A spatial location–allocation GIS framework for managing water sources in a savanna nature reserve

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Associated with the establishment or removal of water sources in savanna ecosystems is the issue of the effects of such management actions on animal movement and habitat selection, longer term implications on population levels, and impacts of such change on habitat degradation and soil erosion. Extant metrics used to describe the spatial distribution of water sources on the landscape often fall short of providing source-specific information, making them hard to apply in small-scale management settings. Using the Klaserie Private Nature Reserve (KPNR) as a case study, we compare a buffer framework, describing distances to water, a nearest neighbour framework, and a spatial location–allocation framework (SLAF) created in a geographic information system (GIS). These three frameworks can be combined into one GIS to demonstrate site-specific information on water source distribution, in addition to system-wide descriptions. The visually accessible quality of a GIS allows qualitative input from managers and property owners to achieve quantifiable management goals. The duality of database and visual representation provides a useful tool to assess the role of individual water sources and can easily be updated to reflect changes in their distribution.

Key words: GIS, location–allocation models, nearest neighbours, piospheres, water sources.

INTRODUCTION

A primary concern in fenced savanna nature reserves is the management of water, and the impact point sources have on the ecosystem (Gaylard *et al.* 2003; Redfern *et al.* 2003; de Leeuw *et al.* 2001; Thrash *et al.* 1993, 1995; Walker *et al.* 1987). Considerable literature documents the concentric, attenuating utilization zones about water sources created through excessive animal use of habitat around such water points. The collection of these concentric zones was first described as the piosphere by Lange (1969) and later described by Graetz & Ludwig (1978) as a sigmoid curve of receding impact with distance. Piospheres were more formally introduced into the ecological literature by Andrew (1988) as a useful concept for the management of dry ecosystems. A review of piosphere modelling and techniques in 1999 (Thrash & Derry 1999) describes analyses from individual piosphere measurements to system models. How best to measure attenuation with distance and define utilization zones has been the subject of studies in arid systems in Australia, North America, Argentina and Africa (see James *et al.* 1999, for references). In addition, how to identify and define the sacrifice zone – the area close to a water source that is over-utilized and trampled – and the zones of decreasing use has been the subject of studies in the Kruger National Park (KNP) and neighbouring lowveld reserves (*e.g.* Thrash 1993, 1998; Pienaar 1998; Brits *et al.* 2002).

Potential negative effects on biodiversity of animals and vegetation due to concentration about waterholes (Nangula & Oba 2004; Western 1975; Andrew 1988), altered distribution of prey species (James *et al.* 1999) and erosion and degradation of surrounding habitat (*e.g.* Walker *et al.* 1987; Thrash 1998; Parker & Witkowski 1999) arise as dry season water demand increases. These concerns in KNP led, in part, to a water-for-game programme from around 1929 to 1990, with the objective of adding water points to create a more even distribution of utilization pressure, reduce river damage and prevent emigration into neighbouring reserves (see Brits *et al.*

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2002 for details). In KNP and other arid and semi-arid ecosystems, attempts to create even utilization through regular placement of boreholes or adding artificial water sources to the existing distribution have proven unsuccessful, as the whole system becomes concentrated in the sacrifice or high use zones during the dry season (Thrash 1998b; James *et al.* 1999; Brits *et al.* 2002), reducing vegetation diversity across the entire water source distribution and creating sedentary over-utilization by herbivores (Thrash 1998b). Thus current management trends have turned toward removal of artificial waterholes in KNP (Gaylard *et al.* 2003; Redfern *et al.* 2003). de Leeuw *et al.* (2001) pointed out that artificial water sources are often built to attract animals; and, in a small private reserve, this is important for wildlife viewing. In a system where water is managed by individual properties and wildlife is maintained at high densities, the impacts of dry season erosion are readily apparent (C. Rowels, pers. comm.). Removing water sources may be hard to negotiate and may also create greater erosion pressure on the remaining waterholes. Reconciling these potentially conflicting management objectives requires a framework wherein focal objectives can be combined with larger system objectives.

In the absence of piosphere data relating to specific water points in a fenced game reserve, the first step towards formulating a rational water location policy is to use an area allocation concept. What is the area associated with each water point, assuming that the burden on the piosphere is proportional to the size of the area and hence the animals in that area, representing the ‘utilization burden’ of that waterhole? We do not assume that this burden scales linearly with area, because animal densities drop off with distance to water (Redfern *et al.* 2003). A pure area approach, however, represents a first cut at framing a water source location allocation analysis that can later be augmented with specific piosphere data for the park or region of concern. The spatial location–allocation framework (SLAF) shows potential areas for increased impacts on focal water sources in a reserve during the dry season, which provides source-specific information for management. The framework reflects an economics-oriented supply–demand viewpoint. If we picture the reserve as a region to which we want to provide a *service,* water, we derive a focal metric for managers to apply to individual water sources on individual properties. Location–allocation models are used in designing business networks to assess demand for point source suppliers, such as distribution hubs to franchise points. This creates a network model, whose optimal form is found by minimizing the distance between the points (see Hamilton 1967, for further description). When demand is generalized across an area, the locatin–allocation model becomes a point-polygon location problem (Radke & Mu 2000). A contemporary example of this is mobile phone coverage from point-sourced mast towers; each tower must produce sufficient signal for its area. In addition, a SLAF lends itself easily to the substitution model of Teitz & Bart (1968), a process wherein points are removed or added and modelled and compared to prior model outputs. This is an appropriate means for us to model management actions such as adding or removing water sources.

In this study, seasonal effects on the water source distribution are modelled first. Then two hypothetical management scenarios are modelled based on realistic management options for this reserve. For the first management scenario we map the resulting distribution when all artificially supplemented water sources are ‘turned on’ in the dry season. For the second scenario, we augment the largest Theissen polygons above a certain size threshold generated by our SLAF, by ‘turning on’ the nearest artificial water source. This action reduces the area associated with the original sources, while not significantly altering the average polygon area for the whole water source distribution. The results of these two strategies, a reserve-wide goal and a local goal, are compared in each of the three aforementioned frameworks.

STUDY AREA

Klaserie Private Nature Reserve (KPNR) is located in the Limpopo Province of South Africa, bordering Kruger National Park (KNP) on its western boundary (24°3–22′S, 31°2–19′E; 303–535 m a.s.l.; 57 800 ha) (Fig. 1). The reserve comprises multiple private properties, many formerly utilized as farms; it was physically separated from KNP in 1961 with the erection of fences along KNP’s western boundary to prevent spread of foot-and-mouth disease into domestic cattle (Witowski 1983). A western segment of this fence was later removed so that KPNR is now part of the Greater Kruger National Park Management Area, although it remains separated by fences from neighbouring private reserves. The species of herbivores represented in KPNR are similar to the suite of species

