CHAPTER 3

Trade-offs and Decision-making

The need to make trade-offs between different ecosystem services, or between ecosystem services, biodiversity, and human well-being is an inherent part of the decisions that ecosystem users and managers face. Because this often involves diverse actors with different values and competing objectives, choosing between trade-offs can be a contentious and sometimes conflict-ridden process. Trade-offs in the southern African context typically are made against the backdrop of particular pressures that arise from the need to achieve social and economic development goals while securing ecosystem functions. In the Gariep basin, the challenge of making trade-offs is intensified by the need to reverse past discrimination in South Africa that prevented the majority of the population from fully realizing or gaining access to the benefits provided by ecosystem services.

Choices may have to be made between: 1) different services (representing different livelihoods or means of procuring economic benefits); 2) reaping benefits of ecosystem services now and reserving them for future use (related to the issue of inter-generational equity); 3) meeting the needs of society and of ecosystems (related to 2, because society is usually concerned first and foremost with its present needs, and secondarily with its future needs, or the needs of others); 4) the provision of social and economic benefits and the maintenance of human well-being (frequently expressed as the provision of these benefits to one population in one time or place at the expense of the well-being of another).

Part of the difficulty surrounding such situations owes to the fact that they almost universally boil down to a trade-off between values of different stakeholder groups. An upstream industry may value the Gariep system as a sink for wastes; downstream, tourists may enjoy the Gariep River for recreational purposes, commercial irrigators may focus on the importance of water from the river to cultivate crops for local sale and export, and pastoralists in the Richtersveld may value the grazing lands along the river's banks. As noted at the beginning of Chapter 1, while the values of some services can be expressed in monetary terms, others cannot. In addition framing a question of ecosystem services only as an economic issue has several shortcomings.

So how should these situations be dealt with? We suggest that making trade-offs and their implications (ecologically, socially, and economically) transparent to decision-makers can assist the process of choosing between various options and the likely consequences of making alternative choices. Informed decision-making about such trade-offs requires specificity about the temporal and spatial scales of interest, and necessitates the ability to answer the following questions: Do potential future impacts on ecosystem services have a bearing on current decision-making? Over what period will impacts occur? Does the alteration in ecosystem services affect human well-being far away from the intended ecosystem change (e.g. through downstream effects or atmospheric transport)? Do impacts cross administrative or ecosystem boundaries?

A number of techniques have been developed to evaluate trade-offs. Below we present three approaches as case studies of trade-offs between different aspects of the three core service clusters assessed in SAfMA: water, food, and biodiversity or ecosystem integrity. The first addresses trade-offs between two ecosystem services, food production and water, using a model-based approach. The second illustrates a classification framework proposed by the Water Act for allocating multiple water services to provide for the needs of people as well as ecosystems. The third demonstrates the use of a GIS-based method to evaluate trade-offs between food production and biodiversity. Finally, we look at ways to deal with multiple trade-offs simultaneously, with reference to the examples discussed.

3.1 Trade-offs between Services: Water and Food Production

Water and food production are two ecosystem services that sustain the lives of people as well as a host of other species. Water and food are intrinsically connected. Water is essential to the production of major cereal crops. In fact, in the arid environment of much of the Gariep basin, water is a major limiting factor of production. Efforts to increase the productivity of agricultural water use by both commercial farmers and smallholders are thus of paramount importance and must aim to improve not only the economic efficiency of irrigation ("crop per drop") but also the equity of irrigation, as indicated by "jobs per drop" or number of people or livelihoods dependent on a given quantity of water (Kamara and Sally 2002).

The policy dialogue model, PODIUM, is a decision support tool developed by the International Water Management Institute (IWMI) to assess policy options related to national level cereal-based food security and water availability (Kamara and Salley 2002). Based on macroeconomic assumptions, the model provides an analytical framework for assessing water and food demand in 2025 resulting from population growth and changing diets. In particular, it focuses on four uncertainties: 1) population growth; 2) options for meeting food security by expanding irrigated area; 3) increasing the efficiency of irrigation water use or yield improvements; and 4) the impact of increasing the daily water allocation per capita for basic human needs.

