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The Application of Quantitative Assessment of Land Use Changes Impact on Water Conservation for Reservoir Watershed

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Abstract. The recent increased pressure on slope land development in Taiwan has changed the land use pattern in many reservoir watershed areas and affected the hydrologic cycle. There were many local researches examined this related issue, but none of that can fully describe the relationship between water conservation capacity and land use patterns in watershed area. This study is to integrate and analyze the impact to water conservation from deforestation or other land use pattern changes. In this study, an integrated methodology combining Geographic Information Systems (GIS), Remote Sensing (RS), Global Positioning System (GPS), and hydrologic simulation program (HSPF) is utilized to define the factor-consequence relationship of this issue from digital database, satellite images, land use pattern identification, and hydrology model, in respectively. The first part of this research was to determine those factors influenced the hydrological processes, which includes water balance parameters extraction for various input data in hydrological model. Secondly, an environmentally sound database was built using GIS, RS and GPS technologies. Then HSPF hydrologic model was used to estimate the quantity of water conservation capacity. The last part was to link the database with water conservation model and estimate the changes due to land use development. This research also use ArcView Avenue Script and C++ to establish an user interface, that provides users to input data and output the results. It can get the volume change of water conservation capacity caused by land use change real time. It provides watershed manager the reference in reservoirs watershed area conservation and development policy.

1. Introduction

The yearly average precipitation in Taiwan area is about 2510mm, which is 2.6 timed over the world average value. But due to the abundant of mountain area, vulnerable geological structure, steep topography, short and

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rush river flow, and inconsistent precipitation, the difficult in water storage and resources allocation reveals the importance of water conservation.

In recent years, the remarkable industrial business and economics development in Taiwan have enhanced the urgent demand for water resources. The recent increased pressure on slope land development has changed the land use pattern in many reservoir watershed areas and affected the hydrologic cycle. Although there were many local researches examined this related issue, but none of that can fully describe the relationship between water conservation and land use patterns in watershed area.

In this research, Geographic Information Systems (GIS) were adopted to build a digital database for reservoir area and to process hydrologic analysis. Remote Sensing (RS) and Global Positioning System (GPS) were performed to extract the surface vegetation details and land use changes information. The final goal of this study is through the assist of hydrologic model for water conservation capacity estimation; the outcome can provide an important reference for watershed management. This study is also built a GUI, integrate with GIS spatial analysis, database and models. It makes the hydro model easier to be used and solve the problem of data transmittal.

2. Study Area

The study area for model application is Dar-Pu reservoir watershed with 10,000 hectare in area, which locates at the upper stream of E-Mei River with discharges through the north western of Taiwan. The original construction purpose for this reservoir was to provide irrigation supply for neighborhood irrigation association at county level.

Figure 1. The Study Area - DaPu Reservoir Watershed Location Map

3. Methods and Results

3.1. Hydrologic Factors (Parameters) Analysis

Most hydrological modeling for quantitative aspects of the water cycle (Figure 2.) is done using point information and aerial information as various input data and parameters. (PORTMANN, 1997)

From previous research output, those factors affect water conservation capacity of reservoir watershed in Taiwan can be identified, which include the vegetation factors, topographic factor, soil factor, hydrometerological factor...etc. In this study, some general variables and data are used as shown in Table 1.

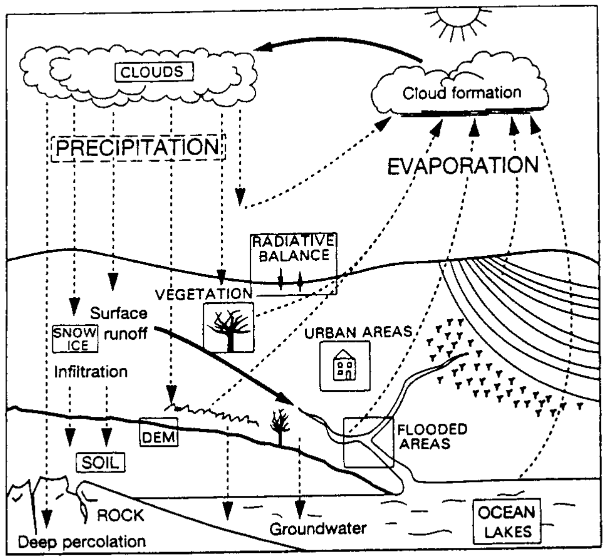

Figure 2. The hydrological cycle. (Based on WMO, 1994, altered by PORTMANN, 1997)

Table1. Data requirements for water conversation capacity estimation

Factor	Data requirements
Vegetation	Land cover/use (forest type and density)
Topography	Slope/aspect, elevation
Soil	Soil moisture content, antecedent moisture content, soil profile
Hydrometerology	Precipitation , water level and discharge volume at gauging stations

3.2 GIS and RS Application

3.2.1 Environmental Database Establishment for Watershed Area. All parameters for hydrological model, include vegetation, topography, land cover/use, slope/aspect, elevation and gauge stations distributing map... etc., can be built into a physical Environment database by the assist of GIS and RS techniques (Teng et al,1995; Ho et al.,1995; Cheng et al, 1994; Nageshwr et al,1992; Mark et al,1992; Muzik,1996). This physical environmental database includes basic data such as geographical features, geological characteristics, hydrological information, and land use/cover information. Among those data set, the geology, Digital Elevation Model (DEM) data, forest stands polygons and land use information were available in digital format. These data were transformed into Transverse Mercator two-degree projection, which is the coordination system currently used in Taiwan.

