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CALIBRATION AND VALIDATION OF THE HYDROLOGICAL MODEL SIMGRO WITH LANDSAT IMAGERY

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Abstract. Calibration and validation of spatial hydrological models is often hampered by the lack of independent field measurements. This paper describes the use of Landsat images to assess how accurate the SIMGRO hydrological model is in estimating the dynamics of surface water in the southwest of Buenos Aires province, Argentina. The evaluation is a necessary step before the model is adopted as a tool to assess what impact a shift in land use may cause in the water inflow to lakes in an area prone to flooding.

Keywords: remote sensing, Landsat image, hydrology, modeling, Buenos Aires province.

1. Introduction

Thirty years ago, the Encadenadas area in the southwest of Buenos Aires province was thriving with tourism and agriculture. Each year, hundred of visitors would go to Carhué and Villa Epecuén to enjoy their thermal waters. In more than 15,000 km^2, a stock of 1 million cattle used to graze and half a million ton of grains were yearly harvested (INDEC, 1974).

In the last 30 years rainfall has increased, particularly as short and intense events. On top of this, water management operations increased the amount of inflow to the Encadenadas. Since the mid 80s, the water level in the lakes has steadily risen. Nowadays, Villa Epecuén as well as 25,000 hectares of agricultural lands have been lost to flooding.

At present, proposed plans rely on engineering structures (William Halcrow & Partner Ltd., 1996). However, lack of funding and the long time span to build the structures suggest that no action may ever take place. Non structural measures are appealing because of their allegedly low cost, insignificant environment impact and short term response (Testa, 2001).

Hydrological models having the ability to capture the essential processes governing water flow on the land offer a methodology to assess the impact of management on the spatial response of a rural basin. As the strength of modeling is dealing with the complexity of the system, it is often an important tool for vulnerability and/or mitigation analyses.

SIMGRO (**Sim**ulation of **gro**undwater flow and surface water levels, Querner, 1997) is one hydrological model describing the state of surface and ground water variables in response to management and environmental factors. SIMGRO has already been tested in a rural basin of eastern Argentina against periodic field observations (Díaz, 2001). However, field data are seldom available, a serious constraint to a widespread application of a hydrological spatial model (Jones and Luyten, 1998).

Satellite images have several applications in spatial hydrology mainly in irrigation and evapotranspiration studies (D'Urso *et al*., 1992, Mauser and Schädlich, 1998). Recently, Jensen *et al*. (2000) calibrated one hydrological model in La Pampa province by comparing its results with the 1999 flooded area from Landsat images.

The objective of this study is to describe how Landsat imagery has been used in the calibration and validation of the SIMGRO model in order to overcome the lack of some of the required model parameters and of field independent observations to check its performance.

2. Material and methods

The Encadenadas water system is in the southwestern portion of Buenos Aires, Argentina. In 1,560,000 ha, where 17,000 inhabitants live, agriculture is the main economic activity. Temperature regime is temperate with a mild winter. Mean annual temperature is 13.8ºC. Mean annual rainfall is 770 mm, ranging from 321 mm in 1949 to 1,372 mm in 2001. Mean annual potential evapotranspiration is 901 mm. (FAO, 1985).

The Encadenadas lake system consists of five lakes sloping from east to west. Their water levels vary considerably between wet and dry periods. Its main discharge is by evaporation from the 50.000 hectares of open water. In 1985 the water level in the lowest situated lake raised by 4 meters flooding permanently Villa Epecuén. **Table 1** shows the changes to water inflows and outflows in contrasting dry and wet periods.

Table 1. Water balance of the Encadenadas lake system. All terms in $m^3\ y^{-1}$.

	Discharge from surface network[1]	Mean annual rainfall over lakes[2]	Discharge through new channel[2]	Evaporation from open water	Change in lake storage
1947-1970	$2.1*10^8$	$1.8*10^8$	0	$1.8*10^8$	0
1981-1993	$3.8*10^8$	$4.4*10^8$	$5.4*10^7$	$6.6*10^8$	$1.0*10^8$

[1] Van Eerden and Ledesma, 1994; [2] Herman and Rus, 2001.

