Chapter 8

Discussion and Conclusions

8.1 Discussion

In this section, some remarks as to the methodology and results presented in previous chapters are to be set forth and discussed.

First, it should be stated that the methodology employed in this study is general and can be applied anywhere if the required information is available. The results obtained, however, are specific for the Upper Neckar catchment.

Concerning the methodology employed in chapter three to five to select parsimonious models for ten runoff characteristics having just the minimum number of variables and parameters has been proved convenient with regard to providing insight into the functioning of the system and easing their applicability in more complex simulation models. Those variables that constitute a given model were selected taking into account two conditions. Firstly, the number of variables in a model should be as close as possible to the dimensionality of the system (i.e. around 7); and secondly, in each model there should be at least one variable directly linked to the morphology, to the climate factors, and to the land cover state of the basin respectively. By doing so, these models not only have saved considerable computing time in the subsequent simulations carried out in Chapter 6, but also have been able to react to changes in macroclimate and land cover as can be appreciated in Table 6.5. In other words, these minimalist models have been capable of detecting many of the entangled relationships between the predictors (which are very often non-linear) contained in their unknown joint distribution function.

Additional advantages of the selection procedure are twofold. The risk of over-parameterization as well as the possible multicollinearity among predictors was considerably minimised. A direct consequence of the latter is, for instance, the significant reduction of the confidence intervals of all model's parameters.

The inclusion of statistically significant variables in a model is also of key importance with regard to finding “good” but “simple” models among the numerous possibilities given by a set of predictors. The main reason for this is that a non-significant variable will increase the total variance, but will not contribute to explain it better. In other words, it will only add noise to the system and deteriorate the explanatory power of other significant predictors. In this respect, the randomisation test employed has proved to be an indispensable analytical tool compared with any conventional parametric statistical tests. In this case, considering the fact that the multivariate joint distribution function of the predictors is unknown, the latter would have provided misleading decision results as to which variable is to be in or out of a model. This would have undoubtedly occurred since all parametric tests are based on assumptions with regard to the distribution functions of the variables.

The use of the Jackknife statistic during the cross-validation of the best models has tremendously facilitated the task of the selection of the "best" model. Additionally it was of essential importance in the present study since it allows estimating at the same time the level of predictability and the robustness of a model in presence of data that contain outliers. One important advantage of this statistic is that it can be used always regardless of the estimator employed.

It has to be mentioned that all of these statistical techniques are very effective for modelling complex systems but they require substantial computing resources, which will increase non-linearly with respect to the amount of data employed.

As said above, the integration of two realms of the system, namely the hydrological behaviour of a catchment and the state of the land cover at a given point in time has been achieved in this study because of the simplicity of the hydrological models employed describing many runoff characteristics and of the character of the Land Use/Cover Change (LUCC) model, which in spite of its simple formulation, has reached an 85% level of predictability in its validation phase (see 6.3.2). This result has been achieved mainly because of the spatially distributed character of the LUCC model. Recalling its basic formulation, it makes the transition probability from one land cover type to another depend on external driving forces that vary over space but not in time. In this case, the driving forces behind land cover change have been considered static just to keep the model as simple as possible under the existing constraints of time and resources assigned for this research. This shortcoming should be improved in future versions, because some of the external driving forces behind land cover change may vary over time, for instance accessibility to towns and settlements with access to railway connection. The LUCC model, however, can be modified to accept dynamic driving forces based on the same formulation presented here. Another aspect of the LUCC model that should be improved in future versions is its link with other factors that induce a land use change. The land use of a given location depends among other factors on its accessibility, the existing land use regulations, and the location of residents and job places. Under specific conditions the state of these variables are such that they can induce a land use change. Then, eventually, a land cover change will follow with all its consequences to the environment. This coupling between land use and land cover models is still a challenge for future versions of this kind of simulation model.

Secondly, as to the results obtained in this study the subsequent remarks can be formulated, which, as was already said, are relevant for the Upper Neckar catchment in general and for the Körsch catchment in particular.