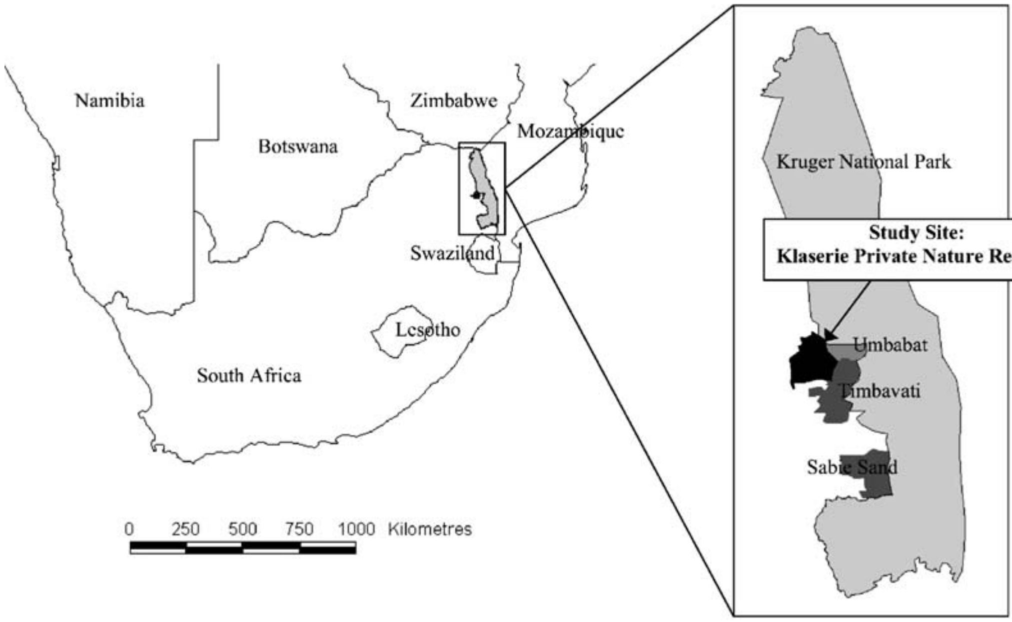


Fig. 1. Location of KNPR (Klaserie Private Nature Reserve).

in the central part of KNP.

The main geological substrate is granitic gneiss, part of the extensive granitic system underlying most of the country (Witowski 1983). The seasonality of KPNR follows a subtropical savanna pattern: both temperatures and rainfall follow a unimodal distribution annually (Fig. 2); mean annual rainfall from 1992–2000 was 486 mm. Two seasons are defined for this study based on the rainfall and temperature records of the reserve. These seasons are a hot, wet season from October to March and a cool, dry season from April to September.

METHODS

Water sources in this study include seasonal pans, artificial pans and catchment dams as point sources and two major river courses, the Klaserie and the Olifants, which have perennial segments in KPNR (Fig. 3). Seasonal pans are natural pans which retain water during the wet season and can remain wet into the dry season, but most dry out. Artificial pans are pans which are either natural or have been hollowed out of the ground and sometimes lined with cement, but which are supplied with water from a pump. Water supplementation is controlled by the property owner and water presence is less subject to season than in seasonal pans. Catchment dams are created by damming a drainage line, creating a three-cornered water source. Some of these dams are supplemented by water pumps in the dry season, but many dry out. What we refer to as *natural removal* of a source results from climate change in the case of seasonal pans and catchment dams, and *artificial removal* via cessation of water supplementation to artificial pans and catchment dams.

Data on the geographic locations and type of water sources in the KPNR were obtained and tabulated by KPNR management (n = 145) (C. Rowels, pers. comm.). We assumed that all the water sources would be active in the wet season. These locations were censused in June 2002 by KPNR management (C. Rowels) for water presence, and this subset is the dry season dataset (n = 74). The courses of the two major rivers that run through the reserve, the Klaserie and the Olifants were included as water sources; along their entire course during the wet season, and along their persistent perennial routes in the dry season. For the first hypothetical management scenario, all of the artificial pans that could be supplemented during the dry season were added back into the dry season water source data set and the three model methods were run. For the second scenario, the water sources associated with the largest polygons lying above a selected threshold value were identified based on a distribution break in a histogram of the polygon areas. Next, an additional available water source was 'turned on' within each

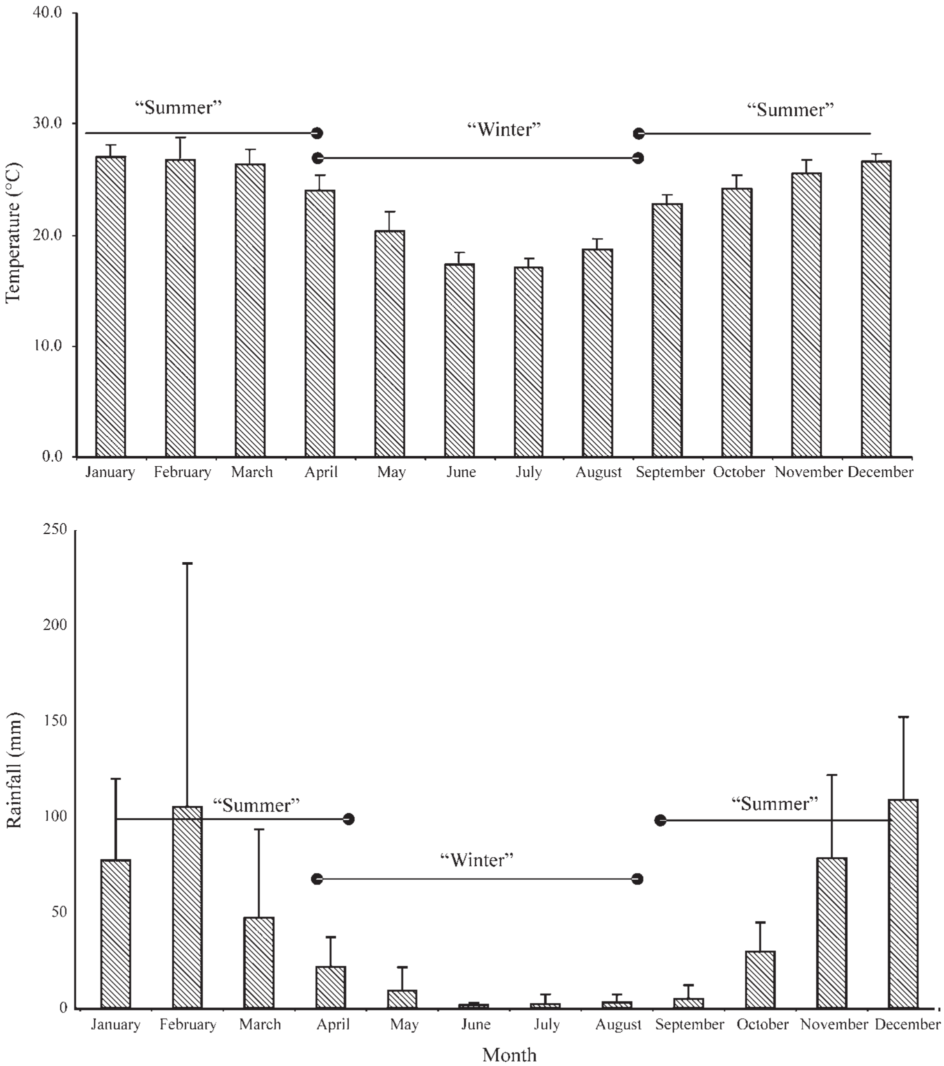


Fig. 2. Unimodal distribution of temperature and rainfall in KNPR. Temperature data represents the average of daily minimum and maximum temperatures recorded at the Warden's office (1991–2000) by month; error bars represent +1 standard deviation. Rainfall data represents the average of monthly data (1992–2000) recorded at the Warden's office; error bars represent +1 standard deviation. Note the designated seasons according to the distribution shape.

of these polygons. We then ran the three model methods once more. Relevant information was manipulated into shapefiles in ArcView© 3.2 and analyses were conducted using ArcView© 3.2, Thiessen ver 2.6 (Ammon 2000), Geoprocessing Extension and Edit Tools 3.4 (Tchoukanski 2002).

