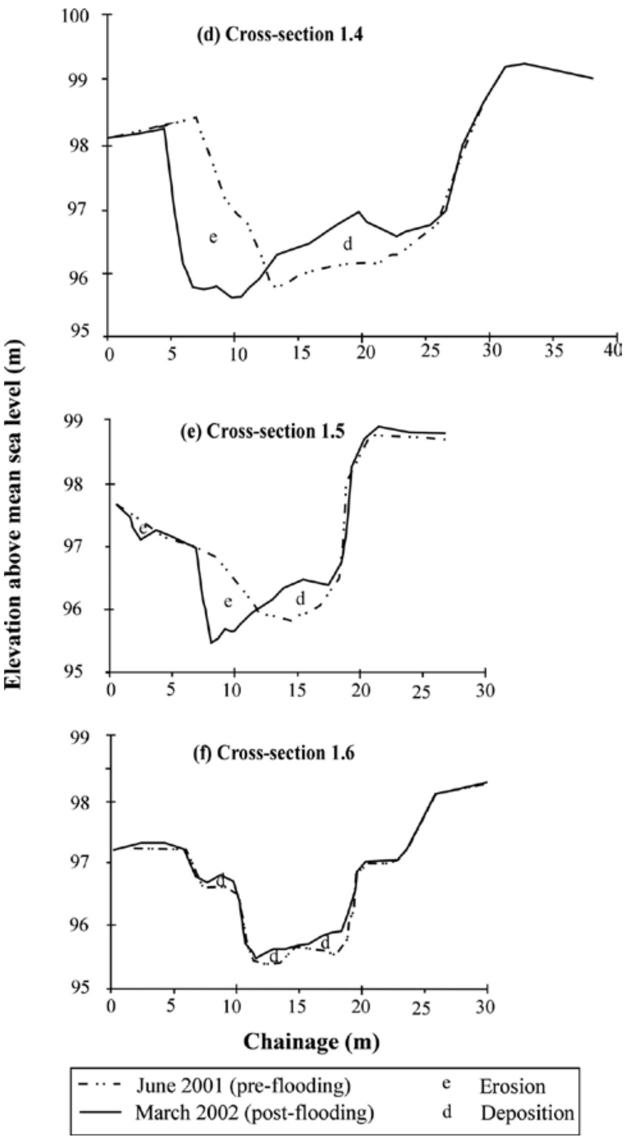

Figure 5d-f
Cross-section surveys at the study site before, during and after the flooding events in 2001

