School catchments network in the Upper Negro River basin, southern Brazil: Scientific research and environmental education

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ABSTRACT

The Upper Negro River (UNR) basin (3552 km²), southern Brazil, is one of the headwater basins of the Iguaçu River basin, and is characterized with the Subtropical Ombrophilous Forest (SOF) which formerly covered the southern Brazilian plateau. The downstream region of the UNR possesses some hydroelectric dams which change the regional hydrological processes. Local communities have thought that water-sediment related problems have frequently occurred because of dams and/or transformation of the SOF to pine reforestation and agriculture. To increase the understandings on hydrological effects of land-uses and of catchment size and to answer a question of what kind of land-use is best for the water resources management, the school catchments network has been implemented in the UNR basin. At the moment, seven small experimental catchments (0.1-10 km² scale) with hydrological monitoring system were constructed inside the UNR basin. Furthermore, this network contains larger experimental catchments (100-1000 km² scale), among which four have been operated by the Brazilian government. In all the experimental catchments, two types of activities (research (monitoring and computational modeling) and extension (environmental education)) have been executed, which transforms the experimental catchments to the school ones. This work shows the current situation of the school catchments network in the UNR basin. Scientific investigation preliminarily showed that the increase of catchment’s size decreases the annual ratio of runoff on precipitation and the specific sediment discharge. Scientific results and the network are used for environmental education. This network would serve as the instrument to increase an individual’s knowledge on hydrology and enhance individual’s participation in community discussion. Then, it implements the community-based management for the natural disaster reduction.

Keywords: school catchments network, Upper Negro River, environmental education.
1. INTRODUCTION

The Paraná River basin (1,510,000 km²) is socio-economically one of the most important basins in South America and possesses the largest capacity of energy generation in Brazil. Located in the border between the Paraná and Santa Catarina States, southern Brazil, the Iguaçu River basin (68,410 km²) is one of the sub-basins of the Paraná River (Figure 1). Though the mean specific discharge in the Paraná River is just only 13.9 L/s·km², its value of the Iguaçu River basin is 21.8 L/s·km² and highest in the Paraná River basin. It implies that this Iguaçu River basin is characterized with a very high potential to generate the hydroelectric energy (ANA, 2001).

![Figure 1. Paraná River basin and Iguaçu River basin.](image)

There are 5 large hydroelectric-power-dams along the Iguaçu River (from the upper to downstream, Foz do Areia, Segredo, Salto Santiago, Salto Osório and Salto Caxias) (Figueiredo et al., 2007). Because of the socio-environmental aspects, the number of small hydropower plants will increase from now on in this basin (ANA, 2001). Since this basin has a geological, topographical and climatic heterogeneity, the hydrological processes are very complex and difficult to be understood.

The Upper Negro River (UNR) basin (3552 km²) is one of the headwater basins of
the Iguazu River basin (Figure 2), and is characterized with the Subtropical Ombrophilous Forest (SOF). Since the remainders of the SOF which formerly covered the plateau region of the southern Brazil are now only 2% of its original area, this ecosystem must be preserved. Recently the conversion of the pine reforestation areas to the SOF has been strongly requested without the consideration that the regional economy depends mainly on the reforestation activities. The above mentioned large dams are located in the downstream region from the UNR. According to ANA (2001), it is necessary to comprehend how the operations of these dams change the regional hydrological processes. Some local communities have thought that the frequent floods are caused by the dam construction.

Therefore, the ecological and hydrological researches in the UNR basin are indispensable to reduce the damages caused by the water-related disasters. In these circumstances, Kobiyama et al. (2007) constructed seven small experimental catchments (0.1 to 10 km² scales) with hydrological monitoring in the UNR basin in order to answer the question about what kind of land-use is better for the water resources management.

With the above mentioned small experimental catchments and some preexistent relatively-large experimental catchments, the school catchments network (SCN) has been implemented in the UNR basin. The objective of the present study was to present the concept of the SCN, some results from scientific researches, and extension activities (environmental education) in the UNR basin.

According to Kobiyama et al. (2006), the natural disaster management mainly aims (1) to understand the natural phenomena that trigger the natural disasters and (2) to
raise society’s resistance to such phenomena. It is, therefore, very clear that the present SCN implementation can contribute to the natural disaster management. Since this type of network did not exist in the Iguazu River basin or the Paraná River basin, the present SCN in the UNR basin will serve as a pilot strategy for reducing the water-related disasters.

