ABSTRACT

The Sustainable Landscape Planning (SLP) approach is based on Landscape Ecology principles. It can be applied to integrated and sustainable planning and management of resources such as water. It considers the interrelations occurring in the landscape, including those between human and natural systems. In this paper this approach is applied to a salinated coastal aquifer located in Portimão (South of Portugal). Mainly due to tourism exponential growth along the coastline, groundwater has been over-exploited causing salination to occur. Scenarios of development will be created for envisioning the future water quality/quantity under different possible policies. Outputs of this work will include current groundwater protection zoning analysis for effectiveness and compliance with legislation and also the proposal of best practices and other recommendations.

Key Words: Sustainable Land Planning; Groundwater resources; Landscape Ecology; Scenarios; Ecological Indicators; Salination; Mediterranean.

INTRODUCTION

Sustainability is an underlying and fundamental goal of spatial planning (Van Lier 1998, Botequilha Leitão 2001). Tools are needed to pursue this goal. Ecological knowledge is the fundamental scientific basis to plan and manage for sustainable systems. Holism and systems theory open new perspectives and provide broader visions for planning. The landscape is an appropriate unit for sustainable planning. Pattern and process relationships are crucial to understand the functioning of landscapes. They are also important to model and anticipate ecological consequences of planning and design alternatives. Finally, human activities must be considered as integral parts of ecological systems. Landscape ecology responds to all these issues and provides useful conceptual and analytical tools, particularly landscape metrics, to bridge the gap between planning and ecology.

The work presented in this paper was developed within the scope of project Simulation and Optimization of Saltwater Intrusion in Aquifer Systems” (SALSIM). The main purpose of this project is to model the saltwater intrusion into the Mexilhoeira Grande – Portimão aquifer. However, to plan for sustainable systems is crucial to broaden the approach and acknowledge the different components of both natural and social systems. Therefore we looked for the key landscape processes that were determinant to the functioning of the overall system, including the water cycle, in both subsystems - surface and underground.

A factor that influences significantly the hydrological system in the study area, and elsewhere is land use dynamics, and more specifically urban development. The urbanization trends constitute one of the most urgent issues to address in physical planning. The proportion of the world’s urban population has risen from 14 percent in 1900 to nearly 50 percent (Rosen 2000). In 2025 it is estimated to reach 60%. Urban fringe areas tend to be more affected by this global trend, as land use change processes are more dynamic as a consequence of urban expansion. Suburban sprawl is responsible for additional effects of urban population,
especially in North America and Europe (Landis et al. 1998).

According to Naveh (1998) the case is even worst in the Mediterranean than elsewhere. Few areas in the world have undergone a transformation such as the one that has taken place in the Mediterranean Basin (Petrus and Manera 1997). Here the above-mentioned problems are aggravated by a rapid growing tourism, by the intensification of agro-industrial agricultural land use, and by urban-industrial expansion, on one hand, and land abandonment on the other (Naveh 1998). One third of the world’s tourism goes to the Mediterranean: in the summer, 115 millions tourists come to this region to enjoy their holidays; adding to this number is the 100 million domestic tourists that enjoy their holidays in their own countries (Petrus and Manera 1997). The Mediterranean Blue Plan (1988 cited in Naveh 1998, p. 8) estimates a total population increase in this region, from 360 millions in 1988 to 550 millions until 2025, doubling the population in the costal areas, which h already the largest concentration of urban-industrial uses, and an increase of the tourism flow from 95 million to 220 million.

Portugal is a paradigmatic example of this trend with half of the total populating living in the coast. The Algarve has been subjected these last two decades to tremendous pressure from tourism, as the South of Spain, the Ligurian Coast in Italy, Crete, etc. (Grove et al. 1993 cited in Naveh 1998, Petrus and Manera 1997).

The Sustainable Land Planning framework method (SLP) (figure 1) as proposed by Botequilha Leitão (2001) provides an overall planning framework, a set of tools, and one way to approach holistically planning and relate components, processes and understand the evolution of landscapes.

Viewed as a space for problem-solving, the SLP seeks a balance between (basic) human needs and ecological integrity, over time; views sustainability as a pre-condition for management rather than an afterthought; focuses on the source, not on the resource; considers space and time as fundamental dimensions for sustainability; argues for a symbiosis between natural sciences, social sciences, and humanities; seeks a proactive attitude towards planning; promotes public participation into the planning process; promotes the use of adaptive management techniques; strives for cultural cohesiveness and cultural sustainability; and advocates for the use of advanced methods and techniques to support better planning. All constitute relevant variables to consider when planning for sustainability.