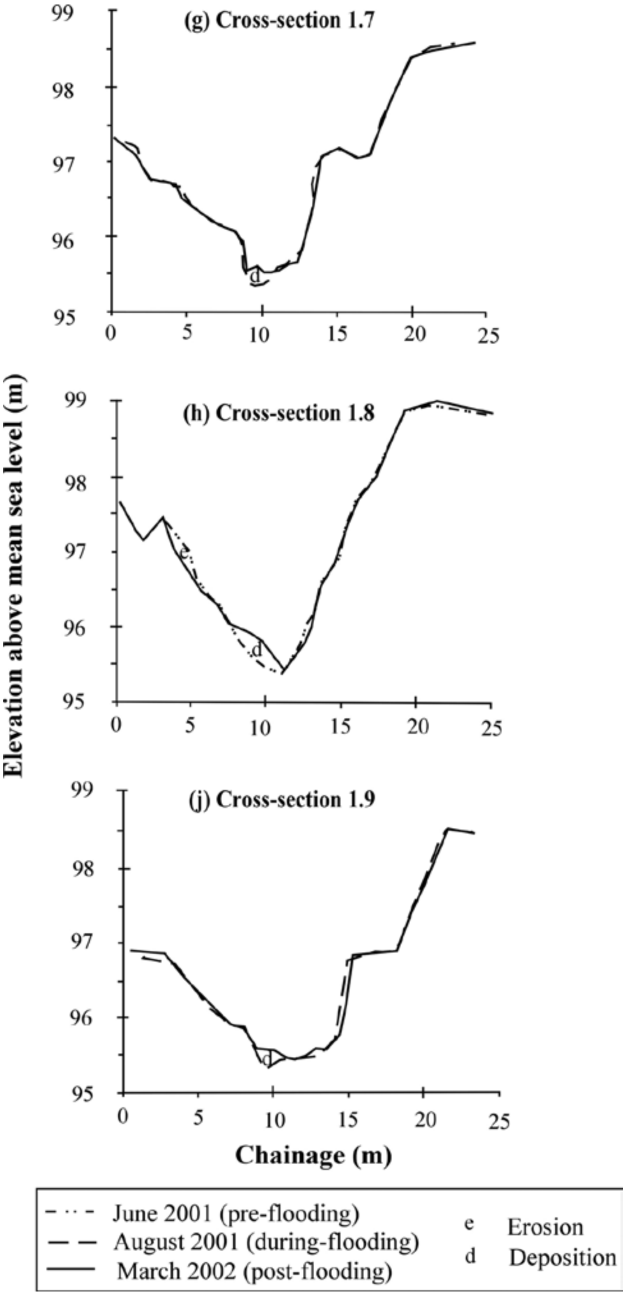

Figure 5g-j
Cross-section surveys at the study site before, during and after the flooding events in 2001

Plate 2
Extensive localised erosion and deposition caused by the 2001 winter flooding events at the upper section of Study reach, Lourens River. (a) View of channel scour and widening on the left bank channel looking downstream (Photograph taken on 18 September 2001). Note the active left bank retreat on the outside bend (lateral migration) and the removal of the established vegetation cover. (b) View of mixed gravel and fines deposited in the form of a lateral bar on the right channel bank. Note the pioneer herbs, grasses and tree seedlings which are sprouting from the deposited sediment and organic material, centre and background (Photograph taken on 28 January 2002).

Active undercutting led to enhanced instability of the left bank (Plate 2a). It would be reasonable to place the bank retreat along these cross-sections in the vicinity of between 5 m to 7 m. It is a matter of direct observation that at least a considerable part of the bank retreat was due to slumping that either occurred late in the flooding events of 2001 or after the individual flooding events had passed. The timing of bank collapse was demonstrated after the flood on 3 July 2001. During the first half of July 2001, blocks from the top of the left bank collapsed onto a bench created during the flood, partially burying the veneer of sand deposited there by floodwaters. Continued collapse was evident during successive field visits following July 3.

Repeat surveys showed channel deepening at cross-profiles 1.2, 1.4 and 1.5 and deposition of sediments in the channel at cross-profiles 1.1, 1.3, 1.4 and 1.5 (Fig. 5). Channel deepening is demonstrated at cross-profile 1.2 (Fig. 5b), where erosion of about 0.3 m resulted in a lowering of the active channel bed and adjacent right-hand lateral bar. Upstream bank scour resulted in an average of 0.7 m of sediments being deposited at cross-profile 1.1 during a moderate flooding event in August 2001. Deposition of 0.5 m of sediment (Plate 2b) occurred at the adjacent right-hand lateral bar. Undercutting took place behind gabion mattresses located upstream of the study site. The erosion and deposition processes (abbreviations) are indicated on the diagrams (Figs. 5a-j) (King et al., 2003).

In summary, from the above it is evident that the upper section of the study site underwent both deepening of the channel and a build-up of areas adjacent to and in the main channel

Available on website http://www.wrc.org.za
ISSN 0378-4738 = Water SA Vol. 33 No. 4 July 2007
ISSN 1816-7950 = Water SA (on-line)