Mean annual rainfall for the 1947-1970 period was 639 mm and 928 mm for 1981-1993. After 1970, catchment area increased by the construction of the Ameghino channel. The size of the lake system grew from 35,000 ha in 1981 to 60,000 ha in 1993. Management operations have been unsuccessful to restore lost hydrological balance. The challenge remains to permanently decrease the lake storage from $1.0*10^8\ m^3\ y^{-1}$ down to 0.

The study area is the catchment area of the Malleo Leufú river, south of lake del Monte (**Figure 1**). In the 36,000 ha of this watershed, the southern part empties through the mentioned river, while the northeast drains directly to the Encadenadas. Here small lagoons are formed in wet periods.

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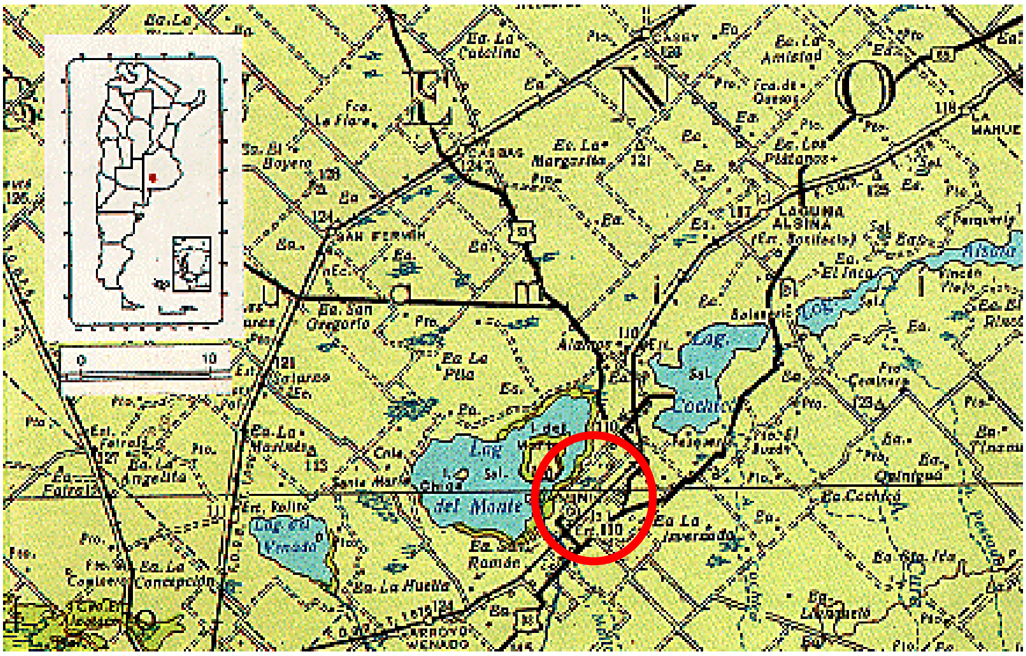

Figure 1. The Encadenadas lake system and location of the study area (in red circle).

The soil has two contrasting productivity levels: 1) low: cattle grazing (30% of the area) having flooding and salinity associated with, and 2) moderate productivity (70% of the soils) used for growing artificial pastures and grain crops. In a typical rotation, 4 years of pasture grazing will be followed by 3 years of cropping. Double cropping of winter and summer grain crops is tried whenever moisture conditions are favorable.

SIMGRO describes groundwater flow in a multi-layered aquifer system (Querner, 1997). In our study saturated groundwater flow was modelled by dividing the region into a network of 803 nodal points. A number of nodal points for the saturated groundwater flow represents a subregion. In 33 subregions, eight different land uses were accounted for. The number of soils is 5. The unsaturated zone is modelled per land use by means of two reservoirs, one for the root zone and one for the subsoil below. Actual evapotranspiration depends on the moisture content in the root zone. Groundwater level is calculated from the water balance of the subsoil. The groundwater calculations advanced in time steps of 1 day and the surface water of 0.1 day.

Monitoring of the flooding process was made with satellite images from LANDSAT TM5. Path-row used was 227086. Pixel size is 30 m^2. Images were composed of a combination of bands 4, 3, and 5, suitable for hydrological assessments. Map coordinates were assigned to image data using Military Geographic Institute maps (1:50.000) to georreference the images into Gauss Kruger projection system. From 1993 to 2000 almost every month an image was made resulting in a collection of almost 100. From these images two types of information were extracted:

1) The area of flooding was determined for the wettest and driest surface water conditions of the series.
2) The size of the lagoons from all available images in order to describe water level fluctuations.

