APPLICATIONS OF GIS AND REMOTE SENSING IN THE HYDROLOGICAL STUDY OF THE UPPER BERNAM RIVER BASIN, MALAYSIA

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ABSTRACT

Rising concern over the degradation of the environment, such as erosion and sediment loads, warrants the integration of the complex and dispersed geographical data sets. This paper describes the use of Geographic Information System (GIS) and remote sensing for assessing the impact of land use changes to water turbidity in multiple watersheds. In this study, necessary data sets representing land uses, hydrology, weather, soils, elevation, and surface characteristics were integrated in a GIS in tabular, vector and grid formats. The land use maps that were derived from Landsat-5 TM imagery using a combination of different classification strategies gave an average accuracy of 95 %. Results from data analysis had shown that there exists a close relationship existed between the extent of open area and sedimentation loading rate. However, the sediment loading rates were found to be non-linear ranging from 1.47 to 2.13 tonnes per millimeter of rainfall for each kilometer-square increase of open areas, depending on their location of open areas with respect to factors such as availability of sediment, soil type, slope length, and slope steepness etc.

Keywords: *GIS, Remote Sensing, River Basin, Sediment Load, Sedimentation*

1. INTRODUCTION

In recent years, Malaysia has undergone very rapid development with subsequent population growth, urbanisation, industrialisation, logging activities, and expansion of agricultural areas. These changes have caused complex environmental problems and the most affected natural resources is water. Inherent in the solution to the above problem and many environmental problems is the need to bring together dispersed geographical data sets. The complexity and size of these databases make the requirement for application of Geographical Information System (GIS) and remote sensing technology all the more necessary. By bringing key data and analytical components together under a GIS environment, the problems of lack of integration, limited coordination, and time-intensive execution typical of the more traditional assessment tools faced by most users can be overcome.

Rising concern over the degradation of the environment, such as erosion and sediment loads on water ways, justifies the use of remote sensing data as input in a GIS environment. The objective is to simulate the impact of land use changes to particularly water turbidity in multiple watersheds. To achieve the above objective, the Landsat TM images were used to obtain the land use information, and ArcView GIS was used to manage all the necessary data as well as for further analysis.

2. REVIEWS

Remote sensing data has been applied in hydrologic modeling with elements of GIS. Many hydrologically significant parameters can be obtained through remote sensing, including land covers, vegetation properties, thermal and moisture indices. The information obtained from remote sensing allows the determination of parameters for distributed models with an extremely high resolution in space [1]. One of the advantages of satellite remote sensing is that it inherently 2 provides spatial averaging of certain land cover variables that are needed by hydrologic models [2]. GIS is more and more used in hydrology and very valuable for areal representation of relevant parameters and variables. The combination of remote sensing with other GIS data, e.g. digital elevation models (DEMs), digitised maps, weather data becomes a powerful tool for the hydrological modeling. Comprehensive reviews about the utilisation of remote sensing in the partial area hydrology, parameterisation and distributed modeling are found in Van De Griend and Emgman, Schultz, Stewart and Finch, Blyth, and Rango [3, 4, 5, 6, 7].

GIS applications are becoming popular in the application of hydrologic modeling for parameter estimation and watershed partition. Data overlays were used in estimating the selected model parameters such as vegetation type and density, soil physical properties Shih [8] used GIS and Landsat data for land use classification and found that GIS is a very useful tool for land cover classification of Landsat data, moreover the cost and time requirement are much less than the conventional methods. Sasowsky and Gardner [9] used the GIS technique to produce various watershed configurations by progressive simplification of a stream network delineated from DEMs and to obtain model