About 60 percent of South Africa's potentially utilizable water resources are already developed; this is referred to as its *degree of development*. Beyond a 80 percent degree of development (i.e. in which 80 percent of water resources are developed, with 20 percent remaining to meet environmental reserve requirements), the country will experience *physical water scarcity*, at which stage few or no options for further water resource development are likely to exist (Kamara and Sally 2002). A country experiences *economic water scarcity* if the growth in total diversions - by development of additional storage, conveyance, and regulation systems - exceeds 25 percent of its 1995 levels (Seckler *et al*. 1998). Economic water scarcity is thus an indicator of a country's ability to make investments in water development and associated infrastructure required for sufficient water provision. By IWMI's calculations, for example, Lesotho will be economically water scarce in 2025, but will not experience a physical water scarcity.

Below some findings from the application of PODIUM to South Africa by Kamara and Sally (2002) are highlighted concerning the first three uncertainties noted above. Table 3.1 reveals that population growth in line with the UN's high-growth estimate for 2025 (resulting in a population of approximately 48 million people) will lead to threatened food security (production < 0 tons) if water utilisation, irrigation efficiencies, and crop yields remain stable.

The implications for developing additional irrigated area as a way to alleviate food deficits are presented in Table 3.2. According to the model, an increase of about 40 percent increase in irrigated land area (equalling about 1.778 million ha of total irrigated land area) would be needed to achieve surplus food production if current yield levels and the trade balance remain unchanged. To achieve such a large increase is highly unlikely, and would require significantly large investments.

Table 3.1 PODIUM Results: Implications of Population Growth on Water and Food Demands (2025). *Source:* PODIUM Model Estimations 2002 (Kamara and Sally 2002).

Population 2025 (million) [d]		Water development and food security indicators		
Variant	Predicted	DOD (%)[a]	Growth (%)[b]	Food Security [c]
Low	39.96	67	28	2.0
Medium	43.77	68	29	0.73
High	47.52	69	31	-0.51
Constant	49.21	69	32	-1.08
UN-ECA	66.90	72	40	-6.96
Agricultural water productivity (crop per drop): 1.18 kg/m^{3}ET				

[a] Degree of Development (percent of potentially utilisable water resources)

[b] Growth in total water diversions to agriculture, domestic and industrial uses (percent)

[c] National level food security: surplus (+) and deficit (–) in million tons

[d] Projections: UN Population Division and the Economic Commission for Africa (ECA)

Table 3.2 PODIUM Results: Implications of Increasing Irrigated Area for Water and Food Situation (2025). *Source:* PODIUM Model Simulations 2002 (Kamara and Sally 2002).

Increase in net irrigated area (2025 million ha; current 1.27)			**Water resources development And food security indicators**		
Annual %	Total %	Actual Area	DOD (%)[a]	Growth (%)[b]	Food Security[c]
0.32	10	1.377	59	13	-0.23
0.47	15	1.461	61	16	-0.18
0.61	20	1.524	63	20	-0.14
0.75	25	1.588	65	23	-0.10
0.88	30	1.651	67	27	-0.05
1.13	40	1.778	71	34	0.03
Agricultural water productivity (crop per drop): 1.18 kg/m^{3}ET					

[a] Degree of Development (percent of potentially utilisable water resources)

[b] Growth in total water diversions to agriculture, domestic and industrial uses (percent)

[c] National level food security: surplus (+) and deficit (–) in million tons

A third set of options involves using agricultural water more efficiently by improving the effectiveness of irrigation systems. The PODIUM model was used to investigate the implications of increasing irrigation efficiency from 55 through 65 percent (under flood systems), to 75 and 80 percent (under sprinkler systems) for degree of development and total diversions (Table 3.3). Thus, an increase in the efficient use of irrigation water from 55 to 60 percent would reduce the degree of development by 4 percent and total diversions by 9 percent.

Table 3.3 PODIUM Results: Irrigation Efficiency and Water Resources Development. *Source:* PODIUM Model Simulations 2002 (Kamara and Sally 2002).

Increase in Irrigation Efficiency (%)	55	60	65	70	75	80	85
Degree of Development (%)	71	67	63	59	57	54	52
Total Diversions (%)	36	27	20	14	8	4	0

In summary, at the country level, expanding irrigated area in isolation of other interventions is not likely to improve food security significantly. On the other hand, modest increases in irrigated area and improvements in efficiency are feasible and do not imply the need to allocate large amounts of water to the agricultural sector. Research and investments need to continue into both technical and institutional options to improve irrigation efficiency, intensification possibilities, and yield enhancing alternatives in both irrigated and rainfed agricultural production (Kamara and Sally 2002), as well as opportunities to produce less water-intensive crops and to increase imports of grain through “virtual water” schemes. The scope and scale of this analysis, which focuses only on cereal production at the national level, may obscure key trends that would emerge in studies of other crops or specific catchments. Work is commencing to expand the PODIUM model so that it may accommodate analyses of additional crops and finer-scale data.