Under a vertical perspective the SLP proposes a toolbox, where landscape ecological concepts and metrics, and its spatial approach to the landscape as its planning unit, stands out as a pivotal science for the remaining proposed SLP tools. Literature provides extensive examples of the use of landscape ecological concepts and metrics for water resources planning (Naiman 1996, Grove and Burch 1997, Pickett et al. 1997, Barten 1998, Jones et al. 2001, France 2002 to name but a few).

The cultural (human) component is approached in the SLP framework by integrating concepts and methods from several human and social sciences, from landscape history to collaborative design methods, and intends to contribute to the planning discipline movement towards transdisciplinarity, as proposed by several authors, particularly by Naveh (2001).

The present article is structured under the five planning phases as proposed by the vertical perspective of the SLP framework method: Focus, Analysis, Diagnosis, Prognosis and Synthesis (Botequilha Leitão 2001, 642).

Figure 1. The Sustainable Land Planning (SLP) Framework method - a planning cycle (Botequilha Leitão 2001).
Botequilha Leitão and Ahern 2002). We found this to be useful to structure our research. Additionally we argue that it can help the readers to follow through and compare other research that eventually is structured in similar terms by ourselves and other authors. It is our opinion that this procedure can lead also to a clearer and more transparent form in transmitting scientific findings to a lay audience.

**METHODS**

**Focus**

In this paper we focus our attention in groundwater, since our investigation is intended to find solutions for its quality/quantity problems, namely salination. Other elements of the landscape that could be analysed under SLP methodology (e.g. biodiversity or soil) are referred only in their relation to groundwater. However, groundwater can also be faced as an indicator of the entire watershed health, as it was done in Mueller et al (2002). This means that the other elements are implicitly included in this investigation.

**Analysis**

**The study area**

The study area is located in the South of Portugal, within the Algarve Region, in the Portimão and Monchique municipalities (figure 2). It encompasses 12 982 ha, which include the Mexilhoeira Grande-Portimão aquifer system and the watersheds of the two influent streams (Torre and Farelo). The study area’s northern tip includes part of the Monchique Range, an eruptive formation that dominates the region’s landscape and exerts an Atlantic influence in a typical Mediterranean climate.

The Mexilhoeira Grande - Portimão aquifer system is composed of two layers: one Jurassic (limestone) in the north area of the aquifer; another Miocene (limestone and sand) in the south area (Salgueiro & Ribeiro 2001). The main flux is made from north to south, that is, from Jurassic formations, where the recharge is made by direct infiltration of rainwater and from Farelo and Ribeira Streams, to the Miocene formations. The aquifer discharges are made from the Jurassic layer to the Boina Stream and the springs of Fontainhas (Reis 1993 in Salgueiro & Ribeiro 2001). The Miocene layer used to be recharged by the Jurassic layer before exploitation, but not anymore (INAG 1997 in Salgueiro & Ribeiro 2001).

Until recently groundwater was the main source of drinking water for the Algarve as well as for the study area. Currently all water used in municipal systems comes from superficial sources. However, due to the increase of population during the summer and the climate of that season – hot and dry – additional sources can be needed. Groundwater is therefore a strategic water reserve.

Saltwater intrusion due to overextraction has been a problem in many aquifers of the Algarve and still is although the main extractions have stopped. In figure 3 the chloride levels of the Mexilhoeira Grande – Portimão are shown. It must be pointed out that there are other pollution problems besides salination, e.g. chemicals probably leached from agriculture¹.

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¹ E.g. nitrates (Salgueiro, 2001)
The study area was divided into 5 sub-systems or homogeneous zones - landscape units (LU) (figure 4). This procedure allowed a more directed and focused analysis, diagnosis, and subsequent phases. The main characteristic of the study area is its south-north, shoreline-interior asymmetry, which is revealed both in the natural and in the social and economic features (table 1). The LUs can be summarily characterised in the following way (table 1, figure 4):

- **LU1** – warm and dry low altitude plateau, mainly made of detritic materials. It corresponds roughly to the Miocenic aquifer layer. It is highly urbanized and concentrates the most of the area’s population.
- **LU2** – it comprises the protected wetlands of the Ria de Alvor and its environs, which are mainly farmlands;
- **LU3** – a plateau crossed by steep stream valleys, mainly occupied with agriculture, especially orchards. It corresponds to the Jurassic aquifer layer and contains the main recharge areas. Its low population is mainly concentrated in a few villages;
- **LU4** – hills with steep valleys associated with the abundant streams. There are no aquifers in this LU, which has a xyst substrate. It is very scarcely populated. The main land uses are agriculture, shrubs and forest;
- **LU5** – milder climate through the influence of altitude; very steep hillsides, belonging to the Monchique Range (protected area). It is mainly forested, although there is also some agriculture. It is also scarcely populated.