Based on the relationships thoroughly discussed in Chapters 4 and 5, which relate several runoff indicators for basins exhibiting various sizes and morphological characteristics, having different percentages of land cover shares and at different points in time, it can be inferred that land cover variables are certainly having an effect on the hydrological cycle at mesoscale basins. In all cases that have been analysed, the subset of the best performing models always contains one or more of these variables. The test of independence has shown that such variables are certainly not independent of the explained variables at the 5% level, and in some cases at even less than that significance level.

The magnitude of the effects of land use/cover change on the hydrological cycle of a mesoscale basin, of course, cannot be compared with those triggered by sudden meteorological changes. It should be borne in mind that the hydrological system is driven by the weather and that the morphological characteristics of the basin and its land use/cover can only modulate the response of the system. However, the effects of land use/cover change are cumulative and may cause long-lasting consequences. For instance, they will further a continuous increase of the total discharge in winter and will induce long periods of drought in summer (see Table 6.5). Both effects will have enormous consequences for the environment and the economy of the region.

More specifically, the effects of land use/cover change on the hydrological system of a mesoscale basin under two extreme climatic scenarios can be summarised below.

The total discharge in winter, Q_2, will increase at about 6.9% per decade in the worst-case scenario C1S1, i.e. a very rapid urban sprawl (about 1.3% per year) accompanied by a continuous increase of mean air surface temperature caused by global warming. If the growth rate of impervious cover will decline to a modest 0.4% per year and climate will continue with the actual warming tendency the growth rate may be about 5.4% per decade (i.e. development scenario C1S2). These growth rates may decrease only if the global community really will minimize the amount of emissions of greenhouse gases to the atmosphere. If this becomes true, then these figures will be reduced to 3.7 and 2.4% per decade for development scenarios C2S1 and C2S2 respectively. The 95% confidence intervals shown in Figure 6.8 indicate that the average total discharge in winter up to 2025 would be 17% to 44% bigger that that of the base period (1961-1990) for scenario C1S1. In the most favourable scenario (C2S2) these figures will be as low as 7% and 34% respectively.

The total discharge in summer, Q_3, will in general tend to decrease because of higher temperatures and corresponding increasing evapotranspiration. This variable, for instance, will suffer a decrement of 6.8% per decade in the development scenario C1S2 (which contemplates an increase in forested areas). In development scenarios C1S1 and C2S1, however, it may endure increments as to the reference period.

Specific peaks in winter, Q_4, will tend to increase in all scenarios. However, the largest deviation from the historical mean corresponds to the development scenario C1S1 (i.e. urban sprawl accompanied with future climatic conditions exhibiting hotter winters). Land use/cover change plays a very important role in this runoff indicator. The difference in percent between the socio-economic scenarios S1 and S2 is about 3% per decade regardless of the macroclimatic settings.

Specific peaks in summer, Q_5, will tend to decrease in all scenarios with the exception of scenario C2S1. In the latter, summers will not be much hotter as during the reference period but an increase of impervious cover will reduce the concentration time of surface runoff, which, in turn, will tend to increase peak flows at the rate of 0.1% per decade. However, the confidence intervals estimated for each scenario show that this variable might have a large fluctuation around the mean of the base period. Summer peaks are often local phenomena caused by convective precipitation.

The specific volume of the annual peak event, Q_6, is the runoff characteristic that is mostly affected by land cover changes simulated in the Special Study Area. The difference between the growth rates of this variable under socio-economic scenarios S1 (i.e. urban sprawl) and S2 (i.e. densification) may range from 5.8% to 6.7% per decade, depending on whether the future macroclimate conditions will be either moderate or exacerbated respectively (i.e. climate conditions of scenario C2 or C1 correspondingly). Furthermore, if impervious cover will follow the actual trend, and mean temperature will increase at the rate of 0.4°C per decade (i.e. a grow of 2.4% per decade in average) due to global warming (C1S1), then, this variable will grow at about 9.9% per decade. This implies that if scenario C1S1 would become true, the future volume of the annual peak flow could be between 15% and 43% greater than during the reference period with a 95% level of confidence. In other words, more intensive floods can certainly be expected downstream of the Special Study Area.