Buffer framework

For the buffer framework, the locations of all the water sources tabulated during the wet season were buffered in concentric 1 km rings and clipped to the reserve boundary to assess the area of the reserve at different distances to water (Fig. 4a); this process was repeated for the dry season water sources (Fig. 4b) and then for the two hypothetical management scenarios and the results tabulated for comparison (Table 1).

Nearest neighbour framework

The locations of the wet and dry season water points were used to calculate the nearest distance to river sections and then to nearest water source. The nearest neighbour distance between two point water sources was calculated as a vector,

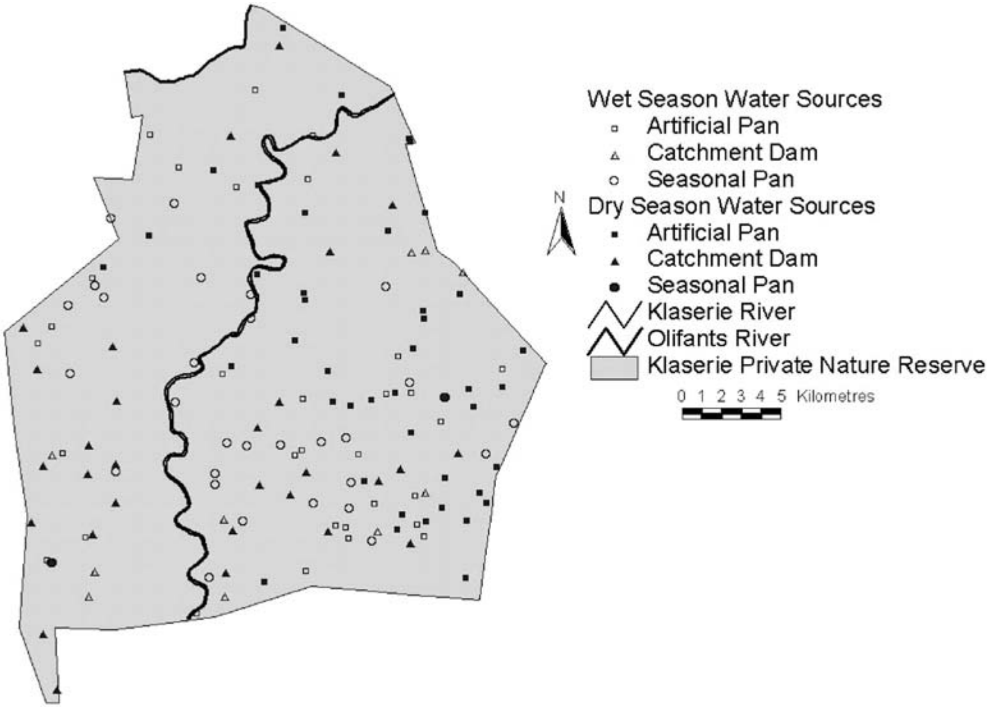


Fig. 3. Water source locations and types in the KPNR. Note that water presence in the dry season is represented by filled symbols.

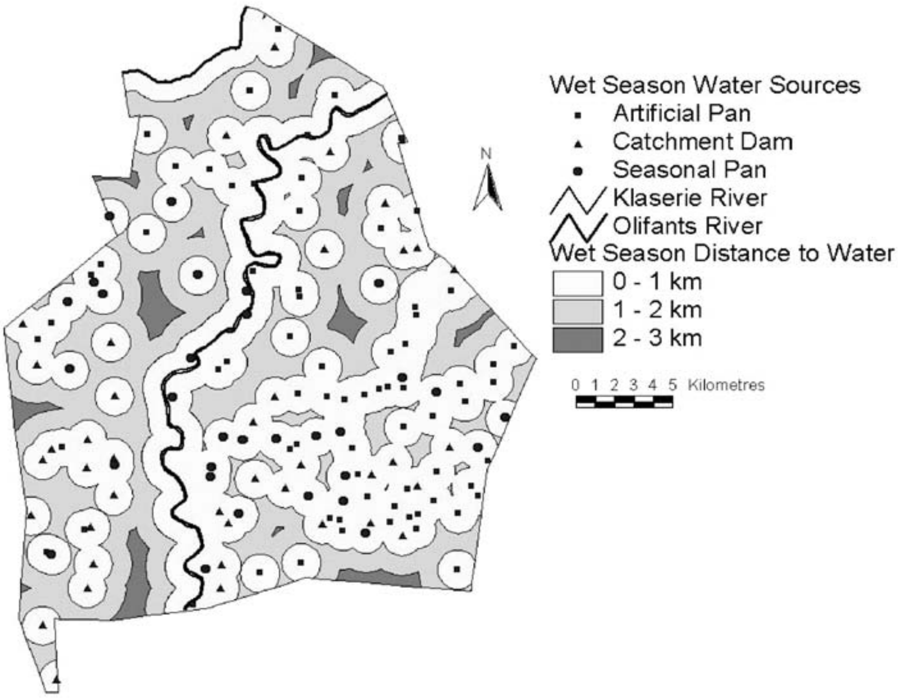
by minimizing the results of a triangular matrix calculator for Euclidian distance in Microsoft Excel©. The lesser of the distance to nearest river or nearest neighbour was taken as the nearest neighbour distance to water.

Spatial location–allocation framework (SLAF)

The simplest spatial representation of an unconstrained location–allocation model of supply points to demand regions uses the Dirichlet tessellation to generate Voronoi or Thiessen polygons (Okabe *et al.* 1992). A tessellation is essentially a mosaic, a tiling created in a geometric plane. This tessellation is created by the intersections of perpendicular bisectors between each point in a set, as depicted in Fig. 5. It is constructed such that all the area contained within each polygon is closer to the point with which the polygon is associated than to any other point. If we have an unbounded set of points, this tessellation will generate internal polygons that are complete and boundary polygons that stretch to infinity. In this framework, the tessellation is modified to create Theissen polygons whose outer boundary edges are that of the area in question. In absence of data on the heterogeneity of the landscape with respect to water access, and the heterogeneity of species impact on these water sources, this model is the simplest and most straightforward representation of the potential pressure exerted on each water source with respect to demand. The larger a polygon associated with a water source, the greater the area it must provide water for, and the sparser the local distribution of points. Thus we expect a higher rate of herbivore utilization impact at these sparser points because they are in higher demand.