3.2 Trade-offs between Utilisation and Protection of Water Services

Competition for water services exists in several dimensions. Users compete spatially for water, with upstream users influencing water that flows to downstream users, and water pollution induces further competition when polluters displace the effects of their activities to other parts of the basin. Trade-offs also exist between the use of surface water and groundwater abstraction, typically in rural areas where groundwater is a key resource. Competition for water is also temporal, whereby modifications to increase the quantity or reliability of water supplies in the short term may compromise the quality of water in the long term (although increased quantities can result in localized improvements in quality), and ultimately threaten aquatic ecosystem integrity. Inter-generational equity introduces another type of competition, between the water users of the past, the present, and the future.

In another sense, trade-offs between the different services provided by water revolve around sectoral competition for limited supplies, a fact that carries various social and economic connotations. Water is needed for different purposes: urban and rural domestic use, irrigation, mining, industry, power generation, afforestation, biodiversity, and ecosystems. Most of the major sectors of water use in the Gariep basin have unique spatial distributions, but they all withdraw water from what is essentially a common, limited source. While past developments have enabled a high level of assurance of most of these sectors' requirements, it is uncertain how well these needs will continue to be met in the future without compromising the ability to meet the reserve.

With sustainability a major goal of water management, trade-offs must be made in such a way to safeguard the future capacity of ecosystems to continue functioning. The Water Act recognizes both the conservation significance and economic value of water resources, and that varying levels of impacts on water resources must be tolerated in order to provide services, but must not exceed these levels. Some water resources will require greater protection because they support endemic or threatened biota, or provide runoff to a protected area. Other resources would require less protection because they perform a vital economic role by supporting the water demands of an urban area or absorbing industrial wastes.

Table 3.4 illustrates a framework to classify South Africa's water resources that enables a balance between the protection and utilisation of water services (Mackay 2000). For each water resource, typically a quaternary catchment or river reach, a letter from "A" to "F" designates an ecological management to indicate its ecological condition. Resources in Class A are mostly natural, resources in Class D heavily modified, and resources in Classes E and F seriously or critically modified to the point that their functioning may be impaired irreversibly. Management would strive, where possible, to restore resources in Classes E and F to Class D or better. Very low levels of risk would be tolerated for Class A resources, while increasing levels would be acceptable as resources approach Class D. These designations are decided upon systematically by a group of stakeholders who have knowledge of the system to be classified. Clearly, these designations are site-specific, and some quite uncertain, due to the lack of knowledge about relationships between hydrological flows and ecological variables. While this classification system acknowledges that some water resources must be sacrificial "workhorses" in order to allow others to remain pristine, it also provides for suggested improvements of resources that can lead to a reclassification upward.

The application of this framework to the Gariep basin in Figure 3.10 illustrates the configuration of present ecological management classes based on local studies and models, and of attainable classes that indicate the restoration potential of the catchment in the next five years. Table 3.5 indicates the area of the basin in each of these classes. Until this framework is implemented and tested, it is difficult to pinpoint the exact balance needed between protection and utilisation in order to achieve ecological, social, and economic development goals, and in practice, may only be found through a process of trial and error. The current human reserve requirements are already a contentious issue, with the World Health Organization and others maintaining that a daily minimum of 50 litres per capita, rather than the current 25, is much more conducive to securing health benefits. This level of service provision is unlikely to be possible unless directly provided to homes or yards (World Bank 1992), which will require significant financial support and infrastructure investment. Twenty-five litres is considered sufficient for one person's drinking, cooking, and personal hygiene, but is usually inadequate for irrigation of even subsistence crops (Mackay 2003). However, with careful and committed management, it should be possible for people to have more water for basic use and to meet the ecological reserve requirements, though this will require re-allocation of some water from irrigation, for example, to more economically efficient uses.

Table 3.4 Proposed framework for setting ecological resource quality objectives on the basis of a classification system (adapted from Mackay 2000). Class A affords the highest level of protection of resources and would be least amenable to many forms of utilisation, while class D affords the lowest level of protection but allows utilisation that is more intensive. Classes E and F are not included, as these are considered unacceptable and would be managed according to the rules for resources in class D.