3.2.2 Land Use Changes. SPOT images were used to detect land use changes in this study due to their better spatial resolution. Three images from different seasons were chosen for this study, one was taken on December 8,1993, another was on April 17,1996, and the other was taken on November 19,1997. The land use classification process was focused in identifying vegetation and landslide area. First, unsupervised classification was used to group into a large categories. Then, candidate training sites for supervised classification were identified from aerial photos and topographic maps. Field observations were also performed to locate the ground truths and to select final training sites.Three SPOT satellite images were used to identify land use /cover changes in Dar-Pu watershed area. Through these temporal images, the land use changes output and land use distribution information can serve as the input parameters for the hydrological model of water conservation capacity estimation. Using satellite images to identify the land use patterns and land use changes for large area is efficiently in both time and cost. The results from image classification are shown in Table 2.

3.3 Hydrological Model Analsys

3.3.1 HSPF Model. This study use HSPF (Hydrological Simulation Program - Fortran), which developed by U.S. Environment Protection Agency and Hydrocomp Inc., to be the simulation model to estimate the water conservation amount. This model could be used to simulate the hydrology and water quality of watershed and is suitable for water resource management and planning. HSPF model is a Continuous Simulation computer program, input with rainfall, temperate, sunlight intensity, land use, soil property, and cultivation data. The result (output) of the model calculation is : sand, water volume change rate of ground surface, soil zone and ground water. It can forecast the runoff, sediment loads and pollutants amount. In conclusion, HSPF is a Continuous Simulation model that gathers hydrology, hydraulic, soil erosion, sediment loads, and water quality. Users would have detailed watershed data and through cautious certification,and then the simulation results will be accurate and reliable. The main function is to simulate total runoff from percolating area. This research focused on the simulation results from PERLND module for surface runoff and groundwater changes in reservoir watershed. The PWATER program structure is shown in figure 3.

Table 2. Land use/cover identification from satellite images classification

Image Date Land use/Cover	12/8/1993 Area (hectare)	4/17/1996 Area (hectare)	11/19/1997 Area (hectare)
Forest	6410.13	6181.88	6102.68
Orchard	1799.83	2070.52	2329.28
Crop Field	773.49	483.98	425.74
Paddy Rice	377.47	431.83	465.04
Water	185.59	150.62	211.38
Road	145.76	145.57	146.3
Build up area	203.59	423.77	473.53
Bare land/Landslide	77.14	379.45	255.47
Grassland	493.23	175.83	52.47
Undistinguished	0	22.77	4.31
Total	10466.22	10466.22	10466.22

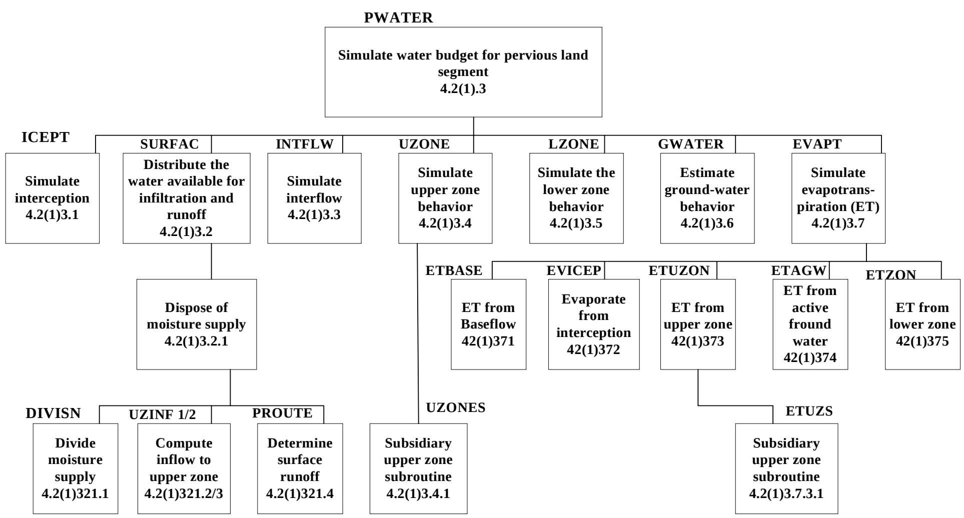

Figure 3. Structure Diagram of PWATER subroutine from HSPF model

3.3.2. Results from Hydrological model simulation. Hydrological simulation bases on the physical property of basin, the meteorological, hydrological, and geographical data to simulate hydrological reaction. HSPF simulates the surface ground runoff, interflow and active groundwater runoff, and then merge 3 runoff to get the total amount. The hydrological equation will be understudied when the model check:

Outflow = Precipitation - Actual evaporation - Amount percolate to dead water zone - Soil moister change (1)

To verify this model, the observation and simulation value for the surface ground runoff, interflow and active groundwater runoff should be compared theoretically. Compare with observation discharge hydrograph and simulation discharge hydrograph because it is difficult to take 3 parts from observation value. The result showed nine main parameters, table 3 has direct effect on water conservation capacities in Dar-Pu reservoir watershed.