Table 1: Background of the river basin

Name of study area	Upper Bernam Basin (UBB)
Catchment area	1090 km^2 upstream of SKC Bridge monitoring station
Longitude/latitude	3^{0}36' to 4^{0}08'N and 101^{0}19' to 101^{0}40'E
Main tributaries	Behrang River, Inki River, Trolak River, and Slim River
Discharge and river stage stations	3813411 –Bernam River at SKC Bridge 3615412 –Bernam River at Tanjung Malim
Suspended sediment	3813511 –Bernam River at SKC Bridge 3615512 –Bernam River at Tanjung Malim
Climatological stations	3615003 – Pekan Tanjung Malim 3714152 – Ladang Ketoyang, Tanjung Malim 3813158 – Ladang Trolak, Trolak 3057"N 101022"E – Felda Trolak Utara 3046"N 101031"E – Haiwan Behrang Ulu

parameters for the hydrologic SPUR model. Jenton and Smith [10] described the technique developed using vector and raster data in GIS to define the spatial variability of watershed characteristics and found that the method is efficient in characterising a watershed and delineation of hydrologic response units (HRU). Schultz [11] used Landsat TM data and DEMs within the framework of GIS for meso-scale runoff model parameter estimation and found that these technologies are the best for the intended purposes without losing accuracy. Sefton and Boorman [12] used a GIS to satisfactorily store land cover classes, soils information and climate descriptors from national available maps and datasets to abstract catchment attributes as physical catchment descriptors (PCDs) based on stream network.

3. GROUND COVER CLASSIFICATION

The overall objective of image classification procedures is to systematically categorise all pixels in an image into land cover classes. Pattern recognition techniques to classify ground cover characteristics through remotely sensed data have been used in many hydrologic modeling studies [1, 2, 11, 13, 14, and 15]. Multi-spectral are used to perform the classification, and indeed, the spectral pattern within the data for each pixel is used as the numerical basis for categorisation. Spectral pattern recognition classification is the process of sorting pixels into a finite number of individual classes. If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to that criteria. Multi-spectral classification can be performed by supervised or unsupervised method based on multivariate statistical criteria. This procedure assumes that imagery of a specific area is collected in multiple regions of the electromagnetic spectrum (e.g. seven bands of TM data) and that the images are in good registration [16].

In the supervised classification, the identity and location on some of the cover types of interest are assumed to be known a priori, from aerial photos, field work, or experience. These known cover types are then identified as a small subset (or training site) of large TM scenes that are used to "train" the classification algorithm for eventual land cover classification of the remainder of the image. Multivariate statistical parameters (mean, standard deviation, covariance matrices and correlation matrices) are calculated for each training site. Every pixel outside these training sites is then evaluated and compared to assign a particular class of which it has the highest likelihood of being a member.

Unsupervised training is also called clustering, because it is based on the natural grouping of pixel in image data when they are plotted in feature space. In an unsupervised classification, the identities of cover types to be assigned as classes within a scene are not generally known a priori because appropriate ground truth is either lacking or surface features within that scene are not well defined. Numerical operations are performed to group (cluster) unlabelled pixel data within the data set into different spectrally homogeneous classes based on some statistically determined similarity criterion, as examined in multi-spectral vector space [17].

4. DESCRIPTION OF THE STUDY AREA

The Upper Bernam Basin (UBB) had been selected for this study. It had been identified as the ultimate and largest source of water supply for the Bernam Valley especially for irrigation. The river basin covers an area of 1090 km^2 with SKC Bridge river monitoring station as the downstream outlet. The SKC Bridge monitoring station is 17 km upstream of Bernam River Headwork (BRH) and 147 km upstream of the estuary of the Bernam River. A brief description of the river basin is summarised in Table 1. Figure 1 shows the locality of the study area.