PROTECTION

UTILIZATION

Class	Water quantity	Water quality	Instream habitat	Riparian habitat	Biota
A	Natural variability and disturbance regime. Allow negligible modification.	Negligible modification from natural. Allow negligible risk to sensitive species. Must be within Aquatic Ecosystems Target Water Quality Range (TWQR)[1].	Allow negligible modification from natural conditions. Depends on the instream flow and quality objectives which are set.	Allow negligible modification from natural conditions. Control of land uses in the riparian zone.	Negligible modification from reference conditions should be observed based on the use of a score or index such as the South African Scoring System (SASS).
B	Set instream flow requirements to allow only slight risk to especially intolerant biota.	Use Aquatic Ecosystems TWQR and Chronic Effect Value (CEV) to set objectives which allow only slight risk to intolerant biota.	Allow slight modification from natural conditions. Depends on the instream flow and quality objectives which are set.	Allow slight modification from natural conditions.	May be slightly modified from reference conditions. Especially intolerant biota may be reduced in numbers or extent of distribution.
C	Set instream flow requirements to allow only moderate risk to especially intolerant biota.	Use Aquatic Ecosystems TWQR, CEV and Acute Effect Value (AEV) to set objectives that allow only moderate risk to intolerant biota.	Allow moderate modification from natural conditions. Depends on the instream flow and quality objectives which are set.	Allow moderate modification from natural conditions.	May be moderately modified from reference conditions. Especially intolerant biota may be absent from some locations.
D	Set instream flow requirements that may result in a high risk of loss of intolerant biota.	Use Aquatic Ecosystems TWQR, CEV and AEV to set objectives that may result in a high risk of loss of intolerant biota.	Allow a high degree of modification from natural conditions. Depends on the instream flow and quality objectives which are set.	Allow a high degree of modification from natural conditions.	May be highly modified from reference conditions. Intolerant biota unlikely to be present.

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[1] See DWAF 1996b for an elaboration on Target Water Quality Range, Chronic Effect Value, and Acute Effect Value.

Because the Water Act emphasizes efficiency and achieving the optimal allocation of water with a pricing system, comparing the relative economic values of alternative water uses (and non-use) has merited much interest in the region in recent years. A suggested framework for the economic analysis of different combinations of water utilisation and protection has been applied to the Crocodile River catchment in Mpumalanga Province (Mander *et al*. 2002).

This framework defines three types of water uses, or "activities:" Type 1 activities affect water resources as externalities, and include forestry and dryland agriculture. Type 2 activities are abstractive; that is, they withdraw water from the catchment, and may also return polluted water to the catchment; these include domestic use, irrigation, mining, and industrial use of water. Type 3 activities are those that depend on in-stream flow and water quality, such as conservation, tourism, recreation, and the provision of ecosystem services. These activities carry different economic and ecosystem values, which will depend in part on the robustness or sensitivity of ecosystems in a given catchment. An illustration of how trade-offs in a catchment can be optimised through increased efficiency is given in Figure 3.2. It demonstrates the "unevenness" of trade-offs in robust and sensitive systems. The value of allocating more water to Type 1 and 2 activities in a sensitive system may be offset by a greater loss to Type 3 activities, while the value of allocating more water to Type 3 activities in a robust system may be offset by a greater loss to Type 1 and 2 activities.

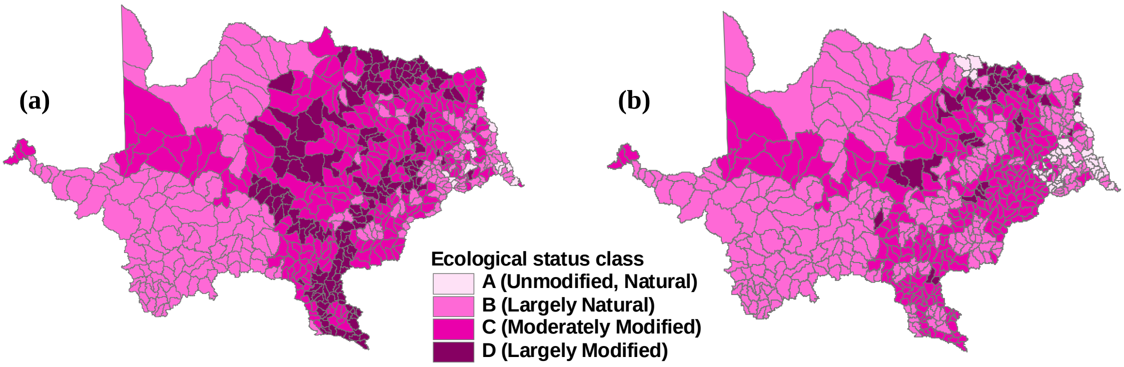

Figure 3.1 (a) Present and (b) attainable ecological management classes. *Source:* WSAM.