Total duration of high flows in winter, Q_9, will be higher on average in the densification scenario (S2) than in the urban sprawl scenario (S1) assuming constant climatic conditions. In other words, discharges that occur less than five percent of the time will persist during longer periods. The reason for that stems from the fact that the former scenario promotes an increase of forest and restricts the development of impervious cover at a low growth rate. The latter, though, does just the opposite. A higher amount of forest would induce lower rates of evapotranspiration in winter, which, in turn, would tend to increase surface runoff. Additionally, it should be noted that even in the most favourable case (i.e. C2), the mean temperature in winter would grow at about 0.8% per decade based on actual trends for the Northern Hemisphere. This increase of heat in the system will induce a faster melting of the snowpack, which, in turn, will also contribute to increase the surface runoff and its persistence at higher discharge levels.

Total duration of high flows in summer, Q_{10}, will do just the opposite of its counterpart in winter, i.e. they will tend to decline in general, mainly because mean temperature in summer will increase. The growth rate in the densification scenario is even smaller because forest will grow under this scenario, which implies higher rates of evapotranspiration and, hence, lower surface runoff. The exception is the scenario C2S1 (i.e. moderate climate and urban sprawl) where this variable will tend to grow at just 0.1% per decade. The main reasons are the moderate temperatures of the climatic scenario and the large reduction of forest combined with a large expansion of impervious areas promoted by the socio-economic scenario S1. Less forest implies less evapotranspiration whereas more impervious areas imply shorter concentration time and drastically decreased infiltration capacity of the basin. All put together they have made this variable to grow at 1.8% per decade.

Frequency of high flows will grow in winter, Q_{11}, and conversely, will decline in summer , Q_{12}. Moreover, the urban sprawl scenario (S1) will exhibit the larger growth rates under the same climatic conditions. In other words, if the actual trends in land cover continue, regardless of the macroclimatic conditions, it is very likely (95% certainty) that the frequency of high flows in winter will be greater than that of the reference period. Although the average tendency of this variable is to decline in summer, sudden increases as compared to the reference period can be expected. The reasons for these developments in general are closely related to those already stated for variables Q_9 and Q_{10}, but they are inversely related. In short, if a combination of factors cause the total duration of high flows to persist at higher values during longer times then the frequency of such flows will tend to decrease.

Finally, the total drought duration in summer, Q_{14}, will tend to increase faster in climatic scenario C1 than in C2. Land use/cover changes will have an impact on this variable but in a lesser degree as compared with those originated by a macroclimatic change.

8.2 Conclusions

The present study was based on three general objectives (see Section 1.4) aimed at investigating the impacts of climatic and land cover/use changes in a mesoscale catchment. Considering these objectives and the results that have been achieved and documented in previous chapters, it is possible to draw the following conclusions.

1. The key element in the analytical part of this study was the use of temporal and spatially distributed data available for 46 gauging stations at the Upper Neckar Catchment from 1961 to 1993. Based on this vast amount of information and with the help of sophisticated optimisation algorithms and nonparametric statistical techniques, it was possible to search and validate “very good” models that describe the state of the system at any point in time and for each spatial unit (i.e. a basin). These numerical relationships have allowed discriminating between the effects of climatic and land cover variability at mesoscale level. The quantifications of the magnitude of a given land cover change is straightforward.
2. Calibrated models for several runoff characteristics in winter and summer have shown that land cover variables are statistically significant (5% level) components of the water cycle at the mesoscale. However, the performance of models in winter is better than that in summer.
3. The integration of these hydrological models with a simple stochastic land use/cover change model has proved to be feasible and enlightening. Although the land use/cover model used in this study is quite simple, the results show that it is a promising planning tool since it allows testing the effects of several land use/cover and climatic scenarios on the hydrological cycle.
4. Further research, however, is still needed in order to improve the land use/cover change model so that it includes other time dependent factors which induce land use/cover changes.
5. Further steps should be carried out in order to promote the use and development of integrated planning tools as logical and systematic constructs that support planners’ actions dealing with the complexities of natural systems and their entangled relationships with anthropogenic activities. By doing so, a step towards sustainability will be realized.