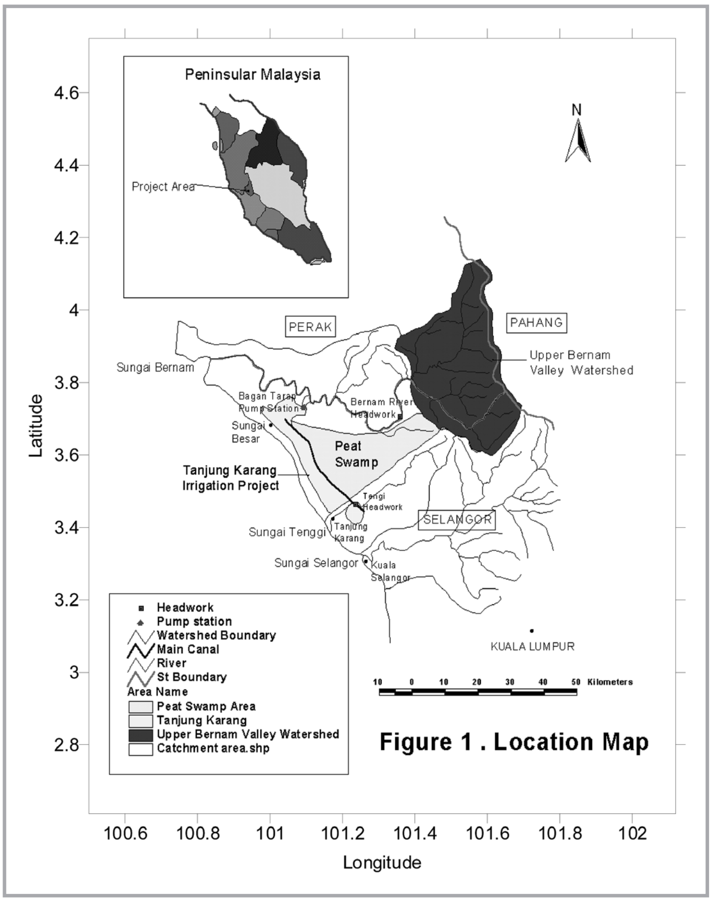


Figure 1: Location of the study area - Upper Bernam River Basin, Perak, Malaysia

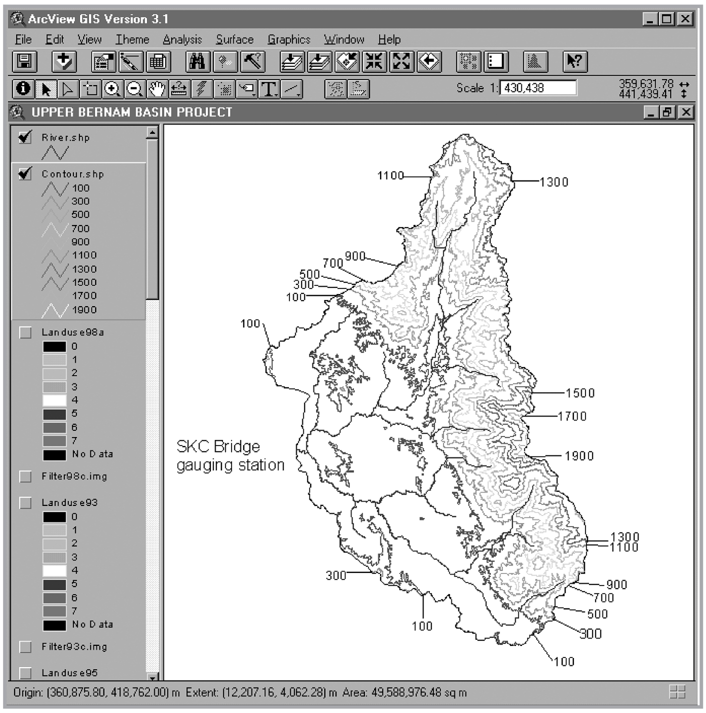
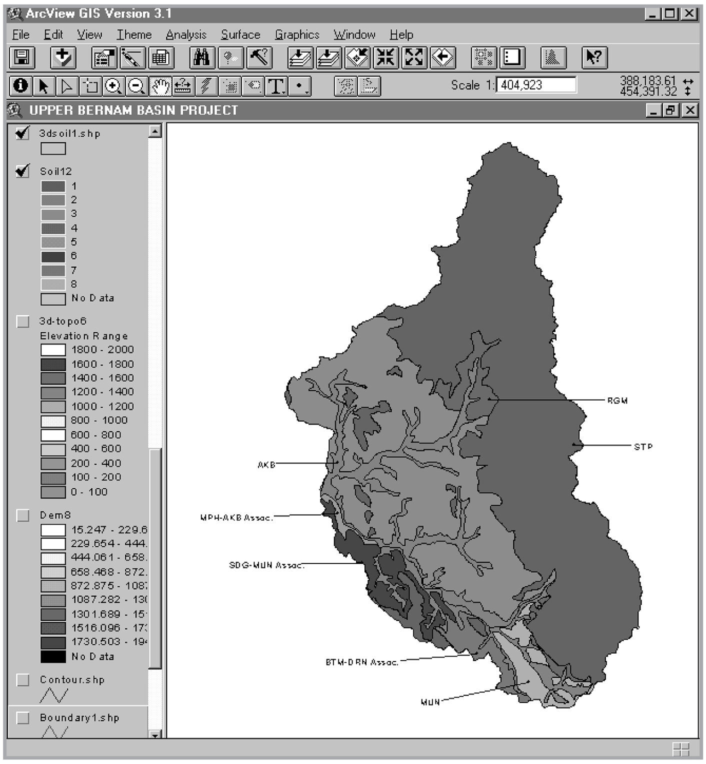