Table 3.5 The area of the Gariep basin (in square kilometres and as a percentage of total area) in each ecological management class under present and attainable configurations shown in Figure 3.1.

Area of basin in class	Present (km²)	Present (% of total)	Attainable (km²)	Attainable (% of total)
A	4102	0.6	16 406	2.4
B	295 999	43.3	390 336	57.1
C	250 198	36.6	201 662	29.5
D	132 619	19.4	74 513	10.9

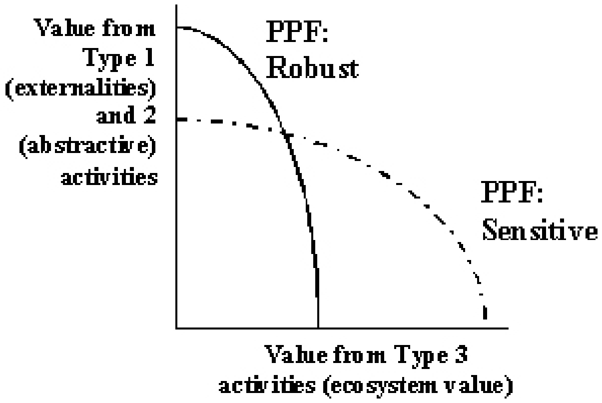

Figure 3.2 Production possibilities frontier (PPF) for water resources in an ecosystem, or the possible combinations of output that can be attained for a given set of inputs, in terms of the allocation of water to Type 1 or 2 activities (externalities or abstractive) vs. Type 3 activities (to the environment) for robust and sensitive ecosystems. *Source:* Mander *et al*. 2002.

3.3 Trade-offs between Land Use and Biodiversity

Land-use planning requires knowledge of the impacts of various decisions on other components of the landscape. A decision to afforest an area cannot be taken without knowledge of the impacts it can have on the provision, regulation and maintenance of ecosystem services (e.g. water, food production, and carbon storage) and biodiversity.

In a similar fashion to the assessment of ecosystem integrity (Chapter 2.9), we used the notion of irreplaceability (Pressey 1999) to assign comparable values to areas of land, based on a variety of ecosystem services and biodiversity. Irreplaceability is a measure of how important the features that an area contains are to the achievement of a stated goal. The idea of irreplaceability originated in the field of conservation planning where the biodiversity features contained in an area are evaluated to determine how important that area is to the achievement of a conservation goal. This concept is applicable to ecosystem services in a similar way. The availability of maps of ecosystem services has allowed us to investigate the amount of a service produced annually in an area. Irreplaceability requires a target or goal in order to calculate an area’s importance or contribution to that target. Some ecosystem services have readily available targets, such as Recommended Daily Allowances (RDA) for protein and calories, which when multiplied by the number of people who rely on these services, results in a target amount for the basin. The services investigated in this fashion included calorie and protein production. As more data become available for other ecosystem services, they too can be included in the assessment.

Food production was divided into two components: calorie and protein production from cereal crops and livestock. It is acknowledged that there are other sources of protein and calories like vegetables and fruit, but little data exist on these crop types in the Gariep basin. This analysis is therefore limited to the calories and proteins from meat and cereals. Cereals are responsible for 54 percent of calories consumed by people and 57 percent of the protein requirements. This analysis thus assigned the remainder of calorie and protein requirements to meat production (i.e. 46 percent of caloric and 43 percent of protein requirements). The area of each quarter degree square (QDS) under cultivation was calculated. It was then extrapolated to provide the tons of each type of cereal produced per quarter degree grid cell. These tons could then be converted into calories and grams of proteins. Meat production was based on the number of livestock units in each QDS. Each livestock unit could then be converted to grams of protein and calories. Table 3.6 shows the total available calories and protein from cereals and livestock in the basin. The amounts required by the Gariep population (i.e. target) of both proteins and calories were calculated from the RDA per person for each, multiplied by the population. Both an upper and a lower target were calculated for each service in order to investigate the implications of different policies. Table 3.7 illustrates the per capita values of these upper and lower targets, as well as the discrepancy between male and female requirements. Targets were set based on an assumed 50:50 sex ratio in the basin. The total targets were then broken down into the amount required from cereals and from meat. These amounts were determined from the percentage breakdown above (i.e. 54 percent calories from cereals, 57 percent proteins from cereals, and the remainder from meat).