For the location–allocation framework, the locations of all the water sources tabulated were used to create the tessellation of Theissen polygons, clipped to the reserve boundary, and the areas were spatially assigned back to the original water sources, using the Geoprocessing Extension. As this method is a point-based calculation, river lines were reduced to point sets along their courses. This generated multiple sliver polygons irrelevant to the study, and therefore we excluded all polygons whose area did not include a non-river water source (Fig. 6). Again, this was repeated for with dry season water sources (Fig. 7) and the point set generated under the two hypothetical management scenarios, and the results compared (Tables 1 & 2).

a



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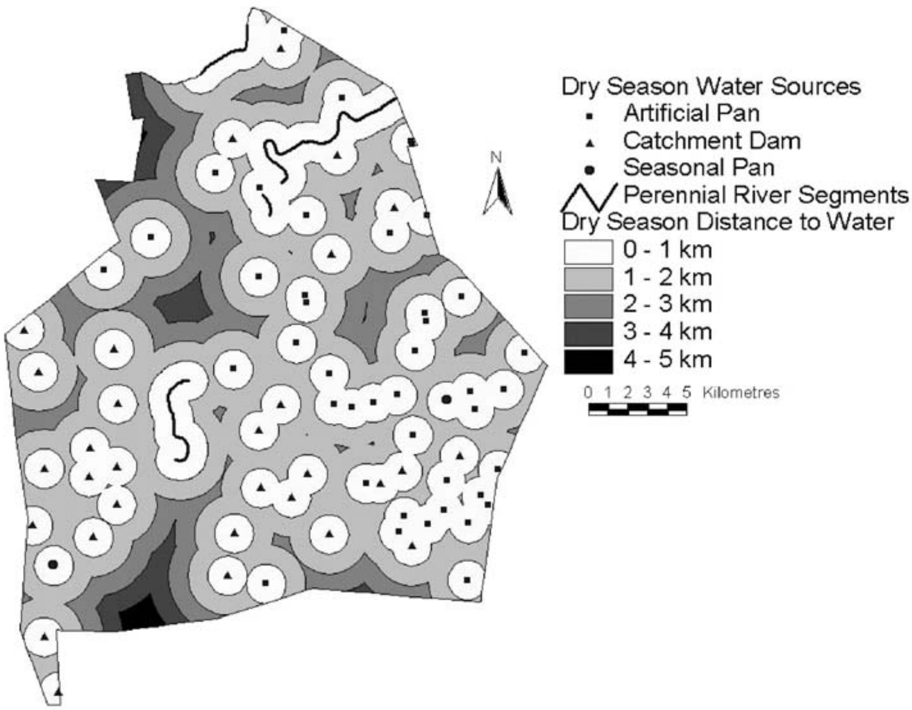

Fig. 4. **a**, Buffer model showing distribution of distance to water classes during the KPNR wet season. **b**, Buffer model showing distribution of distance to water classes during the KPNR dry season.

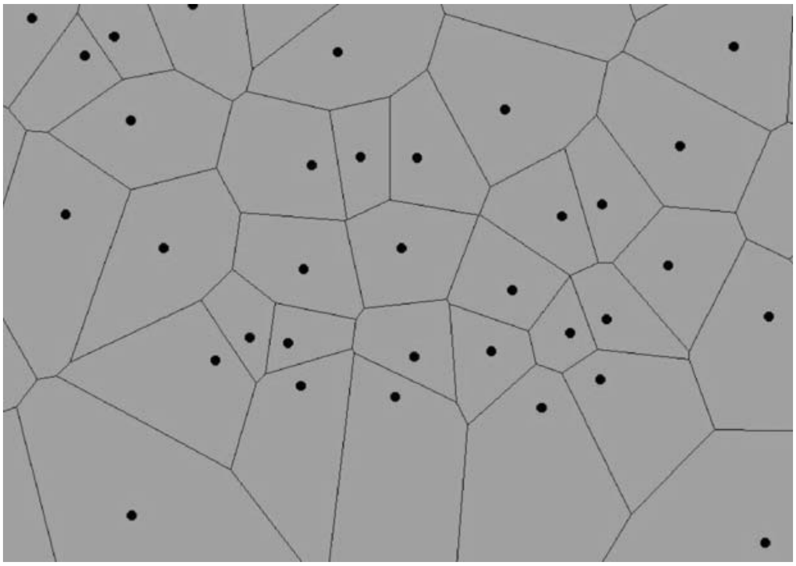

Fig. 5. Voronoi tessellation (Thiessen polygons) generated from a point set.

All statistical analyses were performed using SAS JMP (ver. 4.04).

RESULTS

The dry season KPNR water source census showed that of 145 recorded water sources (74 artificially supplemented, 40 catchment dams and 31 seasonal pans), 74 still held water (42 artificially supplemented, 30 catchment dams and two seasonal pans). For the first hypothetical management scenario, the water sources increased to 106 (74 artificially supplemented, 30 catchment dams and two seasonal pans) and 81 (74 dry season sources plus seven additional supplemented sources) under the second scenario.

Buffer model

The buffer analysis (Table 1; Fig. 4a,b) demonstrated that in the wet season no part of the reserve is more than 3 km from a water source, whereas in the dry season some areas can be further than 4 km from a water source. The proportion of the reserve area that is in close proximity to water sources also changes; in the wet season, 63% of the reserve is within 1 km of a water source and 97% within 2 km, while in the dry season, 39% is within 1 km and 83% within 2 km. Under the first management scenario, no part of the reserve was greater than 4 km from a water source; 48% within 1 km and 89% within 2 km (Table 1). The second scenario changed the proportion of the reserve within 1 km of water to 43% and 89% within 2 km; no part of the reserve was greater than 4 km from water sources (Table 1).

Nearest neighbour framework

The nearest neighbour distance analysis showed that the average nearest neighbour distance to water increases from the wet season to the dry season from 1.00 ± 0.05 km ($\bar{x}$ ± S.E., n = 145) to 1.52 ± 0.09 km ($\bar{x}$ ± S.E., n = 74). The nearest neighbour distance under the first management scenario brought this to 1.12 ± 0.07 km ($\bar{x}$ ± S.E., n = 106). Under the second scenario, an *increase* in nearest neighbour distance from the dry season distribution occurs 1.64 ± 0.08 ($\bar{x}$ ± S.E., n = 81). An ANOVA for multiple comparisons of means was significant (F = 18.50, d.f. = 401, P < 0.0001). Tukey-Kramer's honest significant difference (HSD) (α = 0.05) showed that the wet to dry season change is significant, the first scenario is significantly different from both the dry season and the second scenario, and the second scenario is significantly different from the wet season and the first scenario, although not from the dry season.