As referred above the Algarve and the study area’s shoreline is threatened by urban growth due to tourism. This is the region’s main economic activity, of which it strongly depends. Agriculture, fisheries and industry have been losing importance over the years, while the more profitable tourism-related activities absorb the most of the available labour force. Forest is nevertheless expanding slowly, especially in the steepy interior, but mainly due to the growth of exotics (eucaliptus) with high environmental impacts (CMP 1994; DRAOT Algarve 2002).

The influence of tourism is seasonal, as the main attraction of the region is the sun-beach product. As a result in the high season population doubles, triples or even more, depending on the municipality considered. All this added population settles near the shoreline, as it also happens with the residents (in the study area especially in LU1—figure 4). This phenomenon began in the ’60s and the numbers of tourists have grown ever since. In response the region has been experiencing a very rapid, concentrated and mainly chaotic urban growth (CMP 1994; DRAOT Algarve 2002).

Therefore the key processes occurring in the landscape are urbanization and human concentration in the shoreline.
Prognosis

Scenarios

Planning scenarios are proactive planning tools as they allow predicting the future consequences of alternatives before they are actually implemented. Scenarios are being used both in Europe and in the U.S.A. to explore the consequences of alternative global policies (Greeuw et al. 2000, Alcamo 2001), spatial planning (Freemark et al. 1996, Steinitz et al. 1997, 1998, Botequilha Leitão 2001, Ahern 2002, Mueller et al. 2002), and to promote stakeholder participation in the planning process and discussion about future alternatives (Freemark et al. 1996, Botequilha Leitão 2001, Nassauer and Corry 2002), and to promote stakeholder participation in the planning process and discussion about future alternatives (Freemark et al. 1996, Botequilha Leitão 2001, Nassauer and Corry 2002). Scenarios are used in watershed planning, along with several landscape ecological planning tools, such as landscape metrics, in order to evaluate biodiversity-based scenarios (Steinitz et al. 1997, Botequilha Leitão 2001, Mueller et al. 2002). Landscape metrics can also be of use to predict the consequences of land use change as those built-in in alternative future scenarios, on nutrient and sediment loadings to streams (Jones et al. 2001). According to Freitats (2002) scenarios that combine ecological, historical and socio-economical data are urgently needed to assess the vulnerability of Mediterranean ecosystems to future land use change.

A scenario named TREND was developed for this project (Ahern 2002). It intends to depict the landscape evolution under the current set of (regulatory, economic, demographic, etc) conditions (Botequilha Leitão 2001, Ahern 2002). It is a “business-as-usual” (BAU) scenario (Greeuw et al. 2000, Alcamo 2001). It is useful to visualize future consequences of current policies.

The land use map of 1990, the most recent cartography available, was the baseline for the TREND scenario. The time series available (1991-2001) was analysed in order to establish an urban growth tendency that could be spatially extrapolated for the future. That tendency included the amount of urban growth, its density and where it is likely to occur. The total area licensed for urban development (loteamentos) from 1991 to 2001 was used as a surrogate for the amount of urban growth for the 2001-2011 and 2011-2021 periods (table 2). A fraction of that area (90%) was used as the amount of urban growth for 1991-2001 (The number of housing (fogos) actually built between 1991 and 2001 is lower than the number of fogos licensed, which indicates a growth tendency reproduced in the scenario). It was assumed (1) that the growth in the small fraction of the municipality of

Table 1. Landscape units’ description.
Monchique was neglectable overall (2) that all the urban growth is for housing purposes and (3) that all the growth had low density, since it would happen mainly outside the town of Portimão, which is the only truly high-density urban area. However, some low-density areas that appeared on the 1990 land use map were converted to high density (e.g. shoreline at Praia da Rocha).