TABLE 2 Flow discharges measured at the research site using the velocity-area method (after King et al., 2003)				
Date	**Cross-profile**	**Average velocity (Range) (m s^{-1})**	**Discharge (m^3 s^{-1})**	**Average discharge (m^3 s^{-1}) (Standard deviation)**
10 May 01	1.2 1.8	0.353 (0.001-0538) 0.392 (0.015-0.571)	0.676 0.851	0.76 (0.12)
12 May 01	1.2 1.8	0.144 (0.001-0.353) 0.216 (0.001-0.406)	0.408 0.309	0.36 (0.07)
29 Jun 01	1.2 1.5 1.8	0.214 (0.015-0.511) 0.490 (0.035-0.849) 0.153 (0.001-0.306)	0.818 0.473 0.297	0.53 (0.27)
13 July 01	1.2 1.5 1.8	0.725 (0.124-1.773) 1.043 (0.832-1.405) 1.114 (0.788-1.480)	4.042 4.377 4.423	4.28 (0.21)
28 July 01	1.2 1.5 1.8	0.470 (0.114-1.134) 0.532 (0.001-0.072) 0.578 (0.022-1.001)	2.311 2.064 1.608	1.99 (0.36)
18 Sept 01	1.2	0.298 (0.101-0.703)	2.150	0.00 (0.00)

as a result of very heavy winter rains that caused flooding. In contrast, the downstream section's channel geometry was less variable and much more stable with little change in channel form (Figs. 5f-j). This section displayed a much narrower range of fill values, 0.15 m to 0.25 m, at all the cross-profiles. A small lateral bar also developed at cross-profile 1.6 (Fig. 5f). It is clear that since the cross-sections did not indicate any scouring on the bed or banks, the sediments were supplied from upstream reaches. It is also assumed that the low rates of channel bank erosion were probably the result of dry bank sediments that produced more cohesive banks, capable of withstanding the winter flooding events of 2001.

TABLE 3 Monthly rainfall measured at the study area, Lourensford Estate "Office" (Lynn Taute, 2001)	
Date of discharge reading taken	**Rainfall (mm)**
12 May 2001	63
29 June 2001	117
13 July 2001	234
28 July 2001	341
18 September 2001	20

Discharge change

Discharge readings were very variable between both different and similar hydraulic biotopes (Table 2). This trend can be seen in the readings taken on 13 and 28 July 2001. It is clear that runs and riffles differed in terms of hydraulic characteristics and substratum at any point in time and thus influenced the resultant discharge calculations (King et al., 2003).

Only 117 mm of rain fell during the 28d of June 2001 prior to the discharge reading taken on the 29th of June 2001 (Table 3). The largest floods observed were at the beginning of July 2001, 1 to 8 July, when very intense falls occurred during the day and night. No readings were taken on 5 July 2001 when the left bank channel of the upper section started to collapse at the study site, because flows were too high to access the river following falls of 145 mm in the preceding 4 d in the area. The discharge reading on 13 July was taken after about 234 mm of rainfall had been recorded in the Somerset West catchment area during the preceding two weeks while 341 mm fell prior to the reading taken on the 28th of July 2001 (Lynn Taute, 2001) (Table 3).

The study site had an averaged velocity of 0.286 m·s^{-1} on the 29th of June 2001 (Table 2). This increased to an averaged velocity of 0.961 m·s^{-1} by the 13th of July 2001, the highest reading measured at the reach. The averaged velocity on 28 July was 0.527 m·s^{-1}while on the 29th of June 2001 it was 0.286 m·s^{-1}. When examining the discharge (Table 2) and cross-profile data (Figs. 5a-c, 5d-f and 5g-j), it can be said that the study period was one of above-average flooding events that created velocities that were capable of contributing to the observed geomorphic changes. After September there was little major channel change, but there were appreciable modifications in the form of vegetation encroachment on both banks of the upper section. Low to moderately rainy months followed the May-September period. Post-flooding data acquired during March 2002 revealed that bank erosion also continued on the left bank, although at a much slower rate than experienced during the May-September period.