Figure 2: Watershed boundary and topographic relief of the Upper Bernam Basin



Note: 1. Akob series, 2. Batu Anam-Durian association, 3. Merbau Patah-Akob association, 4. Munchong, 5. Rengam, 6. Serdang, 7. Serdang-Munchong association, 8. Low land

Figure 3: Grid map representing soil types of Upper Bernam River Basin

5. METHODOLOGY

Data required for this project were the topographic, land use, soil, climatic and hydrologic of the specific basin as shown in Table 2 together with their sources. The data collected was processed to obtain the information needed for watershed modelling, including digitising and delineating of the project area, land use classification, numerical data (hydrological and meteorological data) processing and management, etc. These data were then used for further analysis to achieve the influence of land use changes to river basin.

Table 2: Data required and its sources

Sources	Types of data
Survey and Mapping Department of Malaysia	Topographic maps
Malaysia Center for Remote Sensing (MACRES)	Satellite image
Agricultural Department, Malaysia	Landuse map
Malaysian Meteorological Services	Meteorological data
Department of Irrigation and Drainage (DID), Malaysia	Hydrological data

6. GIS AND REMOTE SENSING APPLICATION

The topographic and soil maps (scale 1:50000) were used to produce all the digital thematic layers, grid themes, digital elevation model (DEM), etc, to provide physiological and geographical information. Based on the information, the study area was delineated as shown in Figure 2, where it can be seen that the Upper Bernam river basin has diverse relief. About 80% of the basin is steep mountainous region rising to a height of 1830 m in the northern and eastern direction. The remaining area at the central and downstream part is hilly land with swamps.

The soil information for the study area was digitized as shown in Figure 3. Generally, eight (8) types of soil had been identified in the study area. At the upper main range, which consists of steep land, perennial granite predominantly coarse-grained mega crystic granite is found. In the upper reach area, the soils consist mainly of Rengam and Munchong-Seremban series. These sedimentation soils contain generally fine to coarse quartz sand set in a clay matrix. The lower areas consist of Serdang series, which is more sandy and thicker. Local Alluvium-Colluvium and soils derived from riverine alluvium such as Akob and Merbau Patah series also can be found along the river bed. Most of the soils mentioned above are well drained. Textural classes mostly lie between loam to clay with moderate to average soil moisture holding capacity.

Landsat TM Imageries for the year of 1993, 1995 and 1998 were enhanced to remove atmospheric effects such as cloud, haze and noise that appear in each image. The enhanced images were then used to derive the land use map of the Upper Bernam Basin area using a combination of different classification strategies as shown in the schematic diagram in Figure 4.

A sample of the land use grid layers derived from supervised classification is shown in Figure 5. It had seven (7) broad classes of land cover that were: Bare land, Forest, Oil palm, Rubber, Scrub, Urban, and Water body. Accuracy assessment is used to compare and verify certain pixels in the classified maps with previously tested maps, such as land use maps, topographic maps, aerial photographs, and confirmed land use obtained from field observations. In order to assess the classification accuracy, 250 points were generated randomly throughout each image using the Add Random Point utility available in Erdas Imagine Software. A confirmed land use (class value) was then entered for each of these points, which would be the reference points used to compare to the class values of the classified image.