Spatial location–allocation framework (SLAF)

The SLAF showed that the area supplied by water sources increased significantly in the dry season (Figs 6 & 7). The polygon area per water source increased from 3.19 ± 0.17 km^2 ($\bar{x}$ ± S.E., n = 145), in the wet season to 6.69 ± 0.47 km^2 ($\bar{x}$ ± S.E., n = 74) in the dry season. The proportional

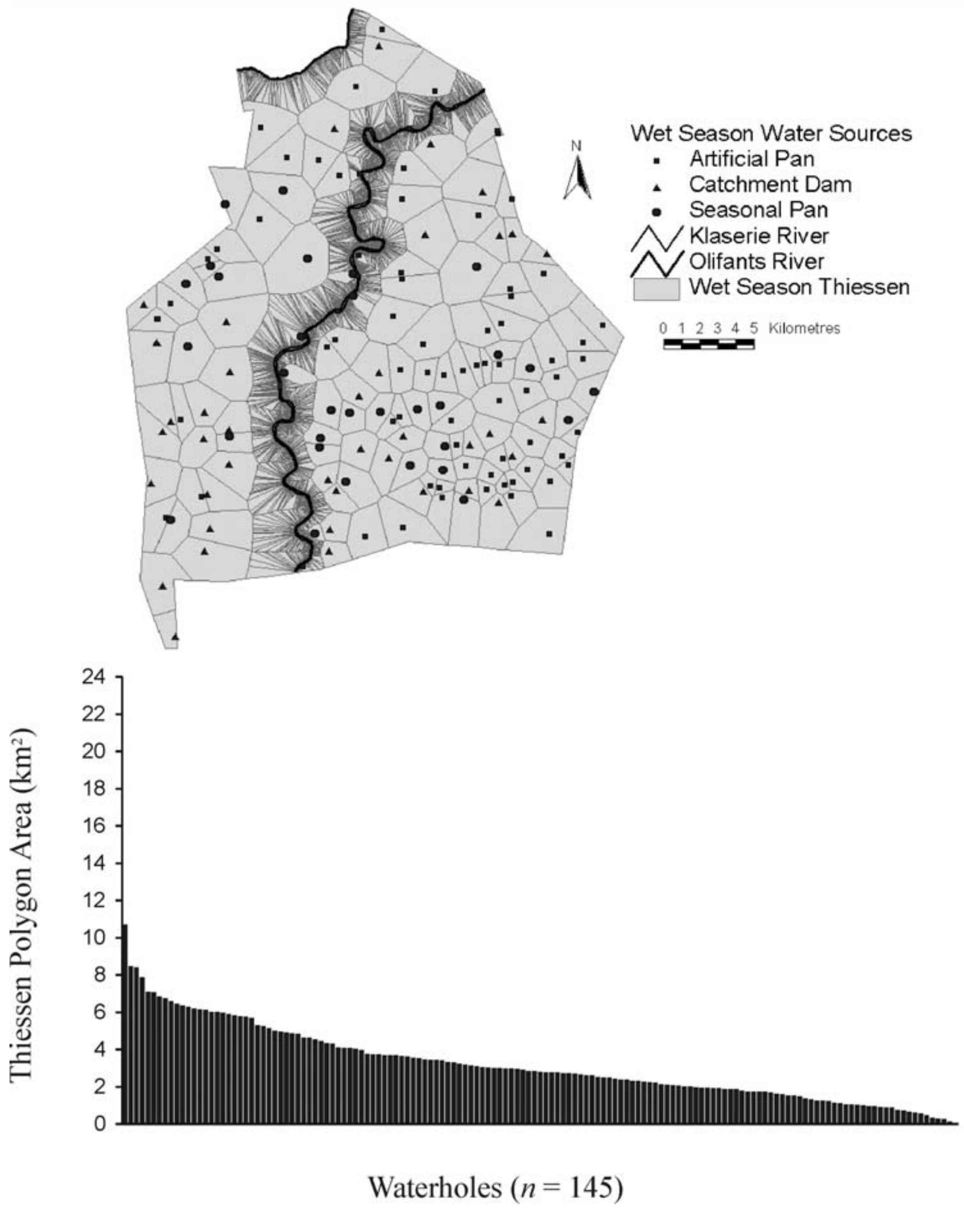

Fig. 6. KPNR wet season Thiessen polygon location-–allocation framework illustrated in an ArcView© screen shot and a distribution chart.

increase in average polygon area for the dry season water sources was 110% ($n = 74$). Turning on all the artificial water sources in management scenario I altered the average polygon area to 4.81 ± 0.30 km^2 ($\bar{x}$ ± S.E., $n = 106$). Under the second management scenario, we identified water sources with the largest areas. We simulated manipulation of sources with polygon areas greater than 12 km^2 (see Fig. 8a), based on a distribution break identified in Fig. 8b. This yielded seven water sources; we then simulated placement of additional water sources within their polygon areas and the resulting reduction in their respective polygon areas is given in Table 2. The overall average area per water source was reduced to 6.67 ± 0.34 km^2 ($\bar{x}$ ± S.E., $n = 81$). An ANOVA for multiple comparisons of mean areas among models was significant ($F = 31.57$, d.f. =

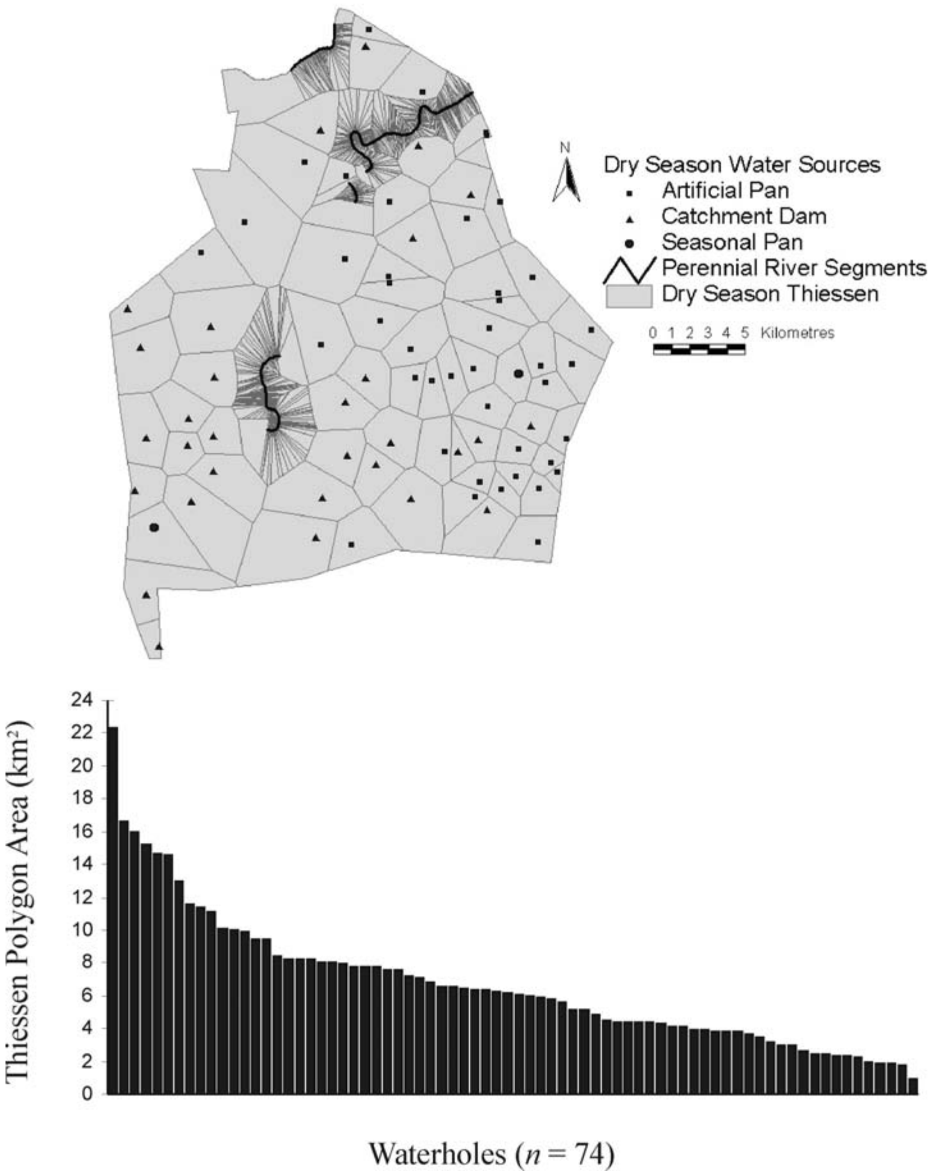

Fig. 7. KPNR dry season Thiessen polygon location–allocation framework illustrated in an ArcView© screen shot and a distribution chart.