Riparian vegetation composition

In 2001 and 2002 the riparian vegetation consisted predominately of herbaceous ground-storey species or sedges, mostly weeds including both indigenous and mostly alien plants (Table 1). This is clearly an indication of a disturbed area since a variety of trees, shrubs and herbs normally colonise different geomorphic features (e.g. lateral bars, flood benches, etc). Generally different environmental conditions are associated with the various geomorphic features (Rowntree, 1991; Hupp, 1992). Examples of persistent species, species that occurred in both years, included *Commelina benghalensis*, *Pennisetum clandestinum* and *Cyperus esculentus*.

Some riparian vegetation species such as *Conyza canadensis* or *Brachiaria eruciformis* were present only in 2001 and vice versa. Both perennial and annual plant communities were identified (Table 4). Most of the plant species found occurred on most of the geomorphic features in both years and consisted primarily of a combination of wet and dry bank vegetation. According to Tharme et al. (1997) wet bank vegetation is restricted to areas where erosion and deposition actively occur during winter high-

TABLE 4 Riparian vegetation recorded at the study reach with growth patterns, origin and weed status (After Levyns, 1966; Bond and Goldblatt, 1984; Bromilow, 1995 and Henderson, 2001)							
Family and plant species name	**2001**	**2002**	**Both years**	**Growth form**	**Annual/ Perennial**	**Origin (e.g. alien or indigenous)**	**Weed**
Apocynaceae – *Dittrichia graveolens*	*			H	A	AN	Yes
Asteraceae – *Conyza canadensis*	*			H	A	AN	Yes
Tarchonanthus camphoratus	*			T (SL)	P	I	No
Fabaceae – *Acacia mearnsii*	*			T (SL)	P	AN	Yes
Scirpus species	*			H	A/P	I	No
Poaceae – *Brachiaria eruciformis*	*			H	P	I	No
Cynodon dactylon	*			H	P	AN	Yes
Asteraceae – *Conyza bonariensis*		*		H	A	AN	Yes
Conyza species		*			A/P		
Hypochaeris radicata		*		H	A/P	AN	Yes
Fagaceae – *Quercus acuta*		*		T	-	-	-
Gramineae – *Panicum gilvum*		*		H	-	AN	Yes
Oxalidaceae – *Oxalis pes-caprae*		*		H	P	I	Yes
Poaceae – *Lolium perenne*		*		H	P	AN	Yes
Polypogon species		*		H	A/P	AN/I	Yes
Paspalum distichum		*		H	P	AN	Yes
Setaria species		*		H	A/P	I	Yes
Setaria verticillata		*		H	A	I	Yes
Polygonaceae – *Rumex acetosella*		*		H	P	AN	Yes
Solanaceae – *Solanum nigrum*		*		H	A	AN	Yes
Tamaricaceae – *Tamarix chinensis*		*		H	P	AN	Yes
Apocynacea – *Distephanus angolensis*		*		H	-	AN	Yes
Verbenaceae – *Verbena officinalis*		*		H	P	AN	Yes
Asteraceae – *Bidens pilosa*			*	H	A	AN	Yes
Lactuca serriola			*	H	P	AN	Yes
Commelinaceae – *Commelina benghalensis*			*	H	P	AN	Yes
Convolvulaceae – *Convolvulus arvensis*			*	H	P	AN	Yes
Ipomoea purpurea			*	H	A	AN	Yes
Cyperaceae – *Cyperus esculentus*			*	H	P	AN	Yes
Cyperus longus			*	H	P	I	No
Fumariaceae – *Fumaria officinalis*			*	H	A	AN	Yes
Plantaginaceae – *Plantago lanceolata*			*	H	B	AN	Yes
Poaceae – *Pennisetum clandestinum*			*	H	P	AN	Yes
Brachiaria serrata			*	H	A	I	Yes
Polygonaceae – *Polygonum* species			*	H or S	A/P	AN/I	Yes
Rumex species			*	H	P	AN	Yes
Salicaceae – *Populus x canescens*			*	T	P	AN	Yes
Tropaeolaceae – *Tropaeolum majus*			*	H	A	AN	Yes
Sapiridaceae – *Dodonaea* species			*	S	P	AN/I	Yes/No
Boraginaceae – *Eustachys paspaloides*			*	H	P	I	No
Total plant species	**7**	**15**	**18**				