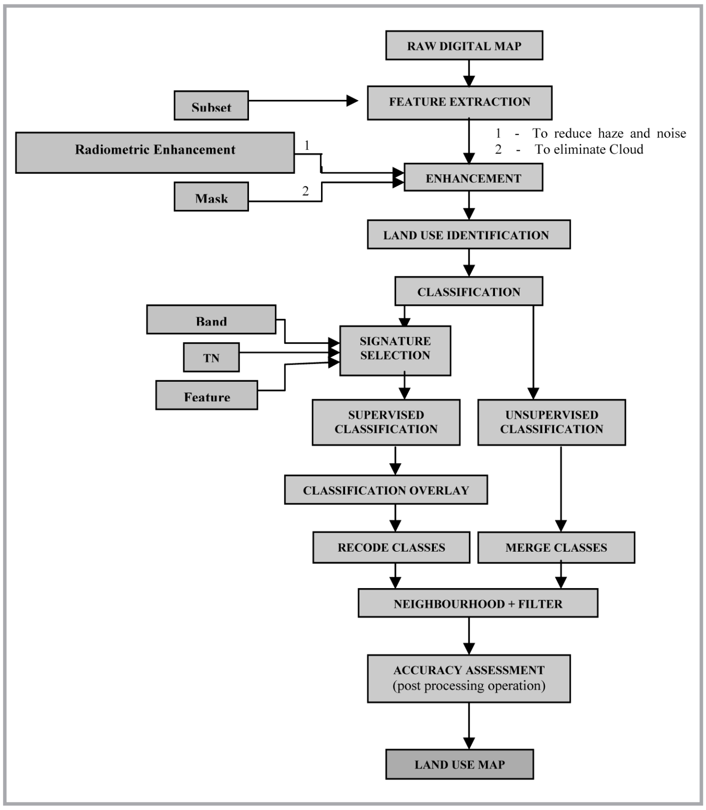
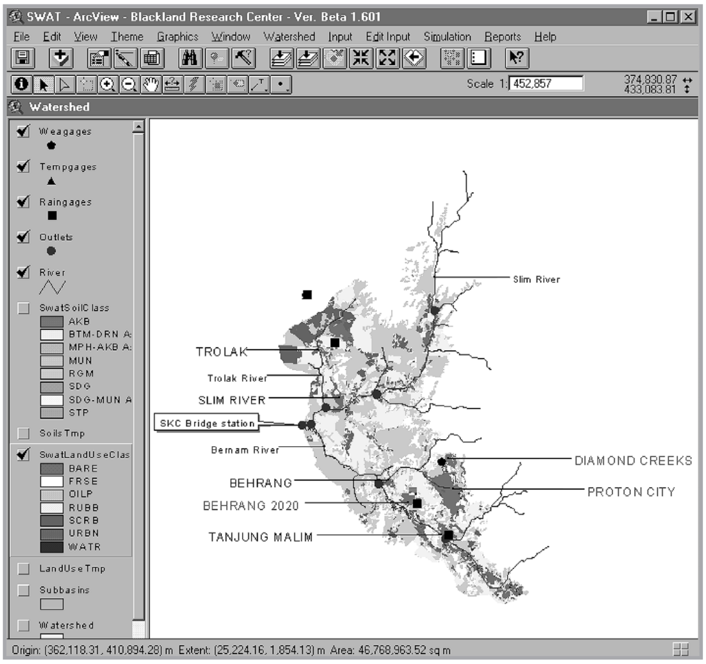


Figure 4: Sequence of Landsat TM image processing



Note: BARE-Bare land, FRSE-Forest, OILP-Oil palm, RUBB-Rubber, SCRB-Scrub, URBN-Urban, WATR-Water body

Figure 5: Classified land use grid map derived from Landsat TM imagery (date: 28/1/1998)

As a result, an overall accuracy of 95% has been generated by the software.

By comparing the classified imageries, information on land use for the entire period of study was obtained as shown in Table 3. Major development and urbanisation had occurred from 1993 to 1998 in the study area with the launching of several mega projects such as the Diamond Creeks, Behrang 2020 and Proton Mega City. As such, the bare land area increased almost twice from 20.73 km^2 to 38.61 km^2; the urban area increased 266.84% from 3.92km^2 to 14.38km^2. The coverage of oil palm plantations also experienced a rapid increment of 295% in the period of study. Whereas the areas of rubber, scrub, forest, and water body were decreased for the above purposes.

7. HYDROLOGICAL ANALYSIS

Daily time step hydrological and meteorologicaldata from several river monitoring stations and weather stations (see Figure 6) was obtained for this study, as most of the data was not in correct or readable format required by the GIS interface, the data had been sorted and transformed into organised GIS database tables for further analysis and modeling purposes.