Table 3.6 Total calories and protein produced by cereals and meat in the basin. Upper and lower targets for calories and protein are also illustrated. These targets are then split into the proportion of the target met by cereal and meat production respectively.

Service	Total produced by cereal	Total produced by livestock	Total	Lower target	Upper target	Cereal lower target	Cereal upper target	Meat lower target	Meat upper target
Calories (cal)	1.8×10^{13}	4.4×10^{12}	2.3×10^{13}	12.0×10^{12}	15.0×10^{12}	6.5×10^{12}	8.1×10^{12}	5.5×10^{12}	6.9×10^{12}
Protein (g)	4.5×10^{11}	6.6×10^{11}	1.1×10^{12}	3.3×10^{11}	4.0×10^{11}	1.9×10^{11}	2.28×10^{11}	1.4×10^{11}	1.7×10^{11}

Table 3.7 Per capita amount of calories and protein for upper and lower targets for males and females.

	Male	Female	Source
Calories - lower	2350	1740	FNRI*
Calories - upper	2840	2250	FNRI*
Protein - lower	56	56	SA's RDA**
Protein - upper	73	63	FNRI*

* Food and Nutrition Research Institute (FNRI), recommended energy and nutrient intakes (RENI), 2002

** South African Recommended Daily Dietary Allowances (RDA) for labelling purposes, Act 54 of 1972, G.N.R. 1130/1984

As is obvious from Table 3.6, the total calories and protein produced in the basin exceed the requirements of the basin by at least an order of magnitude. This is not surprising as the basin is the source of most of South Africa's cereal and meat (Chapter 2), providing cereal for 70 percent of South Africa and a surplus for livestock (20 percent of total production) and export (50 percent of total production). There is also three times as much meat in the basin than is required by the population. These service values per QDS were inserted into the irreplaceability calculation. However, because the Gariep more than meets its own caloric and protein requirements the irreplaceability values of the QDS were all very low. The targets were therefore modified to include the requirements of 70 percent of South Africa's population (the estimated number of people that rely on the Gariep's food production - in essence another 30 percent of the population), another 20 percent of cereal for food for livestock and an additional 50 percent for the export of food. This doubled the targets, which provided a more realistic picture of requirements in the basin. For the sake of simplicity, this assessment assumes that the food produced within the basin can be transported to all other areas of the basin where demand exists.

Figure 3.3a illustrates that irreplaceability values for most QDSs are still low for the amended upper targets for protein and calorie production. However, this is not an indication that targets are easy to meet in the basin but rather that many combinations of sites could meet those aims, as irreplaceability is a measure of options for meeting targets. However, the sites with high values are excellent sources of the services and as such should be incorporated into any decisions made on land use. The areas highlighted are better at achieving the targets than those not highlighted, but are not essential as none of them is totally irreplaceable. The chances are high that if these highlighted sites were not available for food production, it would require several areas to replace just one of these high production ones. The upper and lower targets do not change the picture dramatically as the difference between the final targets is small compared with the size of the target. The irreplaceability surface using combined species and vegetation targets as discussed in Chapter 2.9 is represented by Figure 3.3b.

