Chapter 7

Summary

7.1 Conclusions

The main findings of the thesis can be summarized as follows (the respective items listed below correspond to the specific objectives defined in the introductory chapter):

1. In Chapter 2 different antecedent soil moisture proxies representing catchment wetness status were tested for their ability to improve Curve Number-based peakflow predictions for 186 unregulated Australian catchments. The examined antecedent soil moisture proxies were based on gauged precipitation, baseflow (obtained by separating the observed streamflow record), TRMM precipitation, and AMSR-E surface soil moisture. It was found that the 5-day antecedent precipitation index computed from gauge precipitation, the generally recommended soil moisture proxy for use with the Curve Number model, performed considerably worse than an antecedent precipitation index based on gauged precipitation using an optimized decay factor. It was further found that the latter performed better than the soil moisture proxies based on AMSR-E surface soil moisture and TRMM precipitation, demonstrating the continued importance of a sufficiently dense precipitation-gauge network. The greatest improvements in model runoff prediction performance were typically obtained for arid catchments, possibly reflecting the larger variability in catchment wetness levels occurring under such conditions compared to more humid climates.

2. In Chapter 3 the degree of agreement between four widely used AVHRR-NDVI datasets (PAL, GIMMS, LTDR V3, and FASIR) for assessing vegetation productivity was examined. In addition, these datasets and the NDVI based on the more modern MODIS instrument were globally validated against 11,764 high-resolution (∼30 m) NDVI samples (20 × 20 km²) derived from the Landsat-5 Thematic Mapper, which has on-board calibration devices. The trends in mean NDVI were positive for all continents and all four AVHRR-NDVI datasets, with trends derived from the PAL dataset generally being the strongest and the ones from the GIMMS dataset generally the weakest. Significantly equal trends between the datasets were found over 48% of the total land surface only, which is a low proportion considering that each dataset was based on the same AVHRR Global Area Coverage archive. The LTDR V3 and PAL showed trends in desert areas devoid of vegetation and were thus improperly calibrated. The validation against Landsat-derived NDVI values indicated that the LTDR V3 dataset is the most accurate in terms of absolute NDVI values, whereas the GIMMS dataset is the most accurate in terms of NDVI change over time. However, NDVI derived from the MODIS instrument strongly outperformed all AVHRR-NDVI datasets examined. As such, it is considered unlikely that these AVHRR-NDVI datasets presently can be used to obtain accurate global information on land cover or land use change, as the data are subject to a high degree of uncertainty. In addition, they have a coarse spatial resolution (0.05° for the LTDR V3 dataset and 0.08° for the other AVHRR-NDVI datasets) and employ the maximum-value compositing technique, which favourably selects patches with high NDVI values within a pixel. Finally, it was found that taking the simple average of the four AVHRR-based datasets resulted in NDVI values which compared better to Landsat-NDVI than all of the AVHRR-NDVI datasets individually, indicating that the errors in respective datasets are to a certain degree unrelated.

3. In Chapter 4 the possible impacts of forest regrowth on streamflow characteristics were examined for 12 meso-scale (23–346 km²) catchments on the humid tropical island of Puerto Rico. Long-term records of precipitation and potential evaporation were used to drive a simple conceptual rainfall-runoff model (HBV-Light), producing simulated streamflow that integrated the effects of carry-over water storage between successive years as well as climate variability during the streamflow observation period. For each catchment, simulated and observed time series of four streamflow characteristics were calculated: (1) the annual 95th percentile (i.e., the percentage of time that this level of flow is not exceeded) of daily streamflow (indicative of peak flows); (2) the annual mean streamflow (indicative of total water
yield); (3) the annual 5th percentile daily streamflow (indicative of low flows); and (4) the annual mean dry-season (January–March) streamflow. In addition, trends in the deviations between simulated and observed values for the respective streamflow metrics were evaluated. These represented the change in observed streamflow characteristics after taking the effects of water storage carry-over and climate variability into account. However, no clear relationships were found between changes in streamflow characteristics and changes in either forested or urban area per catchment. These findings are in line with previous studies of meso- and macro-scale (sub-)tropical catchments, which generally found no significant change in streamflow that could be attributed to changes in forest area. Possible explanations for the presently found lack of a clear relationship include: (1) data errors (notably for precipitation); (2) the changes in forest area occur mainly in the less rainy lowlands (thereby having a less pronounced effect on overall streamflow relative to the same change in forest cover if effected over the wetter upland parts of the catchments); and (3) heterogeneity among the catchments in terms of the streamflow response to forest regrowth (due to differences in vegetation cover and/or land-use history not being accounted for by the semi-quantitative classification used, or because of differences in morphology, geology, and/or soils between the catchments).

4. In Chapter 5 relationships between 18 catchment physiographic characteristics (related to soils, topography, climate, and land cover) and two important baseflow characteristics were analyzed using a diverse set of 3520 unregulated catchments worldwide. Previous studies have typically used < 200 catchments and regional datasets, resulting in less reliable relationships with potentially limited applicability elsewhere. The used baseflow characteristics were: (1) the baseflow index (BFI), defined as the ratio of long-term mean baseflow to total streamflow; and (2) the baseflow recession constant \( k \), defined as the rate of baseflow decay. The two baseflow characteristics proved to be related to several physiographic characteristics, notably mean annual potential evaporation, mean catchment elevation, mean surface slope, fraction of open water, and the mean sand content of the soil. The relationships were generally highly non-linear and heteroscedastic (i.e., showing variable scatter). Artificial neural network ensembles were subsequently used to estimate the two baseflow characteristics for the catchments. Mean training \( R^2 \) values of 0.73 and 0.62 were obtained for BFI and \( k \), respectively, suggesting that artificial neural network ensembles provide a viable alternative to the commonly used multi-variate linear regression approach. In addition, global maps of the two baseflow characteristics were produced using global physiographic data as input to the established artificial neural network ensembles. These maps offer unique opportunities for macro-scale hydrological studies, including the diagnosis and parameterization of macro-scale hydrological models (land surface schemes and global hydrological models), water resource assessments, catchment classification, and groundwater recharge estimation (see also below).

