This paper was peer-reviewed for scientific content.
Pages 321-323. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). 2001. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Monitoring the Sediment Loading of Itaipu Lake and Modeling of Sheet and Rill Erosion Hazards in the Watershed of Parana River: An Outline of the Project

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ABSTRACT

The Itaipu hydroelectric project, the worlds largest, did not have a problem with sediment loading initially and was expected to have a life of +300 yr. Since, land-use change from forest to crops increased sediment to the lake. This change caused a reduction in quality of aquatic habitat, reduced capacity, and shortened the project life. To determine the extent of sedimentation and target areas producing sediment, a study began to monitor sediment flux, and model the watershed to determine those areas to concentrate conservation efforts. A methodology was developed which includes: 1) Monitoring major tributaries with a network of gauging stations and turbidity meters. 2). Measuring stage height and developing calibration curves relating height to discharge. 3). Measuring turbidity and calibrating to sediment load. These measurements will be digitally recorded and allow computation of water and sediment flux hourly to the lake. Modeling will use the Revised Universal Soil Loss Equation (RUSLE) in a Geographic Information System (GIS). RUSLE erosivity (R) will be collected from a network of climatic stations, erodibility maps (K) from existing data, topographic (LS) data from digital elevation models (DEM) and cropping and management (C and P) from remote sensing and field plots. These parameters will allow predicting erosion spatially in a GIS. Monitoring will be compared to predictions on smaller watersheds to calibrate the RUSLE/GIS model. The calibrated model will be used to develop erosion potential maps for the watershed. The impact of this project is a prediction of the effect that land-use change has had on the project life and areas can be targeted for conservation efforts to protect the project life.

INTRODUCTION

The Itaipu hydroelectric facility on the border of Brazil and Paraguay (Figure 1) is presently the largest in the world producing 12600 MW/yr. Its total watershed drainage area has 820,000 km^2, involving 5 Brazilian States and part of Paraguay (Figure 2). Sediment loading, at the time of construction of the power plant, was a minor problem and the project was expected to have a life span of some 300 years based on estimates of flow and sediment concentrations prior to construction. Since construction, significant land use change from forest to intense row crop production must have changed the amount of sediment entering the lake. This may have led to changes in the quality of the aquatic habitat and the storage capacity of the lake, thus altering the life of the project. In order to determine the extent of sediment loading and target areas within the drainage basin that produce the greatest sediment for conservation, a study was begun to monitor the sediment entry, and to model areas in the watershed to determine where the most sensitive areas are to concentrate conservation efforts. This paper presents an outline of the project, which could be applied to other large reservoirs.

Monitoring of the water and sediment fluxes of the major tributaries will be accomplished with a network of gauging stations and turbidity meters. Calibration curves for relating stage height to discharge will be developed for each station and the height digitally recorded. The turbidity measurements will also be calibrated to sediment concentration and digitally recorded. These measurements will allow for computation of water and sediment flux on an hourly scale into the lake.

The modeling will be performed with the Revised Universal Soil Loss Equation (RUSLE) in a Geographic Information System (GIS) framework. The model considers only sheet a rill erosion and does not include potential for gullying. Rainfall erosivity (R) data will be collected from a network of climatic stations, erodibility maps (K) from the SOTERLAC database, topographic (LS) data from

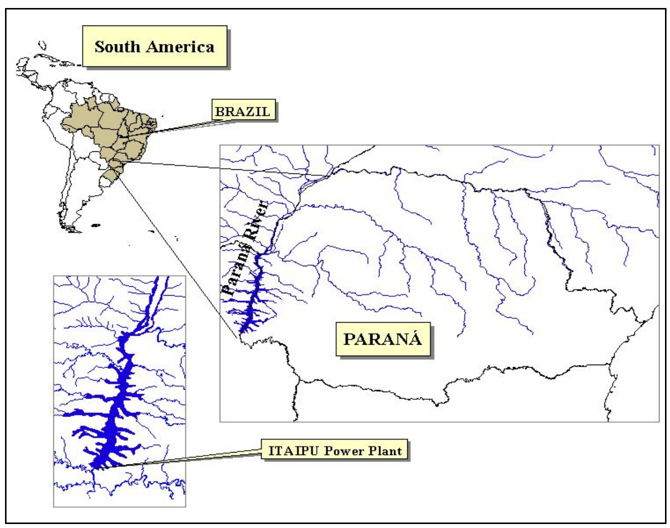

Figure 1. The location of Itaipu Power Plant and the Parana River.