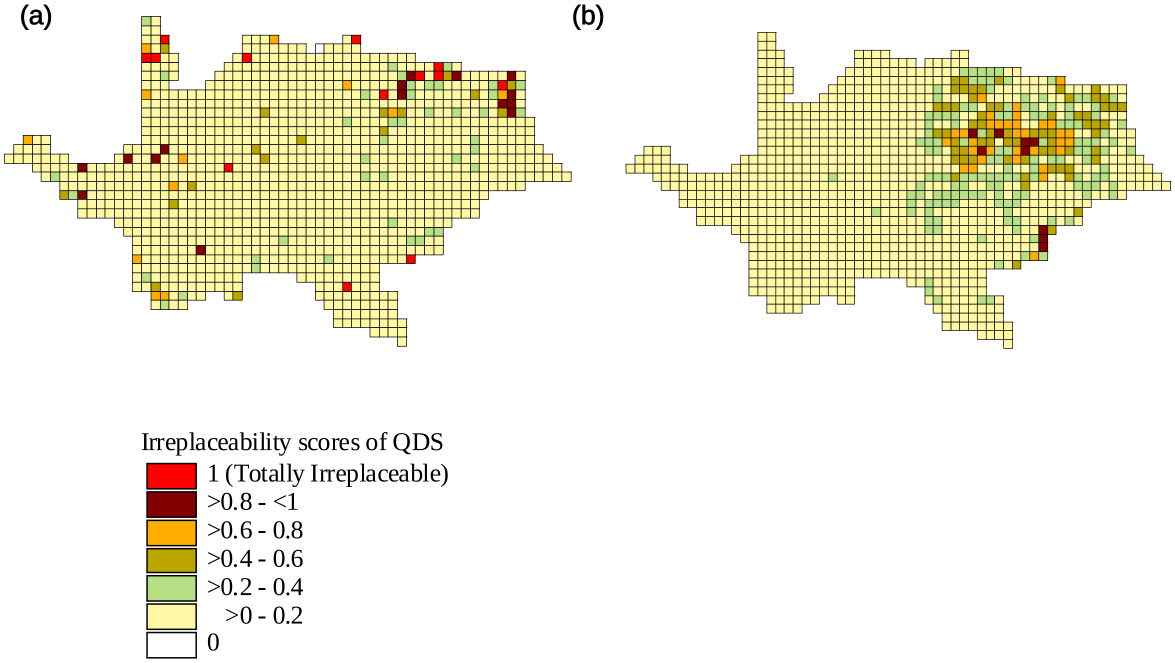

Figure 3.3 Irreplaceability maps for the Gariep basin based on upper targets for (a) biodiversity and (b) proteins and calories. Irreplaceability values range from 0 (very low importance for target achievement and many options for this cells substitution with another cell to achieve target) to 1 (totally irreplaceable, if this cell were not included in the provision of services, the targets for those services would not be met).

There is some congruence between areas important to calorie and protein production and biodiversity in the eastern portion of the basin, yet overall, the conflict between areas important to biodiversity and food production appears to be very low. However, this analysis is very preliminary and the targets are basic. Biodiversity targets were set very low while the food production targets need refinement. In addition, the irreplaceability analysis highlights areas important to target achievement but does not illustrate final target achievement. This would happen as decision makers chose grid cells for uses like conservation or cultivation and thus excluded them from other uses. In addition, the landscape of the Gariep is not a blank canvas as assumed in this assessment, as some areas are already cultivated and conserved. These factors would significantly influence the irreplaceability surfaces produced, and thus must be included in future iterations as these data become available.

One alternative to the irreplaceability assessment of protein and calorie production illustrated above is to use the potential production of all areas in the Gariep rather than the actual production used in the current assessment. This would add value to a planning framework for land use as it would highlight areas best suited to food production rather than areas currently in use. While new policies have replaced much of the inappropriate land-use planning in South Africa in the past, its legacy remains in the current patterns of land use. These do not necessarily lend themselves to the most beneficial and efficient harnessing of ecosystem services (Reyers *et al.* 2000). However, as data on potential production are not available for the entire basin, this assessment uses current production figures. This approach can be applied to potential values in much the same way, once these data become available.

The grid cells with high values for each service are illustrated in Figure 3.4. These are cells with an irreplaceability greater than 0.4. Land use trade-offs can then be further explored in those grid cells where there is conflict between conservation goals and ecosystem service supply. It must be noted that trade-offs need not be absolute. Some ecosystem services are more amenable with one another and with biodiversity than others are. For example, biodiversity conservation can take place in the same area as grazing (Pressey 1992, Scholes and Biggs 2004). This will obviously be limited to low-intensity of these uses; in other words, commercial-scale grazing on unplanted pastures would not be considered amenable with biodiversity conservation. This means that an area can be used for crop agriculture while still maintaining much of its biodiversity, through, for example, the implementation of corridors, retention of wetlands, and other key habitats. Similarly, areas allocated for conservation could still support a viable small stock industry without compromising biodiversity and services. It is important that ecologically sustainable land use management is never compromised. The secret to successful land-use planning in areas where multiple objectives are pursued is to give preference to compatible or more appropriate land-uses.

The trade-offs in the Gariep basin between biodiversity and food production are not fully understood and elucidated by this approach. Work is ongoing within the basin to improve these models of trade-offs using simulated annealing algorithms and opportunity costs.