Key to abbreviations
Growth Form: SL = Seedling; H = Herb; S = Shrub; T = Tree
Ann/Perr/Bia: A = Annual; P = Perennial; B = Biannual
Origin: AN = Alien; I = Indigenous
- = Information not available

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ISSN 0378-4738 = Water SA Vol. 33 No. 4 July 2007
ISSN 1816-7950 = Water SA (on-line)

flow levels. These areas may be inundated for lengthy periods in winter. In contrast, dry bank vegetation occupies areas which are only immersed during floods, when silt is deposited (Tharme et al., 1997). The number of species found along all transects increased slightly during the study period (Table 1).

Discussion

Cross-section change

In the present study it is proposed that the degree and rate of the observed channel adjustments were most likely attributable to vegetation composition and cover, duration of the rainfall (excessive and prolonged rainfall) and flooding events, which in turn, affected erosion and deposition processes. It is inferred that the heavy rains most likely aggravated the observed channel responses. Likewise, limited evidence suggests that several other factors such as the characteristics of the Lourens River catchment area to some extent could also have influenced channel morphology changes at the study reach. For example the forest in the upper catchment has recently been replaced by vineyards and the enormous scale of this operation must have resulted in a shift in the runoff pattern and sediment load.

A winter of heavy and prolonged rains and flooding events during the study period resulted in increased current speeds in the Lourens River channel. On the 29th of June 2001 the study area had an averaged velocity of 0.286 $m \cdot s^{-1}$ which increased to an averaged velocity of 0.961 $m \cdot s^{-1}$ by the 13th of July 2001 (Table 2). These discharges exerted greater shear stresses on the river bed and banks and resulted in channel instability in primarily the upper section. Evidence was presented in the form of in-channel deposition, channel widening and narrowing, bed and bank scour, lateral bar formation and channel migration. Severe left bank erosion led to an increase of 5 m to 7 m in the active channel width (Figs. 5c, d and e). It is proposed that processes of wet bank slumping and bank undercutting resulted in bank erosion. Bank retreat results when the flow scours the bed at the base of the channel bank to bring about gravitational failure of the intact bank. A detailed account of these processes and mechanisms appears in Thorne (1982; 1990), Knighton (1984, 1998) and Simon et al. (2000). These processes probably operated interdependently, although undercutting was perhaps more significant.

Drying (contraction) and wetting (swelling) of the bank and lack of stabilising vegetation caused the outer blocks from the left bank to be pushed away from the bank to such an extent as to cause slumping of blocks onto the base of the bank and eventually into the channel (Plate 2). Wet bank slumping took place during the falling limb of floods or after the individual flooding events had passed, in other words, after the confining pressure of the water was removed (Casagli et al., 1999; Simon et al., 2000). Increased positive pore water pressure during the full saturation of the bank material probably led to decreased cohesion and bank material strength and an increase in bank material weight. Increased velocities also introduced scouring of the non-cohesive sandy bank which consisted of very small fractions of silt and clay and a covering of shallow rooted herbaceous alien weeds and overhanging alien tree species (Plate 2 and Table 4). Undercutting of the lower bank therefore also contributed to bank instability, resulting in further bank erosion and sediment input into the river. Without exception, undercutting coincided with floods on the river, therefore heavy rains itself did not cause the severe bank losses. It was rains and floods in association followed by drawdown of the river stage that caused really marked changes (Rowntree, 2000).