Figure 7 shows the relationship between discharge and sediment load for the years derived from the available data. Generally, steeper curve slope means that sedimentation rate increases more rapidly resulting from higher erosion risk. Among the three years (as in Table 3) with classified open area information, greater severity of erosion and sedimentation occurred in 1998, as compared to 1995 due to larger open areas. It is clear that close relationship exists between the extent of open area and sediment load. The sediment load of 1999 is included for comparison that has seen a sharp decrease of sedimentation. However, the study focuses on the scope of open areas for 1993, 1995 and 1998.

The curve for the year 1993 shows that high sedimentation occurred in that year. This sediment load was due to the extensive land developments happened in the area such as the Proton Mega City project in which the earth works started in 1993.

Table 3: Land use changes derived from Landsat TM imagery

Land Cover	1993		1995		1998	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Bare	20.73	1.90	18.77	1.72	38.61	3.55
Urban	3.92	0.36	13.77	1.26	14.38	1.32
Oil Palm	63.72	5.85	89.61	8.23	251.71	23.12
Rubber	212.48	19.51	209.57	19.24	152.46	14.00
Scrub	182.90	16.79	157.72	14.48	36.66	3.37
Forest	603.10	55.39	597.75	54.88	593.90	54.55
Water Body	2.06	0.19	2.05	0.19	1.16	22.49

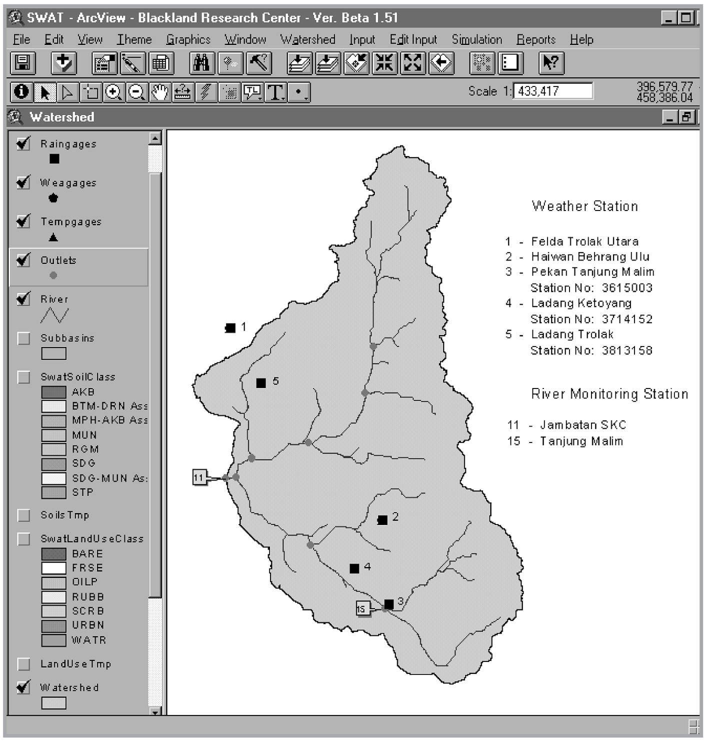


Figure 6: Weather and river monitoring stations available in Upper Bernam River Basin

Using the sediment data taken from the S.K.C. Bridge station and daily rainfall data from five gauging stations located in the study area, the impact of open areas to sediment load was calculated as shown in Table 4. It can be seen that from year 1993 to 1995, for each square kilometer decreased in open areas, the sedimentation rate decreased by 1.40 tonnes/mm rainfall, whereas from year 1995 to 1998, it increased by 0.43 tonnes/mm rainfall for each square kilometer increased in open areas. These figures further show that there is a relationship between sediment and open areas. But it is not linear over the years. In this case, some other factors such as locations of the open area with respect to river, soil type, slope length, and slope steepness must also be considered.

8. CONCLUSIONS

In order to assess the classification accuracy, 250 points were generated randomly throughout each image using the Add Random Point utility. A class value was then entered for each of these points, which would be the reference points used to compare to the class values of the classified image. From this study, land use maps with an average accuracy of 95% had been derived from the Landsat TM image classification. Necessary digital maps had been overlaid against each other successfully and all the necessary data were well managed under a GIS environment. Results from the data analysis had shown that there is a non-linear relationship between open areas and sedimentation loading rate.