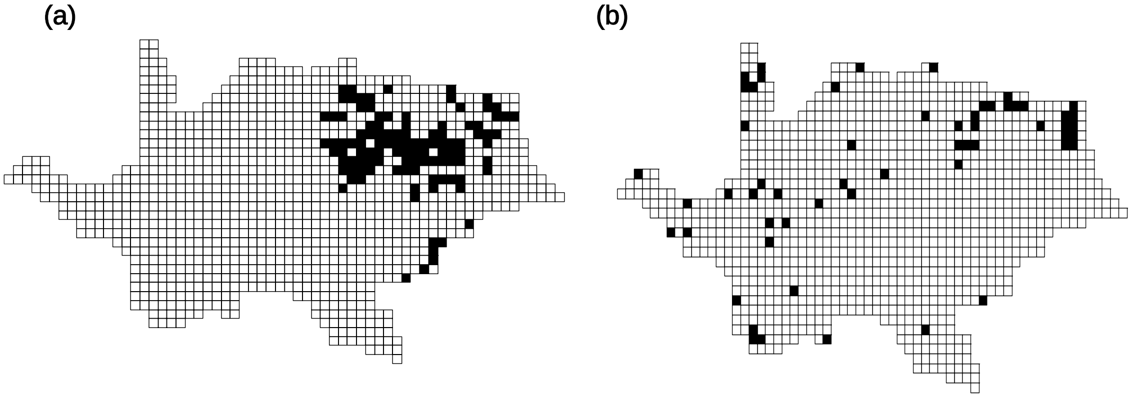

Figure 3.4 Grid cells with irreplaceability values of more than 0.4 illustrating areas of importance to the provision of (a) food and (b) biodiversity conservation.

3.4 Summary: Assessing Trade-offs

The examples presented here represent a small sample of the growing number of approaches used to confront complex decision-making problems. In the Gariep basin, these examples demonstrate that it is, in principle, possible to address societal and ecosystem needs simultaneously, that the land use requirements for biodiversity conservation and food production can be determined, and that appropriate land-use decisions are possible to achieve multiple objectives, sometimes even in the same area. Furthermore, a switch to more intensive production systems is feasible when land for extensive production becomes limiting and access to markets is adequate. However, managers must take care to work across sectors and spatial and temporal scales, which thus far, has not always been common practice.

How can the different approaches presented here be integrated in a way that they effectively communicate options and trade-offs to decision-makers? The Millennium Ecosystem Assessment Working Group on Condition and Trends uses graphical depictions of the trade-offs in ecosystem services associated with alternative policy options to provide useful input to decision makers (Daily 2000, Balvanera *et al.* 2001). Such depictions can take various forms, including the “spider diagram” approach, which depicts hypothetical trade-offs among ecosystem services associated with a policy decision

(Figure 3.5). Comparison of the ecosystem services available before and after the decision is made, allows a decision maker to account for the full suite of ecosystem services affected by the conversion.

We could therefore take the outputs of the PODIUM model, the production possibilities frontiers for water use, and the irreplaceability maps of biodiversity and convert them to such diagrams. This would involve more precise data sets and validation with stakeholder groups, but would resemble the hypothetical example below.

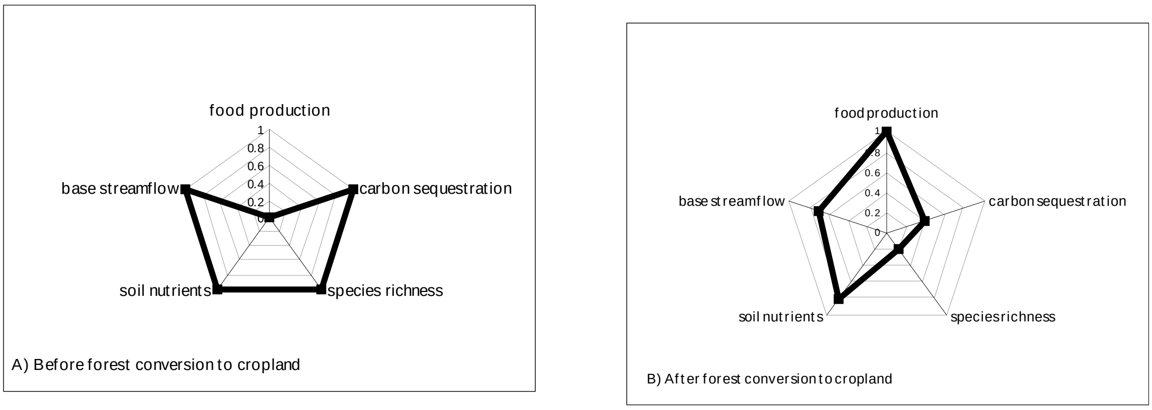

Figure 3.5 Hypothetical trade-offs in a policy decision to expand cropland in a forested area. Indicators range from 0 to 1 for low to high value of service. The values of the indicators vary according to the spatial and temporal scales of interest. Adapted from Millennium Ecosystem Assessment (first review draft, 2004b).