2. SCHOOL CATCHMENT

By reporting the Forest Hydrology Project (FHP) which is the cooperative activity between the Federal University of Santa Catarina (UFSC) and the local reforestation company Modo Battistella Reforestamento S.A. - MOBASA (currently Battistella Florestal), Kobiyama et al. (2007) defined the school catchment as an experimental catchment which serves for scientific researches and environmental education activities. In this project, all the experimental school catchments can be used for the environmental education activities of local communities and also for some qualification lectures for technicians that work for the water and forest resources. Farrell (1995) showed a historical perspective of experimental catchments and their necessity for the hydrology and water resources management.

The FHP has been realized in Rio Negrinho City which is located at the central part of the UNR basin. In this city, there are not researchers or information enough to recognize the relationship between water and forest. The local communities require universities to provide some scientific and technical support, which justifies the importance of the participation of UFSC in the FHP.

Since the reforestation companies like the Battistella Florestal possess a lot of headwater catchments, the participation of such companies in any forest hydrology project through offering their headwater catchments is fundamental. It might be almost impossible to construct any experimental catchments without the cooperation of the reforestation companies. In this context, the cooperation between the UFSC and the Battistella Florestal converted the common headwater catchments to the experimental catchments. Furthermore, the execution of environmental education with participation of local communities and city office converts them to the school catchments (Figure 3).

In this way, school catchments increase an individual’s knowledge on hydrology, which enhances his (or her) participation in the community in terms of water resources management. Consequently, an enhanced participation of each member elevates the quantity and quality of the community action. According to Hillman & Brierley (2005), the community-based management is essential for the recent stream rehabilitation programs. Such a management with governmental supports must be executed for any program that
treats catchments and water resources. Figure 4 shows the relationship between the school catchments and the community-based management. This kind of cooperation between universities and reforestation companies, together with local communities’ participation, might be indispensable in any forest hydrology project which ensures the integrated management of water resources. It is worth mentioning that school catchments are important not only for local communities but also for the hydrological sciences’ community. They are fundamental fields (objects) for achieving catchment hydrology. According to Uhlenbrook (2006), in catchment hydrology pure scientific interests overlap with practical water management to support sustainable development.

As mentioned above, the UNR basin’s communities need to understand hydrological effects of land-uses and dams’ operations, which requires to have a certain number of school catchments characterized with different land-uses and dams. Furthermore, the fact that the hydrological processes depend on the catchment scales (Pilgrima et al., 1982, Laudon et al., 2007) requires having school catchments with different scales. Therefore, by constructing a set of school catchments with different land-uses and different scales, the SCN has been implemented for the UNR basin’s management. The concept of catchment network is not new. In justifying the catchment studies and the long term monitoring system for the investigation of hydrological effects of forest, Whitehead & Robinson (1993) reported some European examples of the catchment networks. Besides, O’Connell et al. (2007) introduced the Catchment Hydrology and Sustainable Management (CHASM) research program that contains the catchment network in the UK and that
adopts a common multiscale experimental design. These networks seem to be established just for the scientific researches. The concept of such networks is, therefore, very different from that of the present study where the SCN contributes not only to the scientific researches but also to the environmental education activities.

![Diagram showing the relation between school catchments and community-based management](image)

Figure 4. Relation between school catchments and community-based management.
(Source: Kobiyama et al., 2007)

3. STUDY AREA

In this study, the outlet of the UNR basin is determined as the point of the gauge station of Rio Negro (Code No. 65100000). Then the total area of the UNR basin is 3552 km². The northern and southern parts of the Negro River belong to Paraná and Santa Catarina States, respectively. Inside the UNR basin there are more three preexistent gauge stations (Rio Preto do Sul (650950000), Avencal (65094500) and Fragosos (65090000)) (Figure 5).

The climate is Cfb (Maritime Temperate climate) in the Köppen classification. The principal geology is Paleozoic sedimentary rocks (sandstone and shale) that demonstrate horizontal stratification. The general relief is moderate and there are a lot of swamps in headwater areas (Kobiyama et al., 2007).

Historical analysis of Rio Negrinho city shows the increase of hazard zones’ occupation in the urban areas, which implies the fundamental roles of the city office’s actions to reduce flood disasters (Schoeffèl, 2004). This aspect is very common for other cities inside the UNR basin.
4. ESTABLISHMENT OF SCHOOL CATCHMENTS NETWORK

As mentioned above, the present network uses the four preexistent gauge stations and constructs 10 more river gauge stations. Then the network consists of 14 school catchments (Table 1). The outlets of all the school catchments are shown in Figure 5. The small-size catchments (5 to 11) and the middle-size catchment (12) are all inside the Rio Preto do Sul catchment (3) which will permit to discuss the hydrological effects of small catchment-scale. All the school catchments receive two types of activities: the hydrological researches (monitoring and computational modeling); and the extension activities (environmental education courses).