401, $P < 0.0001$), and *post hoc* Tukey-Kramer's HSD (α = 0.05) tests for differences in means showed that the wet season mean polygon area was significantly different from the dry season's; the first management scenario was significantly different from both seasons and the second scenario, and the second scenario was significantly different from the wet season and the first scenario.

DISCUSSION

The three frameworks used to assess the change in distribution of water points in the reserve yielded generalizations, which are useful as descriptors of system change, but can be hard to translate directly into management action on specific water sources. The advantage of the SLAF over the two other frameworks is that the area of the polygon associated with each water source is visually

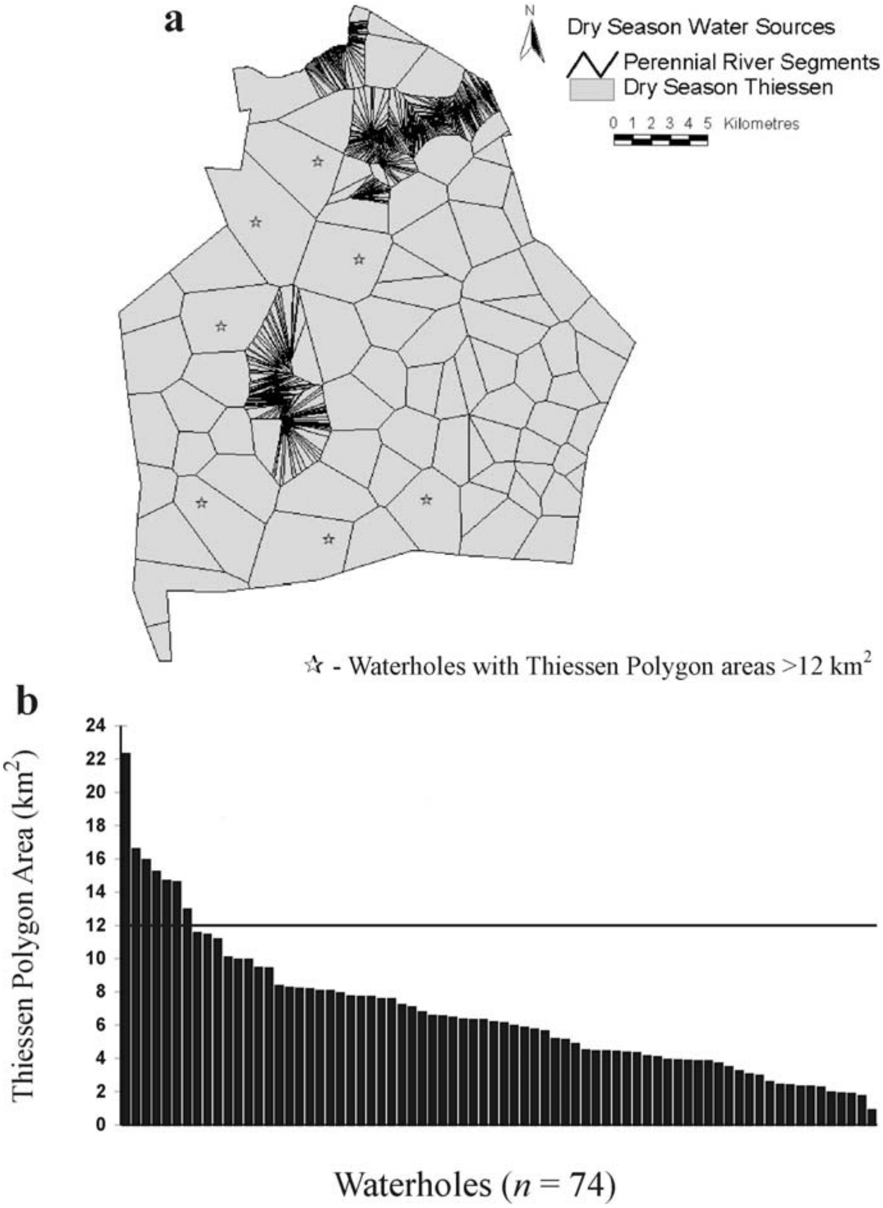

Fig. 8. **a**, Thiessen Polygons of KPNR waterholes showing the seven waterholes identified as having Thiessen Polygons of area greater than 12 km^2. **b**, Distribution of Thiessen polygon areas associated with KPNR dry season water sources. Note the distribution break above 12 km^2 that identifies the water sources used in management scenario II.

accessible and quantified individually.

In this study, the first method used was to buffer each water source to model the areas of the reserve that lie at certain distances from water sources in the wet season and in the dry season. Clearly, the proportion of the reserve in proximity to water source changes with the dry season water source removal (both natural and managed) (Table 1, Fig. 4a,b). Game species, for which in large part, water sources are placed and managed, may become concentrated into smaller areas, which may increase local degradation, concentrate prey species and alter vegetation use. This reserve represents an environment with relatively high water availability and a similar stocking rate to KNP (Thrash 2000); the number of non-river water

Table 1. Summary of area and proportions calculated using a buffer framework for dry season, wet season, management scenario I (all artificial water sources are turned on in the dry season), and management scenario II (the three largest Theissen polygons generated in a SLAF are reduced by turning on the nearest artificial water source). The distance to water is in 1 km bands, the area is given in km^2, and the proportion shown is the proportion of the total area in the distance category.

	Dry season		Wet season		Management scenario I		Management scenario II	
Distance to water	Area	Proportion	Area	Proportion	Area	Proportion	Area	Proportion
0–1	227.27	0.39	363.53	0.63	274.50	0.48	245.47	0.43
1–2	252.83	0.44	194.71	0.34	236.83	0.41	266.61	0.46
2–3	76.18	0.13	19.59	0.03	56.71	0.10	60.80	0.11
3–4	19.00	0.03	na	na	9.79	<0.02	4.99	<0.01
4–5	2.54	<0.01	na	na	na	na	na	na

sources has increased from 6 in 1965, to 144 in 1980 (Parker & Wittowski 1999), to the 145 reported in 2002. Even in the dry season, KPNR is well supplied with water, compared to the water availability of KNP, in which, under the new borehole removal programme, portions of the park are more than 8 km from water, including ephemeral sources driven by dry season rainfall (Redfern 2002). The buffer method yields a system-wide metric and demonstrates visually and quantifiably which areas are most subject to change of season. However, from the perspective of a property manager, who may need information on specific water sources, it is difficult to apply this metric to specific management actions. This follows because it is hard to compare the distance buffers generated under different management scenarios at a local scale.