Channel incision was evident from the analysis of the cross-section data, cross-sections 1.2, 1.4 and 1.5. Incision of the channel bed led to an increased depth of approximately 0.3 m (Fig. 5b). The results also indicated deposition of sediments in the channel (Figure 5d and e) and adjacent to the channel in the form of a lateral bar (Figs. 5a-c and Plate 5.2b). Localised deposition may result during a flood where a change in channel geometry, for example, a decrease in channel bed gradient, or an increase in channel width, causes flow velocity to decrease (O'Connor et al., 1986). In-channel deposition occurred during a moderate flood in August 2001, with sediment supplied during the flood by observed upstream bank erosion and failure and lateral bar scouring. Although infilling of 0.5 m was observed at the lateral bar (right bank), bar scour of 0.3 m and subsequent re-depositioning of sediments into the channel also occurred. Initially, the lateral bar occupied 22 m of the riparian zone (Fig. 5.2b). With continued sedimentation it grew until it occupied 40 m (Fig. 5.2c) of the riparian zone and became vegetated (Plate 5.2b). According to Church and Jones (1982) bars represent major storage places for traction load sediments. They also serve as energy dissipaters (e.g. through resistance) that permit stable channel configurations to be maintained in the presence of sediment transport (Church and Jones, 1982).

A comparison between pre- and post-flood cross-sections 1.3 and 1.4 (Figs. 5c and d) clearly indicated a lateral shift in the plan form of the river to the left. Bank erosion resulted in an increase in channel width (left bank retreat) followed by a period of lateral bar accretion with a corresponding reduction in channel width (convex right bank 'catching up'). Left-bank erosion and its associated channel widening therefore played a role in the observed change in channel plan form. Continued left bank migration was evident during successive field visits following the study period.

The downstream section (cross-sections 1.6-1.9), were more stable with little change in channel morphology. This indicated that the lower section was able to 'absorb' the impact of the winter 2001 flooding events much better than the upper section. In-channel deposition of 0.15 m to 0.25 m at all the cross-sections was observed though (Figs. 5f-j). The sediments were probably supplied by the upstream section of the river as visualised by cross-sections 1.2 to 1.5. These profiles did indicate erosion on the channel bed or banks. Also, the floods did not remove the riparian bank vegetation. Hence, for this reason the vegetated banks at cross-sections 1.6-1.9 were better drained and drier than the unvegetated banks of the upper section, implying that the impact of moisture-related processes was reduced. These drier banks were more stable simply because the bulk unit mass of the soil was reduced, cohesion was increased and the reduced moisture levels resulted in less frequent saturation conditions in the banks (negative pore-water pressure) (Thorne, 1990; Rowntree, 1991).

Riparian vegetation pattern change

The vegetation data analysis indicated that herbaceous species occur at the study site. These species were mostly fast-growing mono-specific stands of ruderal or invasive species that spread vegetatively and through the reproduction of seeds (Table 4). These species out-competed the pre-existing natural vegetation. Only remnants of tolerant indigenous flora remained. These established mature species survived simply because they showed greater tolerance to inundation, groundwater level changes and channel morphological changes. According to

Gowing et al. (1994), colonisation by ruderal species might increase the botanical diversity of an area but the ecological value might be reduced. Therefore, the expansion of alien taxa at the expense of key indigenous taxa has resulted in a general reduction in the ecological value of the riparian vegetation at the Lourens River.

A comparison of the vegetation data for 2001 and 2002 showed a greater average number of species for 2002. These pioneer species were predominately r-strategists (they produced large populations quickly) (Miller, 1996) that timed their seed releases to follow the flooding events experienced during the study period. Vacant habitat niches ready for colonisation by pioneer species were created by these flooding events. Cycles of fill and scour processes can create new habitats but can also make establishment very difficult (Tickner et al., 2001). The flooding regime thus, both reduced the plant species through erosion processes and increased the riparian plant species through deposition processes at the study site.

Riparian vegetation encroachment also influences channel form through its combined effect on geomorphic processes (Wohl, 2000b). Channel instability can be the result in steep undercut banks because the mass of the potential failure block is increased by the surcharge weight of trees. Overhanging trees can therefore drag the bank face down (surcharging) (Thorne, 1990; Rowntree, 1991). Woody plant stems may continue to retard the flow to very high velocities, but can generate serious bank erosion through the local acceleration of flow around their trunks. Channel morphological changes such as channel narrowing or widening and lateral migration may be the result (Rowntree and Wadeson, 1999; Wohl, 2000b).