At each station, water-level and SS (suspended sediment) are monitored. Though these parameters have been manually measured at the station (3), its monitoring system will be automated in the near future. Then, the monitoring interval at the stations (1 to 4) will be all one hour. And the rest of the stations will have the interval of 10 minutes. At theses station, the short time interval is necessary, because the time of concentration in the corresponding catchments (5 to 14) is relatively short. If the early warning system needs to be introduced to the catchments in future, this shorter interval will be very useful (Kobiyama & Goerl, 2007).
Table 1. Gauge stations and their corresponding school catchments’ characteristics in the Upper Negro River basin.

<table>
<thead>
<tr>
<th>No.</th>
<th>Station</th>
<th>Area (km²)</th>
<th>Year</th>
<th>Institution</th>
<th>Catchment characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rio Negro</td>
<td>3552</td>
<td>1930</td>
<td>COPEL*</td>
<td>Code No. 65100000. Mixture (agriculture, pine reforestation, native forest)</td>
</tr>
<tr>
<td>2</td>
<td>Rio Preto do Sul</td>
<td>2611</td>
<td>1951</td>
<td>ANA**</td>
<td>Code No. 650950000. Mixture (agriculture, pine reforestation, native forest)</td>
</tr>
<tr>
<td>3</td>
<td>Avencal</td>
<td>1001</td>
<td>1976</td>
<td>ANA</td>
<td>Code No. 650945000. Mixture (agriculture, pine reforestation, native forest)</td>
</tr>
<tr>
<td>4</td>
<td>Fragosos</td>
<td>800</td>
<td>1967</td>
<td>COPEL</td>
<td>Code No. 650900000. Mixture (agriculture, pine reforestation, native forest)</td>
</tr>
<tr>
<td>5</td>
<td>P1</td>
<td>0.16</td>
<td>2006</td>
<td>UFSC</td>
<td>20-years-old pine reforestation</td>
</tr>
<tr>
<td>6</td>
<td>P2</td>
<td>0.24</td>
<td>2006</td>
<td>UFSC</td>
<td>20-years-old pine reforestation (after calibration period, the clear cutting will be done.)</td>
</tr>
<tr>
<td>7</td>
<td>A</td>
<td>0.20</td>
<td>2006</td>
<td>UFSC</td>
<td>Agriculture (corn, soy beans, etc.)</td>
</tr>
<tr>
<td>8</td>
<td>M1</td>
<td>2.69</td>
<td>2006</td>
<td>UFSC</td>
<td>Mixture (Agriculture, reforestation, native forest)</td>
</tr>
<tr>
<td>9</td>
<td>M2</td>
<td>8.98</td>
<td>2006</td>
<td>UFSC</td>
<td>Mixture (Agriculture, reforestation, native forest)</td>
</tr>
<tr>
<td>10</td>
<td>N1</td>
<td>0.15</td>
<td>2006</td>
<td>UFSC</td>
<td>Native forest</td>
</tr>
<tr>
<td>11</td>
<td>N2</td>
<td>0.24</td>
<td>2006</td>
<td>UFSC</td>
<td>Native forest</td>
</tr>
<tr>
<td>12</td>
<td>R</td>
<td>201</td>
<td>2008</td>
<td>UFSC</td>
<td>Reservoir for small hydropower plants</td>
</tr>
<tr>
<td>13</td>
<td>W1</td>
<td>195</td>
<td>2008</td>
<td>UFSC</td>
<td>Current water-supply catchment (Negrinho River)</td>
</tr>
<tr>
<td>14</td>
<td>W2</td>
<td>78</td>
<td>2008</td>
<td>UFSC</td>
<td>Future water-supply catchment (Bugres River)</td>
</tr>
</tbody>
</table>


5. PRELIMINARY SCIENTIFIC RESEARCHES

With the Thiessen method and the daily data obtained at 16 rainfall stations used by Lino et al. (2007), the present study estimated the mean daily rainfall for the large school catchments (Fragosos, Avencal, Rio Preto do Sul and Rio Negro) and applied the HYCYMODEL proposed by Fukushima (1988) (see Figure 6) to the daily rainfall-runoff processes occurred at these four catchments for the period of 1982 to 2000.