Flooded area information was used to calibrate the model. A careful inspection of both rainfall historical data and Landsat images showed that from August 1993 to January 1994 both an extremely wet and dry period occurred. Therefore calibration period was from June 1991 to January 1994. Using ARCVIEW all the wet areas in an image were identified and polygons drawn around the edge of lakes and ponds. To filter out areas of transient intercepted water following a rain event, the program compares several consecutives pictures.

As subregions are also drawn as polygons, the flooded area was a fraction of the total subregion area. For the model, the percentage of inundated area can be estimated by considering the amount of inundated nodes per subregion. Nodes having a groundwater level higher than 0.05 m below ground level are considered flooded. A few uncertain model parameters were adjusted until a good fit was reached.

In the validation process, simulated lagoon levels were compared with the trend observed in Landsat images throughout the 1991-2000 series. Although validation and calibration period partially overlaps, no lagoon level estimates used in the former were used in the calibration process. By comparing level estimates on two consecutive dates, a general trend was defined as either higher, equal or lower whether the water level of one date increased, decreased or remained unchanged with respect to the previous date. A comparison was made for subregion 26 having three lagoons on eleven dates, from 1993 to 2000, for the change in water level with respect to the previous date.

3. Results and discussion

Model calibration is normal during any modeling task. Finding proper model parameters and combinations thereof allow the simulation to perform well as compared to a calibration target. Our requirement for model performance is an adequate representation of flooded areas and lagoon water levels. Although other criteria are valuable in assessing model performance, independent information is unavailable. Nevertheless, a proper matching in surface water representation does not ensure that the interior hydrologic processes are properly modeled (Beven, 1993).

In this study, calibration focused on quantitative estimates of inundated area. The goal is to match the flooded area per subregion as compared to the observed flooded area using Landsat. A comparison of the spatial distribution of flooded areas per subregion from Landsat image of August of 1993 and the corresponding estimates from SIMGRO model for November 1993 is presented in **Figure 2**. The November result was chosen because it was when a maximum number of nodes were estimated to be under water.

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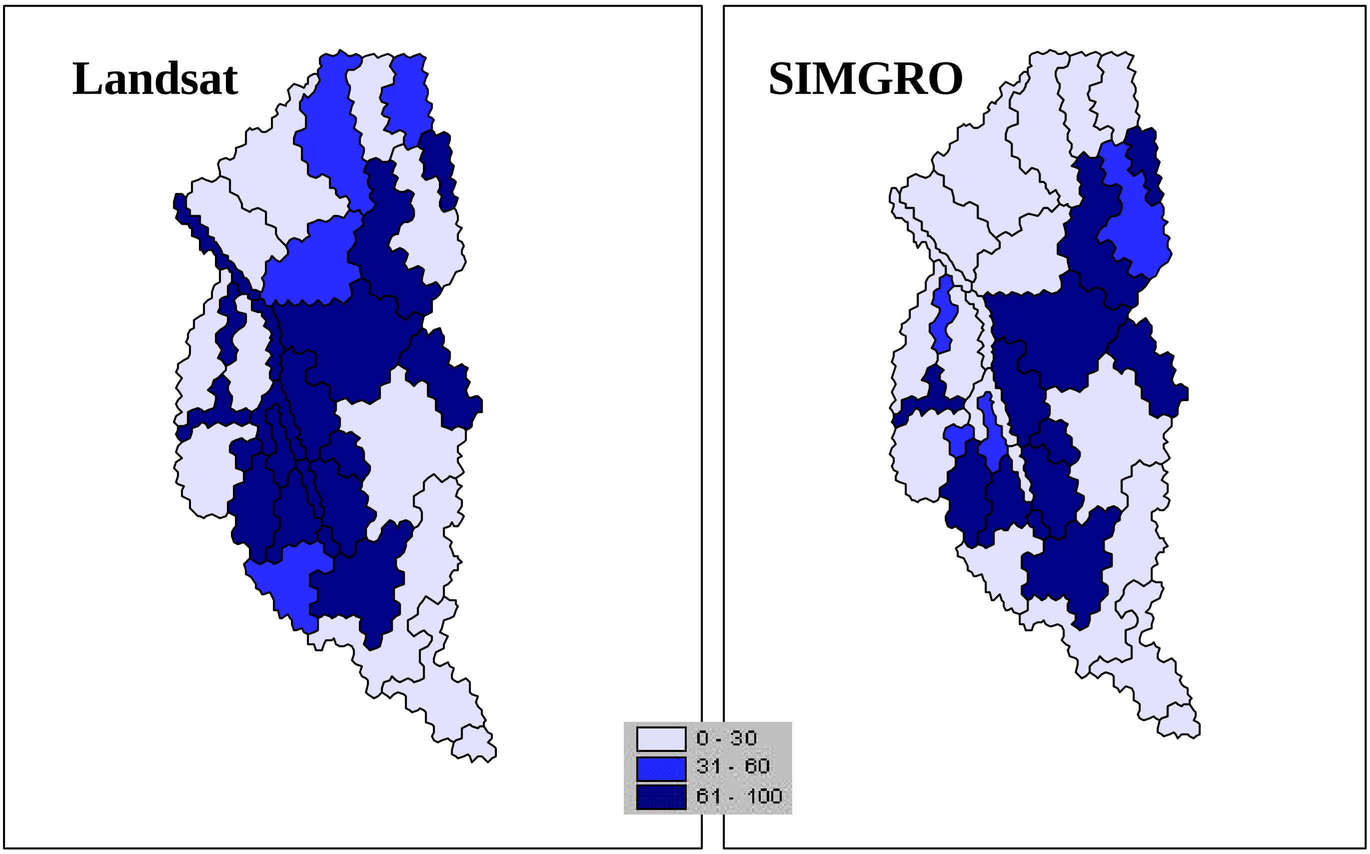