Likewise, species such as *Salix babylonica* (Plate 1b) located on the left bank, which has a shallow rooting system, was unable to withstand flood flows (Rowntree, 1991; Rowntree and Dollar, 1996a, 1999). Roots will reinforce the bank against failure if the bank height is less or equal to the rooting depth hence, the roots need to extend to at least the average low water plane, if not, the flow will undercut the root zone during flood flows (Thorne, 1990; Rowntree, 1991). A detailed account of the benefits of vegetation cover is presented by various studies (Hickin, 1984; Gray and MacDonarld, 1989; Thorne, 1990; Friedman and Auble, 2000). Observations in the field confirmed that these trees resulted in bank collapse through slumping of blocks of bank material due to surcharging, especially in areas of undercutting of the saturated left bank.

In-channel woody debris in the form of dead trees was also present in the vicinity of cross-profile 1.3, at the left bank water's edge (Plate 2a) and it appears as if they contributed to the bank erosion. Dead trees tend to result in instability due to the loss of root-associated soil strength and their relic roots providing pathways for rapid seepage which often leads to piping (Thorne, 1990; Rowntree, 1991). These dead trees were thrown into the path of flooding events and probably lifted sections of the bank into the channel when it fell over. Also, channel morphological changes such as bed degradation caused by floods can lead to water table alterations which, in turn, can result in plant mortality (Friedman and Auble, 2000). For example, *Populus* species and *Salix* species are obligate phreatophytes. Both the maximum depth and the rate of fall of the water table are thus critical to their survival. Phreatophytes track falling water tables rather than utilising soil moisture (Gurnell et al., 2001).

Conclusions

It was hypothesised that channel discharge changes and riparian alien invasion influenced the channel morphological changes at the study site. The impacts of the 2001 flooding events were quite evident from this comparative study. It should be noted that similar results are reported by various other authors. In light of the research aim outlined in the **Introduction** section, the following conclusions can be made. Channel morphology changes at the study reach were influenced by both hydrological changes and riparian alien invasion. Bed and bank erosion, channel migration and narrowing, in-channel deposition and bar formation were therefore the result of increased velocities caused by intermediate discharges and riparian vegetation changes. However, a complex mix of other factors such as land-use changes or catchment characteristics probably contributed to the observed changes. Changes were more visible within the upper section of the study area. The lower section was more stable and indicated minute numbers of in-channel deposition.

A holistic approach is required when assessing the influence of a disturbance on river systems. It is suggested that further research is needed in the following fields: the magnitude and frequency of channel forming discharges, sediment maintenance flows, riparian vegetation response to fluvial changes and vice versa, bed material transport, hydraulic modelling, groundwater levels and river channel interactions. The above would help answer questions regarding the time scales over which river system changes take place and make useful contributions to understanding mechanisms of change.

Acknowledgements

The CSIR's Natural Resources and the Environment operating unit supported the preparation of this paper. This study was funded by the Water Research Commission (WRC) and the National Research Foundation (NRF). We are grateful for input by the WRC steering committee members. We thank Dr J King for her guidance and assistance in river ecology. Prof L Raitt, Mr F Weitz and Dr C Boucher are thanked for commenting on the vegetation sections of this study. Thanks to Miss R-M Fisher for assisting with fieldwork. Mr MC Briers and Mr P Bornman are thanked for their contributions with survey design and logistics. Thanks are due to Dr B van Wilgen for reviewing this paper. Dr S Holness is also acknowledged for his comments on earlier drafts of this work.

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Available on website http://www.wrc.org.za
ISSN 0378-4738 = Water SA Vol. 33 No. 4 July 2007
ISSN 1816-7950 = Water SA (on-line)