The values of the mean annual rainfall for the Fragosos, Avencal, Rio Preto do Sul and Rio Negro school catchments for the period 1982 - 2000 are 1780 mm/year, 1706 mm/year, 1698 mm/year and 1685 mm/year, respectively. The water balance obtained through the HYCYMODEL application to each school catchment is shown in Figure 7 where the annual rainfall is considered 100%. There is no significant effect of the
catchment scales on the water balance.

Figure 6. Flowchart of HYCYMODEL (Modified from Fukushima, 1988)

Figure 7. Water balance obtained from the HYCYMODEL application. \(Q_b = \) base flow; \(Q_d = \) direct runoff; \(E = \) real evapotranspiration; and \(dS = \) soil water storage.

Figure 8 demonstrates the relations of the runoff \(Q = Q_b + Q_d\) and the evapotranspiration \(E\) to the rainfall \(P\). The increasing rate of \(Q\) over \(P\) is larger than that of \(E\). The annual rainfall at which \(P = E\) is here defined as the critical rainfall index. This can be determined graphically as the intersection. The values of this index for the Fragosos, Avencal, Rio Preto do Sul and Rio Negro school catchments are 1964 mm/year, 1434
mm/year, 1811 mm/year and 1818 mm/year, respectively. The catchment scale’s effect on the critical rainfall index is not encountered, either (Figure 9). It seems that this value for the Avencal catchment is different from those of the other catchments, which can occur due to the fact that the rate of the reservoir’s area to the catchment area is relatively high in the Avencal catchment.

Figure 8. Relations of the total discharge $Q$ and the evapotranspiration $E$ to the rainfall $P$: (a) Fragosos; (b) Avencal; (c) Rio Preto do Sul; and (d) Rio Negro catchment.

Figure 9. Effect of catchment scale on the critical rainfall index.
Lino et al. (2007) analyzed the catchment-scale’s effect on sediment transport in the UNR basin and showed the negative correlation between the catchment scale and the specified suspended-sediment yield, which is commonly observed in many studies (for example, Dunne & Leopold, 1978).

6. EXTENSION ACTIVITIES

In 2006, the UFSC initiated the extension project “Learning hydrology for natural disaster prevention” in which several qualification hydrology courses for primary school teachers and technicians that work for the water and forest resources have been already carried out. By reporting some parts of the activities, Kobiyama et al. (2007, 2008) concluded that most of the local participants really wanted to attend more complementary hydrology courses that relate forest, water resources and natural disasters.

It is easily perceived that visiting school catchments allows a person to understand hydrology better. Construction and utilization of school catchments will elevate the quality of individual’s understanding of hydrology (Kobiyama et al., 2008).

7. FINAL CONSIDERATIONS

The present work described the SCN establishment in the UNR basin that is one of the headwater regions of the Iguaçu River basin. Pasquini & Depetris (2007) analyzed the discharge trends and periodicity of South American rivers, including the Iguaçu River. By using the monthly mean discharge data recorded at the Puerto Iguaçu gauge station, the authors showed that the Iguaçu River has the increasing tendency and the quasi-bidecadal periodicity. Though this study was carried out with the large catchment scale, this type of investigation will have to be done in the future with the SCN in order to find the local hydrological effects of climate change. Then this network will also contribute to the global climate change researches.

The main aims of the SCN are: (i) scientific activities to investigate the hydrological effects of land-uses, dam operation, and catchment scales; and (ii) environmental education activities in the UNR basin to elevate the individual’s knowledge on hydrology. Any results obtained with this SCN will possess persuasive powers to local communities, more than those with other catchments (especially foreign catchments). That is why the communities will place reliance on technical suggestions resulting from this SCN.

The final goal of the SCN is disaster reduction (Figure 10). The network
associated with scientific researches and environmental education would certainly serve as the instrument to increase an individual’s knowledge on hydrology which enhances his (or her) participation in the community discussion about water-related problems. Consequently, an enhanced participation of each member elevates the quality and quantity of the community action and creates the community-based management of headwater catchments. In other words, the natural disaster management becomes the participatory natural disaster management. The latter has more efficiency for disaster reduction than the former.

Figure 10. Contribution of school catchments network to disaster reduction.

Since there are few researches on the hydrological processes of the SOF and pine trees in Brazil, the present SCN will serve as a pilot undertaking and contribute to constructing the community-based management of water-forest resources for reducing the natural disasters in this region. ANA (2001) identified various problems in the La Plata River basin management and proposed some programs for solving them, among which there are (i) training courses execution and (ii) establishment and modernization of hydrological monitoring network. These two programs can be efficiently supported by the SCN implemented in the present study.

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9. REFERENCES