The location of new urban development was decided according several criteria: (1) The tendencies recognized in the Municipal Master Plan of Portimão (MMP), or in Portuguese Plano Director Municipal - PDM) (CMP 1994) and Regional Plan of Algarve evaluation studies (DRAOTA 2002) point to future urban growth (a) between the town of Portimão and Praia da Rocha, (b) from Portimão to west and (c) along the shoreline, namely between the Praia da Rocha and Alvor. This would have the effect of creating an urban strip connecting Portimão to Praia da Rocha; furthermore through the coalescence of several villages/places, there would be a risk of urban continuums forming between Praia da Rocha and Alvor and Portimão to west; (2) The urban growth was also constrained by another criterion: it could only occur within the urban / touristic growth areas of the zoning plan (CMP 1994), apart from a “leakage factor” that was considered. This factor refers to unauthorized building, and licenses issued before the MMP was approved. The leakage factor was estimated using the number and area of loteamentos approved from 1991-2001 within and outside those areas (18.5%) and in the loteamentos currently for approval (12.5%). The resulting map for 2021 is displayed in figure 5.

The maximum infiltration zones (MIZ) determined in Oliveira & Ferreira (2002) were compared to the delimited National Ecological Reservation (NER) (figure 6). The NER intends to protect several basic natural features, such as areas locally important for groundwater recharge purposes. The area loss of MIZ due to urban growth was calculated for 2021.

<table>
<thead>
<tr>
<th>Parish</th>
<th>Zone Within urban occupation areas of MMP</th>
<th>Zone Within urban occupation areas of MMP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portimão</td>
<td>118.2</td>
<td>16.9</td>
<td>135.1 (65%)</td>
</tr>
<tr>
<td>Alvor</td>
<td>36.4</td>
<td>5.2</td>
<td>41.6 (20%)</td>
</tr>
<tr>
<td>Mexilhoeira Grande</td>
<td>37.3</td>
<td>3.9</td>
<td>41.2 (1.5%)</td>
</tr>
<tr>
<td>Total</td>
<td><strong>181.9 (87.5%)</strong></td>
<td><strong>36.0 (12.5%)</strong></td>
<td><strong>207.9</strong></td>
</tr>
</tbody>
</table>

Table 2. Area (ha) estimated to be occupied by urban growth in the decades 2001-2011 and 2011-2021. For 1991-2001 was estimated 90% of the total area.

![Figure 5](image1.png)

Figure 5. Urban and infrastructures areas in 1990 and 2021.
RESULTS
Diagnosis

The most known cause for saltwater intrusion is excessive water extraction. However the roots of this problem lie beyond. First this is a matter of water balance. Therefore either too much water is being pumped out of the aquifer or less water coming in, or both. In the Mex. Grande – Portimão aquifer it is probable that both phenomena are occurring. As mentioned before, a key landscape process in the region is urban growth. This has been responsible for the increase of water consumption levels over the years. On the other hand urban expansion means more impermeable surface, which in turn means less recharge.

Urban growth also relates to groundwater quality. The runoff from these areas carries pollutants into aquifers.

The establishment of this relationship between groundwater quantity/quality (the functions to be preserved) and urban growth (element of the structure of the landscape) allows extrapolations to be made. This means that conclusions can be inferred from the future scenarios, e.g. the TREND.

Prognosis
Scenarios

Tables 3, 4 and 5 contain the results so far obtained.

Table 3. Urban growth measured in the 1991 land use map and the TREND scenario for 2021.
DISCUSSION

First it is important to notice that the urban growth projection that was made is not meant to be very precise. This is so not only due to the data available but also due to the simple extrapolating method used. It is meant only to give a global idea of what may be the future urban development in the study area.

It should also be noticed that the method used for calculating the MIZ is just one proposal and shouldn’t be taken as the absolute truth.

The magnitude of the urban growth (table 3) in the several LU is very different. As it was expected, due to the method used for building the scenario, LU1 is the most developed one in terms of occupied area. However the growth in percentage is higher in LU3 and LU4+5, which may indicate a faster change dynamics.

From table 4 it becomes evident that the NER limits are not including a significant part of MIZ (almost half of it overall). On the other hand there are zones protected as NER that are not MIZ. It is also evident that the main problems are located in LU1, where almost all MIZ are not included in the NER. In fact, in 2021, the greatest impact in terms of MIZ becoming impermeable occurred in LU1. This is of course a result of the zoning map of the MMP that guided the location of urban growth in the scenario: the MIZ in that LU were not in a protection category.