More work is still needed to refine the relationship between land use, rainfall runoff, predicted erosion rate and simulated discharge and sediment data. From the initial results obtained, this study had shown that remote sensing and GIS are very useful tools in hydrologic modeling of watersheds.

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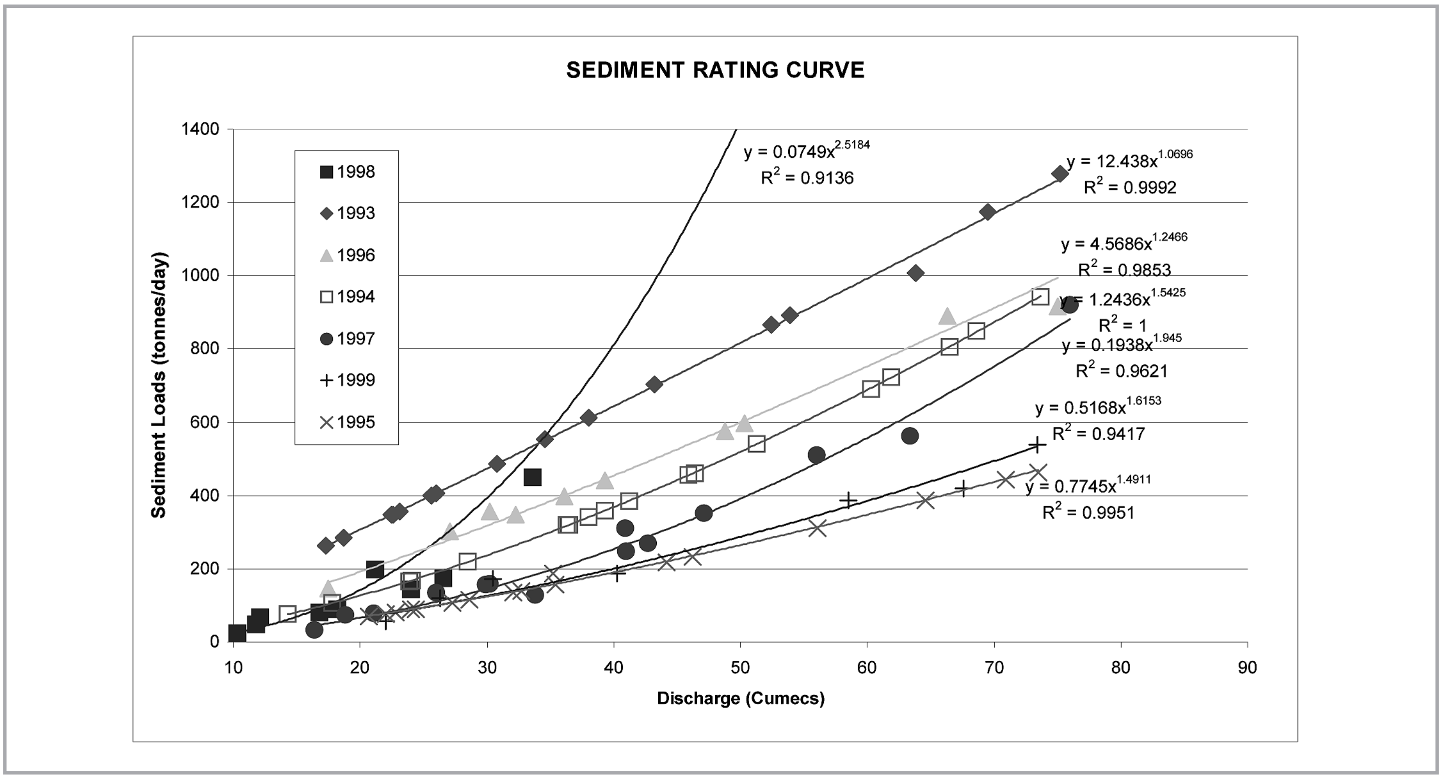

Figure 7: Sediment Load in tonnes per day for various discharge rates by year from 1993-1999

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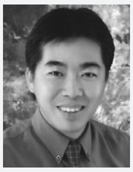

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