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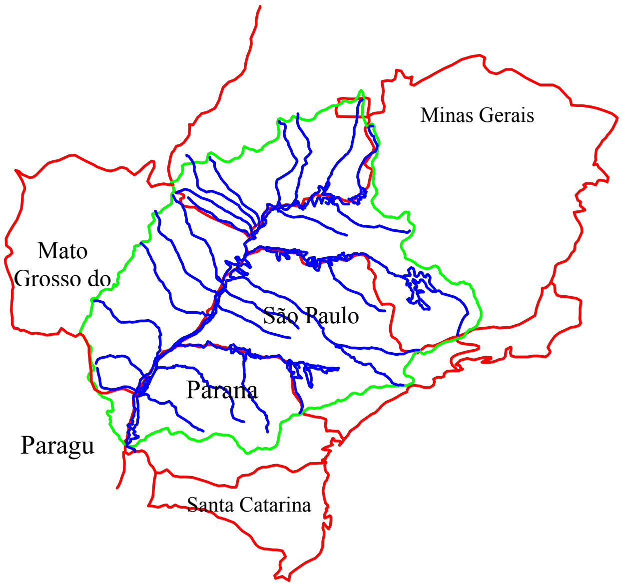

Figure 2. The drainage basin of Itaipu lake.

digital elevation models and cropping and management (C and P) data from remote sensing and field plot data. These parameters will allow predictions of soil loss potential within the framework of the GIS. The monitoring data will be compared to data from the modeling on successively smaller watersheds in order to calibrate the RUSLE/GIS model. The calibrated model will then be used to develop sheet and rill erosion potential maps for the entire Itaipu watershed above the lake.

The impact of this project is to make predictions on the effect land use change has had on the projected life of the dam and to target those areas of the watershed for conservation efforts to protect the longevity of the lake. It will also assist in maintaining the ecology of the lake while reducing the present sediment loading. The project will involve two efforts: 1) Monitoring of the present sediment loading into the lake using modern techniques, and 2) Modeling of the entire watershed using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework to target those areas of the watershed that are producing the most sediment for erosion control. The first part of the project can be conducted at different levels of intensity to provide increasing accuracy of the sediment loading. The second part of the project is needed at all levels of monitoring intensity in order to identify areas that at present produce most of the sediment loading to the facility. The duration of the project will be 5 years with the potential to be extended depending on the results of this study. The results of the project will be a quantitative assessment of the amount of sediment entering the lake under present conditions and a map of the sheet and rill erosion potential within the watershed of the hydroelectric facility.

MATERIAL AND METHODS

Monitoring. The monitoring of sediment flux into the lake will be conducted at gauging stations using small digital stage height recorders. These recorders will take hourly readings of stage height at a fixed cross section of the tributaries entering the lake. The stage height recorders are capable of storing 9 months worth of hourly readings, which can then be downloaded to a portable computer. The stage height will be calibrated to discharge at each sampling point by taking a sonar scan of the stream cross sectional area and relating the stage height to flow velocity measured with an anemometer. The position of the sonar recording of flow depth will be taken using a Global Positioning System (GPS). Periodically the cross sectional area will be checked for changes in stream bed morphology and calibration curves will be changed to reflect those changes. These calibration curves will then be used to convert the recorded stage height to discharge passing the recording station. At the same time, a turbidity reading will also be made using portable turbidity meters. Likewise, these turbidity meters will be calibrated against gravimetric sediment concentration to compute the suspended sediment discharge passing the recording station. These data together will allow for a computation of the water and sediment fluxes into the lake that is entering in the gauged tributary.

The digital recorders are small and nearly non-detectable. They will be placed at strategic points and the number will depend of the level of intensity of monitoring. The placement of the recorders will be in locations where they may be hidden but will be easily accessible, such as bridges, so that the data can be easily downloaded to a personal portable computer.

Modeling. The entire watershed will be modeled to determine which areas are capable of producing the most sediment given the combination of topography, rainfall erosivity, soils and land use. This will be accomplished using the Revised Universal Soil Loss Equation (RUSLE, Renard et al., 1997), which is presently being used to administer billions of US dollars in farm program funds by the U.S. Department of Agriculture in the USA. The data needed to run the model will be obtained using a variety of spatial information in the form of a Geographic Information System (GIS).

The RUSLE uses an empirical approach to compute the long-term average annual soil loss due to sheet and rill erosion from a given area. It has the form of A=RKLSCP, where, **A** is the long-term average annual soil loss, **R** is the rainfall erosivity, **K** is the soils natural ability to erode, **LS** the length and gradient of the slope of an area to be modeled, and **C** and **P** are the soil loss reduction factors for cropping and management practices, respectively.