Several reasons can justify the mismatch between MIZ and NER. First the criteria mentioned in the legislation that created the NER are vague. Second when the limits were drawn, the data available on aquifer systems was very poor. Therefore the establishment of the limits was difficult and imprecise. Additionally the NER includes other features beside MIZ. Therefore it is possible that some areas that are not MIZ were classified as NER for other reason than groundwater protection. Finally the NER is not accounted for within urban perimeters.

The results point to the need of revising the NER limits not only to include all the MIZ, but also to detach areas that were misincluded as MIZ. This is especially important in LU1, where almost all MIZ are at risk. Including the MIZ of LU1 in NER could be an interesting way to sustain urban growth in this LU or at least create some greenways that could prevent an urban continuum to develop.

CONCLUSIONS

From the results obtained so far the main conclusion is the need to revise NER limits to include MIZs and exclude areas that have no protection value. Under these new limits, urban growth could be conducted differently, maybe occupying zones that are currently ill protected or at least driving urban growth trends away from the main aquifer recharge areas. Since the NER is not applicable within urban perimeters, these areas should integrate an urban ecological network, along with other ecologically significant structures, e.g. the

| LU  | Total MIZ (ha) | MIZ Impermeable in 1991 | MIZ Impermeable in 2021 | Loss of MIZ (1991-2021)%
|-----|---------------|------------------------|------------------------|------------------------
| LU1 | 809           | 226                    | 394                    | 20                     |
| LU2 | 187           | 14                     | 14                     | 0                      |
| LU3 | 2476          | 132                    | 209                    | 3                      |
| Total| 3472          | 365                    | 617                    | 7                      |

Table 4. Maximum infiltration Zones (MIZ), National Ecological Reservation (NER) and their intersection.

| LU  | Total MIZ ha | MIZ Impermeable in 1991 | MIZ Impermeable in 2021 | % of MIZ not classified as NER
|-----|--------------|------------------------|------------------------|------------------------
| LU1 | 809          | 226                    | 394                    | 99                     |
| LU2 | 187          | 14                     | 14                     | 98                     |
| LU3 | 2476         | 123                    | 209                    | 25                     |
| Total| 3472         | 365                    | 617                    | 45                     |

Table 5. Impact of urban growth on maximum infiltration zones (MIZ).
streams network, connecting with the Alvor wetland system, to the cultural landscape tracts of value in the upper part of the watershed, all the way up to the Monchique range. In this way, the linkage of the main ecological structures would be assured all across the watershed. This connectivity is crucial to allow the energy, material and species to flow across the watershed, from the headwaters down to the coastal areas.

The data available and more data to be obtained in the future, will certainly allow drawing more in-depth conclusions.

FURTHER INVESTIGATION

The next step will be using the total recharge of the aquifer as an indicator for water quantity. Total recharge will be calculated for the reference map of 1991 and the scenarios, allowing a comparison and determining an evolution trend.

Indicators for quality issues (agriculture pollution, erosion/particles coming from headwaters, etc.) will be investigated. This would also allow determining an evolution trend.

As to the scenarios, there are several refinements to be made. First, other scenarios can be built, that could simulate a new context (new regulations, new economical context, other practices etc.). Second, it would be interesting to include along with urban growth, the development of especially pollutant crops (namely oranges) and forest types (namely eucalyptus). Last we expect to obtain in the near future recent aerial photographs of the study area. This will allow the calibration of the scenarios.

Another output of this investigation will be recommendations on best available practices. There are activities compatible with aquifer recharge areas and others, which are not. This knowledge could be important while designing the regulations for NER areas. Within this context guidelines for land use planning will be produced.

ACKNOWLEDGEMENTS

We would like to acknowledge Portimão City Hall and IGeoE for the cartographic information provided to the project, DRAOT Algarve for the valuable data, LNEC for the data and methods and FCT for the funding the present work through the SALSIM project (POCTI/ECM/2512/95).

REFERENCES


Decreto-Lei n.º 140/99, de 24 de Abril


IGM – Instituto Geológico e Mineiro. Carta Geológica de Portugal. 1:200 000.


SUSTAINABLE LANDSCAPE PLANNING AS A TOOL TO ADDRESS WATER RESOURCE PLANNING – A PORTUGUESE CASE-STUDY ON A COASTAL AQUIFER SALINATION