The second method assessed the change in distance between nearest neighbour water sources under seasonal and management regimes. This is intuitively a useful metric, as it generalizes the distribution of water sources to a local 'choice', and fits well intuitively with constraints on habitat selection and resource availability. The analysis showed that the distance between water sources increased in the dry season, from roughly 1 km to 1.5 km. This measure reflects the increase in the number of water points in the reserve since 1982, when the mean spacing was 2 km (Zambatis 1982; season unspecified). Although statistically significant, these seasonal and managed changes in distances may not be important for visible game species using the water sources, for which they are managed in KPNR. Large herbivores and game species such as buffalo, whose daily range is approximately 5 km (Sinclair 1977), may not be greatly affected by these alterations in distance. Moreover, the SLAF more precisely shows the midpoint between water points along an edge, representing essentially the point of tradeoff between neighbouring points as it might be perceived by an herbivore.

Table 2. Thiessen polygon areas before and after the seven water sources are manipulated in management scenario II.

Thiessen polygon area[1]		
Before	After	% Change
22.31	9.81	44
16.58	10.17	61
15.94	11.10	70
15.23	8.55	56
14.67	7.60	52
14.59	12.43	85
12.97	6.25	48

[1]Areas given in km^2.

The nearest neighbour method is hard to apply to management of focal water sources, as manipulations would require altering the spatial distribution of water sources relative to one another. An average nearest neighbour distance fails to identify which specific sources undergo the largest change or are further from others in the distribution than the average. In fact, when the second management scenario presented was run, the nearest neighbour distance analysis produce a counter-intuitive result in which the average distance *increased* under a plan directed at decreasing utilization pressure. This occurred as the points which were added into the distribution, while closer to the seven points the plan sought to relieve from pressure, were further from the next nearest water points. The selection of these points was purely based on availability of water sources, and

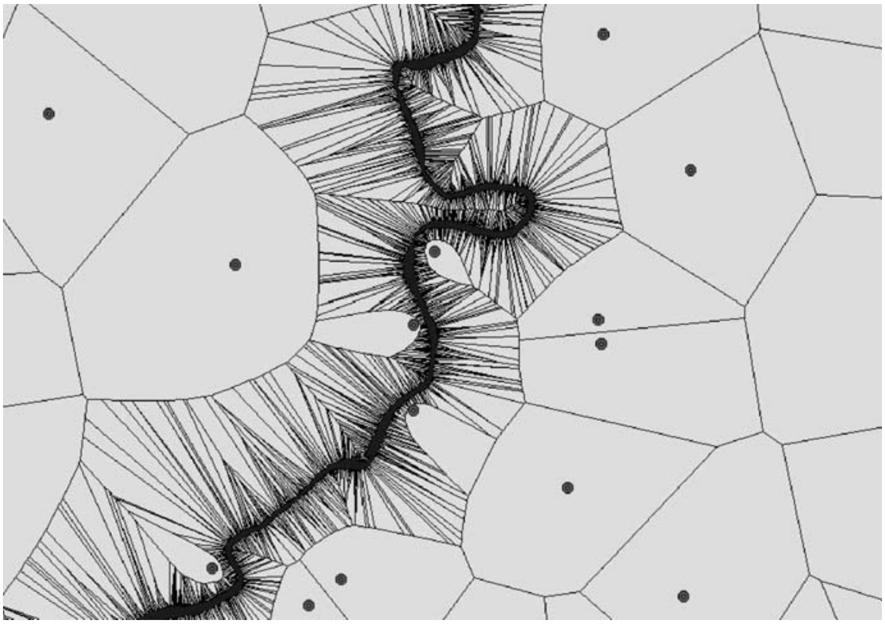

Fig. 9. Accommodating river curvature in a location–allocation model. Note the sliver polygons that are excluded from the analysis, but approximate the curved response on polygon edges.

under the nearest neighbour model, the result could be misinterpreted as a failure to meet management objectives. However, our SLAF clearly shows a reduction in polygon area associated with the seven waterholes, and a minor reduction in the average polygon area for the whole distribution.

The SLAF demonstrated that the average area supplied by water sources in the wet season, represented by Theissen polygons, is approximately 3 km^2. A 167% increase of average polygon area to over 6.5 km^2 gives us insight into the potential for increased impacts around dry season water sources. The increased area will lead to an increased herbivore concentration around the remaining sources. This may be a positive outcome from a local or property management standpoint; given that the rarity of the water source may allow better wildlife viewing. In addition, it is suggested that isolated points positively affect diversity of vegetation (Thrash 2000). These average area comparisons between seasons give us insight into an overall change in water supply in the reserve. We can compare this metric with the first two model metrics and draw similar inferences about dry season impact across the reserve.

Using the SLAF, each water source had associated with it a specific supply area increase in the dry season, apparent visually by the size of the polygon associated with it (Figs 6 & 7). The addition of a chart showing the areas associated with each water source allows another means of visualizing the distribution. Apparent in this distribution is the upper and lower extremes of areas. Using the river segments as part of this analysis gave a more realistic quantification of the space supplied by each water source. The point representation of the curved river course created multiple sliver polygons as seen in Fig. 9. The large number of polygons generated required quite high computational power, but the result approximated a curved edge on the polygon for the nearest non-river water source.

The first hypothetical management scenario sought a very quick and simple means to reduce the potential for impact on water sources present in the dry season, by reducing their average supply area significantly. All the artificially supplemented water sources were 'turned on' during the dry season and analyses run on the new set of data. The buffer analysis showed that this altered the reserve landscape such that less of the reserve was as far from water sources, and the nearest neighbour distance between sources was reduced by around 400 m. In addition, there was a statistically significant reduction in the supply area to the dry season water sources, which could mitigate dry season impacts on those sources.

Although current management strategies in nearby savanna ecosystems are now advocating removal of artificial water sources and increased heterogeneity in water source placement (Owen-Smith *et al.* 1996; Thrash 1998a; Redfern 2002), with high stocking rates and a small total area, this may not be an immediately feasible or desired option. However, the SLAF's visually accessible information on association polygons makes planning for heterogeneity in the distribution simpler than the first two methods.

The second hypothetical management scenario is an example of using the database for a query-based management option, wherein the data on both SLAF polygon size and water source type were sorted and used to develop a management action. The charted dry season Thiessen polygon distribution showed a break in the distribution at slightly over 12 km^2, which we chose to use as our cut-off for the management scenario. The seven largest polygons associated with dry season water sources were selected, and the nearest artificial water source 'turned on'. The resulting reduction in polygon area associated with the original water sources was dramatic (see Table 2), with an average reduction of 59%. This local management action had no significant impact on the distribution-wide average polygon area, and actually caused an increase in the average nearest neighbour distance.