Figure 2. A comparison of Landsat observations and SIMGRO estimates of flooded areas (as % of subregion area) in the Malleo Leufú river basin.

The model estimated that 9,534 hectares were flooded while Landsat estimates amounted to 13,234 ha. Part of the disagreement could be explained by differences in the spatial resolution between methodologies. For Landsat, one pixel represents 30 m^2. For instance subregion 1 of 349 ha is represented by 116,294 pixels while SIMGRO uses 15 nodal points. A more detailed network for the model is possible but the necessary input information not being available precludes replacement of the chosen coarse resolution. In general the performance of SIMGRO was more than adequate. Model representation of wet areas (more than 60% of the total subregion area under water) is very good. SIMGRO underestimated the inundation in relative dry areas and in the subregions that represent the river. While the performance of the model is encouraging, still the timing of the wet episode is incorrect. There is uncertainty in several input data, because geohydrological information was unavailable. Estimates of transmissivity in water bearing layers is one example. Jensen *et al.* (2000) attributed to the quality of the input data the inaccuracies of the results of their MIKE-SHE model estimates of wet areas.

Validation looked among other results to the representation of lagoon levels. This was done because water levels are proportional to the area of the lagoons making a comparison between satellite information and simulation results possible. In the northeast of the Malleo Leufú basin several lagoons are present. According to satellite image analysis, the driest and wettest lagoon levels estimates for subregion 26 took place on september 2000 and august

1993, respectively **(Figure 3)**. The timing in which the size of the lagoons were at its minimum and maximum values was correctly estimated by SIMGRO.