The rainfall erosivity (R) for the area will be determined from published data and data from the Brazilian National Meteorological Center in Brazilia and SIMEPAR from Parana using the procedures of Lombardi (1977) and Rufino et al., (1993). This data will be used to create a rainfall erosivity map for the Itaipu drainage area. The K factor will be taken for the study area from the International SOTERLAC soil maps (Cochrane et al., 1994; Graef and Stahr, 1998) available for the entire watershed (Fig. 3) and published data from Institute of Agronomy of Parana (IAPAR). The LS factors will be computed from a digital elevation models (DEM) database that is available for the entire area (Figure 4) with a fixed cell size (L) of 800 meters. This cell size will be the limiting resolution for the GIS modeling with RUSLE. However, given the very large size of the watershed, this cell

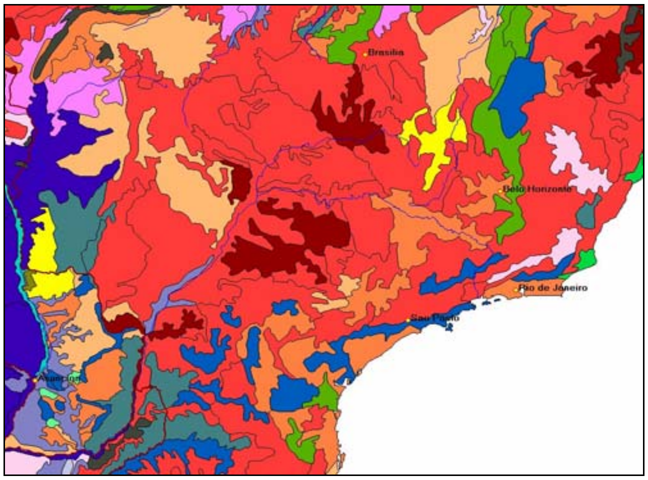

Figure 3. SOTERLAC soil map from the drainage areea

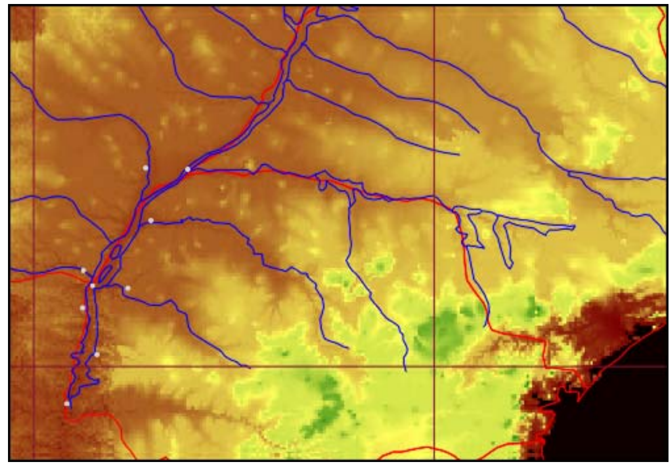

Figure 4. DEM map showing the sites to be monitored.

size is reasonable. Using a smaller cell size would make the modeling effort more unmanageable. The slope (S) of the cell will be determined based on a nearest neighbor search to determine maximum slope.

One of the main factors affecting soil loss in addition to topography, rainfall and erosivity is the different types of land use for an area this large. The only practical way to determine the land use for the entire watershed is through remote sensing satellite data. The land use effect on erosion is incorporated as the C and P factors of the RUSLE and will be determined from automatic classification of land use with Landsat 6 TM imagery (Graef and Stahr, 1998). For example, no-tillage is a very effective management tool to control erosion in Parana (Derpsch et al., 1988), which can easily be detected with Landsat 6 TM. There are a number of Landsat 6 TM photos available for the study area that can be used for land use classification. After determination of the land use and entering the data in the ARCINFO GIS, all of the factors needed to compute the long-term average annual soil loss will be available to make a RUSLE prediction for each ½ km area within the drainage area. This system will be used to generate maps showing the amount of erosion potential for each cell based on the RUSLE prediction.

Points to be considered:

Historical data will be analyzed and compared with data generated by the project to make the appropriate correlations;

- Monitoring will be done preferentially from the bridges where the devices will be located, and the turbulence will allow average readings for the suspended sediment of the channel. Readings will be done every hour therefore, gathering 24 daily readings;
- RUSLE will be calibrated with data generated in Brazil, mainly from the States near the watershed of the Parana river;
- Bedload will also be evaluated to complement the results obtained from the monitored tributaries;
- Identification of the areas with greatest amount of sediment production and land use change simulation to decrease sediment load will be the basis for soil conservation programs in the watershed, which in turn, will affect sediment entering the lake;
- The identification of areas with the greatest sediment production will subsidize the decision making process involving the development of conservation actions on a municipal level.

The sites chosen for monitoring (Figure 4) are: Parana River (near the hydroelectric facility), Sao Francisco Falso (Santa Helena), Iguatemi River (station), Carapa River (Paraguay), Piquiri River (bridge), Ivai river (bridge), Guaira (bridge), Ivinhema river (bridge) and Paranapanema river (Porto Primavera).

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