Although a Dirichlet tessellation was used by Parker & Witkowski (1999) in the design of a piosphere study in Klaserie Private Nature Reserve (KPNR) to identify the furthest points from water sources on the attenuation gradient, the application of this tessellation framework specifically to evaluate and manage the placement of waterholes has not been seen in the literature. Aside from specific terrain considerations (*e.g.* obstacles to movement, and resource gradients in different directions), Thiessen polygon edges essentially represent the trade-off zone for herbivores between a local set of water sources, such that each edge will be the end of the attenuation gradient of the piosphere. Thus, a Dirichlet tessellation, in the absence of more specific habitat information, not only provides a measure of the area each water source supports, but also a visual representation of the limit of utilization zones.

In previous studies, quantifying or describing water source distributions for management has been limited often by the models used. More specifically, inappropriate methods lead to questions being answered that do little to address the real issues at hand. Conventional spatial statistics, in which we describe a point pattern (*e.g.* Ripley's K, Geary's C), tend to focus on clusters of points and deviation from a 'random' distribution. This might be useful to an ecological modeller, but be far removed from applicability in a management setting. Descriptions that average over the entire distribution of water sources, such as mean nearest neighbour (Parker & Witkowski 1999), or distance to water areas (Pringle & Landsberg 2004; Redfern *et al.* 2003; de Leeuw *et al.* 2001) can be useful for examining the consequences of a management action for a distribution of wildlife or livestock. Buffer models, describing distance to water, lend themselves readily to comparison with piosphere studies. The reason is that the zone of attenuating use is radial, and therefore circular distance bands can be surrogates for utilization zones However, when buffer maps are used in an *ad hoc* manner to decide what management actions to implement, they may underestimate potential impacts on specific water sources. The quantitative result of re-modelling a new water source distribution will only yield a distribution-wide descriptive map. Creating appropriate measures for demonstrating change on a local scale, or re-applying the results to a management scenario is often left to guesswork.

The spatially explicit nature of the SLAF output in a GIS interface such as ArcView©, in conjunction with the ancillary attribute database, allow us to see *where* in the reserve the impacts may increase, and one can query these specific locations with regards to property and water source type. Data regarding the proximity to water of the land (*i.e.* the buffer model) within the polygon can be overlaid visually. The distance to the nearest water source can be recorded for each point and other information, such as water source type, the ability to manipulate supplementation, or other management options can be assigned to each water source point and queried by the user (Fig. 10). Perhaps most important is the ease with which these models can be implemented. Although Excel© was used to calculate nearest neighbour distances, all the model functions described can be executed within ArcView© software (ESRI) using included extensions or freely downloadable extensions from the ESRI hosted website (http://www.esri.com). Using the three frameworks in one system, a database of focal information can be created for each source in addition to providing

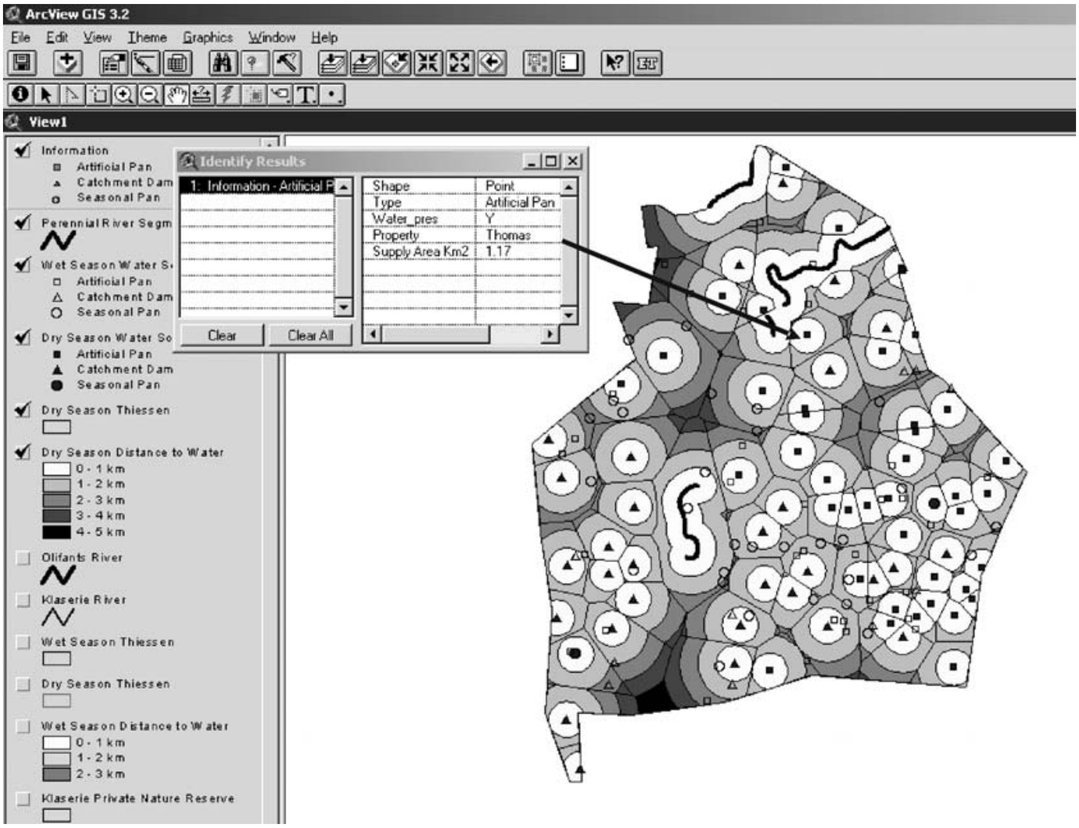

Fig. 10. User Interface for the GIS Model. Hypothetical query result for a water source shows the user the type of water source, the supply area and property owner.

summary metrics of the reserve-wide water distribution. Demonstrating that the management scenario modelled will create statistically different average metrics is useful, though perhaps not always terribly meaningful. Providing this information in conjunction with a user-friendly database, however, creates a management tool in which management goals can be demonstrated and manipulated.

As the impacts of global warming in combination with effects of the El Nino Southern Oscillation become more apparent in this savanna ecosystem (see Ogutu & Owen-Smith 2003 for details), both the tools to manage, and the tools to understand the effects of management of water sources become essential. The potential for this to be used as a management tool for water sources in a small reserve is apparent. Property owners can be involved in informed decisions about placement of sources, supplementation of water and availability of resources, while managers can quickly and quantitatively assess the potential overall impacts. Combining metrics such as the proportion of reserve area at certain proximity to water and the nearest neighbour distance of water sources with the SLAF can assist management of water sources in a framework that is easy to implement.

FUTURE GOALS

This basic GIS tool can also be used in more complex assessment scenarios. Adaptive management models (*e.g.* Riley *et al.* 2003; Seely *et al.* 2003) can be linked to decision theory tools (*e.g.* Westphal *et al.* 2003; Conroy & Noon 1996) and optimization procedures can be used to attain specific management goals. If the goal is even coverage, or even supply areas for water sources, an equity generation model using optimization procedures such as proposed in Radke & Mu (2000) could be used. Alternately, if water source manipulations are subject to other decision processes, such as creating service heterogeneity, the Teitz & Bart (1968) substitution model can demonstrate potential impact changes and an adaptive management strategy adopted. Finally, our SLAF approach is the prelude to a more sophisticated management approach in which each polygon can receive weightings that reflect both the value of resources within specific polygons or degradation ratings that come for a piosphere analysis of each water point.

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