Chapter 1.2.5: Impacts of Vegetation and Land Use on Water Resources

Module 1: Basics of Watershed Management  Case Study

Effects of Large-scale Land Cover Change on the Hydrology of the Tocantins River, Brazil

A. Background

It is evident that there will need to be a substantial and fundamental change in the scale of land use in large river basins, for there to be any demonstrable impact upon the hydrological regime. There are for example noticeable hydrological consequences as a result of large scale changes from natural vegetation such as forest cover to permanent agriculture. However on the other hand if the primary forest cover is removed in a fragmented fashion, and is replaced in a timely manner by some form of secondary vegetation, occurring in various stages of re-growth, then the hydrological impacts are far more subtle and difficult to identify in the observed runoff data.

The Tocantins River in Amazonia has a total drainage area of 767,000 km² and a mean annual discharge of 11,000 m³. Flows from the upper 175,000 km² of the basin have been observed on a daily basis for a period of fifty years (1949 - 1998) at Porto Nacional, which is upstream of where the large scale conversion of the natural vegetation to permanent cropland and pasture has been carried out. This substantial transformation of the basin landscape began in 1960, with the founding of Brasilia as the national capital.

The natural vegetation of the upper Tocantins basin is a combination of tropical forest and ‘cerrado’. The latter dominates the landscape and is a kind of tropical savannah, being a combination of grasses, small palms, closed shrubs and scattered trees. Since the 1960’s, ‘cerrado’ areas have been one of Brazil’s preferred ‘agricultural frontiers’ and therefore a great deal of it has been converted to planted pasture using non native, high productivity grasses. Elsewhere, the pasture is ‘natural’, as it originates from ‘cerrado’, with the trees and shrubs having been removed.
### Table 1: Land use changes in the Tocantins River basin upstream of Porto Nacional 1960 - 1998

<table>
<thead>
<tr>
<th>Land Use</th>
<th>1960</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planted pasture (%)</td>
<td>5</td>
<td>23</td>
</tr>
<tr>
<td>Natural pasture (%)</td>
<td>24</td>
<td>23</td>
</tr>
<tr>
<td>Crops (%)</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Total land in agricultural use</td>
<td>31</td>
<td>50</td>
</tr>
</tbody>
</table>

In order to determine the hydrological effects of this tropical vegetation conversion between 1960 and 1995 (see table 1), Costa et al (2003) divided the observed discharge data at Porto Nacional into two twenty year periods, the first from 1949 to 1968 and the second from 1979 to 1998. The intervening years were discarded to emphasise the differences in land use between the earlier and the later sub-period. Regional rainfall was also examined over these respective timescales to ensure that any incremental change in river flow was not a result of any significant difference in the rainfall climate.

### Table 2: Sub-period mean annual rainfall and discharge in the Tocantins River basin upstream of Porto Nacional

<table>
<thead>
<tr>
<th>Period</th>
<th>Mean annual rainfall (mm)</th>
<th>Mean annual discharge (m³)</th>
<th>Runoff Coefficient (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1949 - 1968</td>
<td>1540</td>
<td>2050</td>
<td>24</td>
</tr>
<tr>
<td>1979 - 1998</td>
<td>1590</td>
<td>2550</td>
<td>29</td>
</tr>
</tbody>
</table>

The annual mean regional rainfalls and the discharge for each period are summarised in table 2. These are combined with the respective runoff coefficient, which is the proportion of the rainfall over the upper basin that appears as stream flow. Statistical tests revealed that:

- The slight increase in mean annual rainfall was not significant
- The 25 % increase in mean annual discharge is significant at the 1 % level
- The corresponding increase in the runoff coefficient is also highly noteworthy

The principal conclusion is that the substantial increase in runoff is independent of any change in the regional rainfall climate and is linked to the changes in land use. The seasonal hydrological impacts are indicated in figure 2.
The difference in wet season rainfall from December through to April was negligible, yet the increase in peak monthly flows is significant and is related to reduced infiltration which occurred subsequent to the changes in land cover. An important point to emphasise in this context is the nature of the cerrado soils under natural conditions. They have an unusual macro-aggregate structure, which allows for very high infiltration rates and, as a result, runoff rates are uncommonly low. When the soil is ploughed for the planting of pasture, this macro-aggregate structure is destroyed and runoff rates increase significantly.

The results presented in figure 2 also reveal the following:

- There was an increase in the amplitude\(^1\) of the mean seasonal hydrograph between the two periods and also the peak of the hydrograph in period 2 was one month earlier, despite the fact that the precipitation peak was the same in both periods. This suggests that a higher fraction of rain ran off as faster overland runoff, which is consistent with a surface less protected by natural vegetation.

- An increase in discharge during the dry season which is a consequence of a decrease in evapo-transpiration over the ‘cerrado’ areas converted to pasture.

B. Lessons Learnt and Relevance to the Mekong Basin

This study convincingly demonstrates that land use changes in the upper Tocantins basin over the last fifty years have had a significant impact on the regional hydrology, primarily as a result of modifications to the natural infiltration and evapo-transpiration processes. The study also confirms the view that wholesale permanent conversion to agricultural land use is required for the hydrological impacts to manifest themselves in the observed data in any significant way.

This is not the case in large river basins where the natural tropical vegetation is being cleared for agricultural use over some areas, and is then later abandoned to allow for some degree of regeneration in the form of secondary land cover. The end result is a fragmented landscape, which is the situation over large areas of the lower Mekong basin.

\(^1\) Amplitude is the maximum absolute value of a periodically varying quantity (in this case the discharge volume).
C. Categorisation of the Case Study

**Scale:** River basin, 175,000 km².

**Impact:** The substantial increase in runoff is independent of any change in the regional rainfall climate and is linked to land use changes, particularly from 'cerrado' to pasture (confirmed).

References and Sources for Further Reading