5. In Chapter 6 global maps of five important streamflow characteristics were produced using the methodology developed in Chapter 5 in combination with streamflow and physiographic data for 3320 undisturbed catchments around the globe. The streamflow characteristics were: (1) mean annual runoff (indicative of total water yield); (2) annual 1st percentile of daily streamflow (indicative of low flows); (3) annual 99th percentile of daily streamflow (indicative of peakflows); (4) BFI; and (5) \( k \). It was found that the global patterns of the newly produced maps differed considerably from equivalent maps as derived from two commonly used macro-scale hydrological models (Noah and PCR-GLOBWB). Next, the HBV-Light rainfall-runoff model was calibrated using values of the streamflow characteristics derived from the newly produced maps for 200 independent catchments. This resulted in substantial improvements in the simulated streamflow characteristics as compared to values obtained with the uncalibrated HBV-Light model. These improvements in streamflow characteristics, in turn, led to improvements in most of the traditional model performance measures calculated from observed and simulated daily continuous streamflow time series, including the long-term bias and the Nash-Sutcliffe efficiency. These findings demonstrate that the newly produced maps of the respective streamflow characteristics examined can be employed to improve the parameterization and/or structure of hydrological models at a global scale.

7.2 Recommendations

A recurring feature of each of the chapters of this thesis has been the use of large observational datasets in order to arrive at more confident conclusions. As discussed more fully in the introductory chapter, such large observational datasets have become increasingly available owing to recent advances in remote-sensing technology, processing power, and data dissemination. Arguably, in each of the chapters, the use of a data-subset only, might well have led to very different conclusions (see, e.g., the Discussion section in Chapter 4 on streamflow response to tropical regrowth in Puerto Rico). Naturally, at the global scale, the use of these large observational datasets is a conditio sine qua non when trying to bet-
ter understand how the hydrological cycle will respond
to global climate change and human-induced changes in
land cover and land use or land degradation (cf. Jones,
2005; Andrésassian et al., 2007; Peña-Arancibia, 2013;
Gupta et al., 2013). In addition, using all available data
(including outliers) is likely to present a more balanced
picture to potential end-users (Andrésassian et al., 2007).

In Chapter 2 it was found that the TRMM-based
precipitation estimates and AMSR-E-based surface soil
moisture data used as proxies for catchment-scale wet-
ness status (and thus runoff response to rainfall) showed
poor predictive performance compared to ground-based
measured precipitation. Better results may be achieved
when using the successor to TRMM, the Global Pre-
cipitation Measurement (GPM) mission (Smith et al.,
2004) which is to be launched in early 2014. The GPM
mission is targeted to provide precipitation data with
significantly improved accuracy, spatial coverage and
resolution, and at an average revisit time of less than
three hours in many regions of the world. Further im-
provements in estimating catchment-scale wetness sta-
tus may be expected using surface soil-moisture prod-
ucts derived from the recently launched European Space
Agency (ESA) Soil Moisture Ocean Salinity (SMOS)
mission (Kerr et al., 2001) or from the National Aero-
nautics and Space Administration (NASA) Soil Moisture
Active/Passive (SMAP) mission (Entekhabi et al., 2010)
which is to be launched in 2015. Arguably, the develop-
ment of remotely-sensed surface soil moisture products
based on observations from multiple sensors (e.g., Liu
et al., 2011; Dorigo et al., 2012) is particularly promis-
ing.

The newly derived observation-based maps of various
important streamflow characteristics developed in Chap-
ters 5 and 6 will be made available free of charge for
downloading, and should be useful for a variety of macro-
scale hydrological applications. Amongst the potential
applications is a global diagnosis of macro-scale hydro-
logical models (land surface schemes and global hydro-
logical models), as demonstrated in Chapter 6 where the
global patterns of the newly derived maps were compared
with equivalent maps derived from two macro-scale mod-
elns (Noah and PCR-GLOBWB). The new maps fur-
ther offer unique opportunities for the parameterization
of such macro-scale hydrological models, including the
type of ‘hyper-resolution’ models that are anticipated
in the near future (Wood et al., 2011). The stream-
flow characteristic maps may also be used for general
water resource assessments and for comparing the be-
havior of different catchments (i.e., catchment classifi-
cation; Wagener et al., 2007). In addition, the global
streamflow map offers possibilities for correcting pre-
cipitation biases in mountainous and/or humid regions
due to topographic biases in gauge placement, interpo-
lation errors, and/or wind-induced snowfall undercatch
(cf. Adam et al., 2006). Furthermore, the global stream-
flow and BFI maps can be combined to provide a first es-
timate of groundwater recharge for any location around
the globe (cf. Szilagyi et al., 2003).

Last but not least, the methodology adopted in Chap-
ters 5 and 6 to produce global maps of various impor-
tant streamflow characteristics proved highly efficient
and flexible, and deserves to be used to derive additional
global maps of other important streamflow characteristics. For example, the addition of a streamflow charac-
teristic related to the timing of flows could be important
to estimate the arrival of spring snowmelt in mountain-
ous and/or sub-Arctic catchments. The methodology
could perhaps also be employed to estimate global pat-
terns of other key biophysical, hydrological, or climatic
variables.