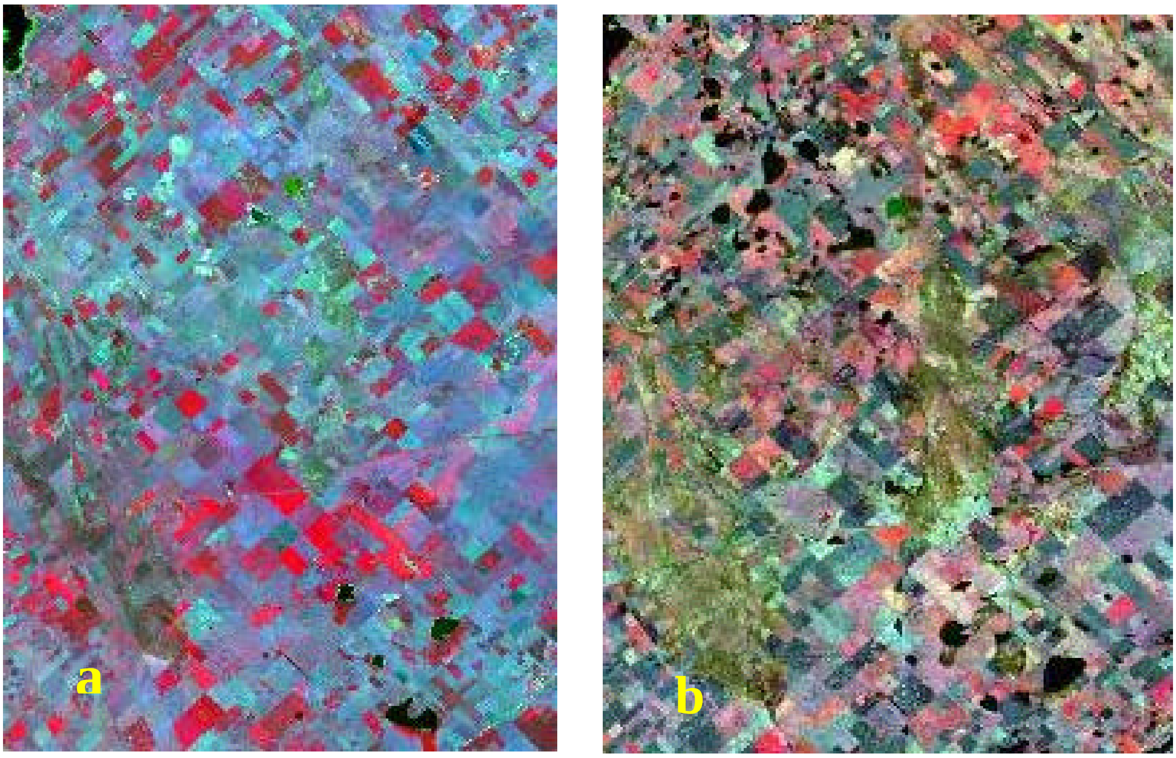

Figure 3. Landsat image including subregion 26 of the basin on: a) driest condition on January 2000 and b) wettest condition on August 1993.

It is important that SIMGRO estimates of maximum lagoon levels are reliable because they may provide an indication of the raising water tables in neighboring subregions. Furthermore, if modeled changes in lagoons levels are adequate some basis for a monitoring system and justification for measurements may be feasible. A comprehensive analysis of SIMGRO performance was made against twelve Landsat images representing the range in lagoon water size (**Table 2**).

Table 2. Trend of lagoon levels based on Landsat images as compared with the trend in estimated lagoon levels as shown in Figure 2.

Date	Trend in lagoon level from Landsat images	Trend in surface water level from SIMGRO
August 1993	Extremely high	---
October 1993	Lower	Lower
December 1996	Lower	Lower
September 1997	Equal	Higher
March 1998	Higher	Higher
May 1998	Higher	Higher
November 1998	Lower	Lower
January 1999	Lower	Lower
April 1999	Equal	Lower
October 1999	Equal	Equal
January 2000	Extremely low	Extremely low
September 2000	Higher	Higher

Of the eleven pairs, nine were in agreement. It can be concluded that the fit between simulated and observed lagoon levels was very good.

From the results presented the following future research should be directed towards the measurements of the properties of water bearing layers and the periodic observation of discharges in several sections of the Malleo-Leufú river.

4. Conclusions

To overcome a lack of time dependent spatial data of state hydrological variables and uncertainties in the input data, the study resorts in indirect ways to calibrate SIMGRO hydrological model by using Landsat imagery. Lagoon levels as related to lagoon size and the amount of flooded area derived from Landsat images were suitable substitutes. The size of flooded area per subregion, an hydrological subdivision of the basin, was well represented by the model as compared to Landsat information at a time the basin was extremely wet. However the nonflooded areas were underestimated by the model. Model estimates of lagoon water level for subregion 26 were adequate in following the dynamics of the water level from satellite information in 9 of 11 selected dates. The agreement covered a wide range of events throughout the 1990-2000 period.

In many situations the lack of detailed ground base information precludes the testing of spatial mathematical models. While field data should be our main concern in calibration and validation a model, an alternative rather “rough” substitute is to verify its performance with variables derived from Landsat satellite.

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