Table 3. Highly related parameters from Pwater of HSPF model for Dar-Pu Reservoir watershed

Parameter	Range	Dimension
Lower zone nominal storage. (LZSN)	0.01~100.0	(in)
Index to the infiltration capacity of the soil. (INFILT)	0.0001~100.0	(in/hr)
Exponent in the infiltration equation. (INFEXP)	0.0~10.0	(none)
The fraction of groundwater inflow (DEEPER)	0.0~1.0	(none)
Upper zone nominal storage (UZSN)	0.0~10.0	(in)
Manning's n for assumed overland flow plan. (NSUR)	0.001~1.0	(none)
Interflow inflow parameter. (INTFW)		(none)
Interflow recession parameter. (IRC)	None~1.0	(1/day)
Daily recession constant of groundwater flow (AGWRC)	0.001~1.0	(1/day)

Select rainstorms in the hydrologic data that is fit the conditions to proceed HSPF simulation then use gene algorithm to get the parameters of the reservoir watershed area. Calculate the water conservation capacity and rate from the simulation results. The rainfall-runoff simulation results are showing in Figure 4. It showed the hydrological model can efficiently simulate the change trend of run-off volume from each observing data set.

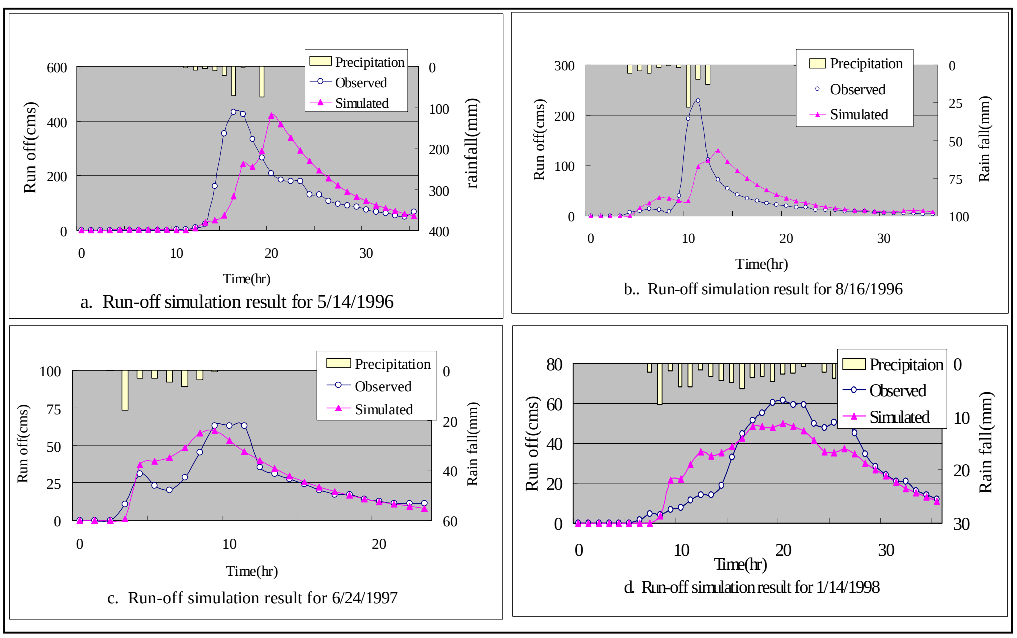

Figure 4. Runoff Simulation for four storm events

3.4 Run off Estimation by Land Use Changes

In HSPF rainfall-runoff simulation results, the discharge hydrograph typify the tendency of floe rate change. This study discusses the parameters change by different land use type. By LINDO, the linear programming program, this study finds out the best resolution of the relationship of every parameter and land use type. As the land use change, the new parameter set will input to the HSPF model to calculate the water conservation capacity of different land use. The flow chart is showing in Figure 5. Table 4 shows the run off volume and the effected coefficient influenced by the land use changes. The hydrological environment was also influenced by land use changes. From the sequence of run off coefficient by land use types are forest, orchard;crop field , paddy rice, grass land; bare land/ landslide, road, and build up area. It can get the runoff estimation from land use changes for study area after input these new parameters to HSPF model. Figure 6 shows results. This Study designs three rainstorm types to be choose. The rainfall hyetograph is shown as Figure 7 and the HSPF simulation results is shown as Figure 8.

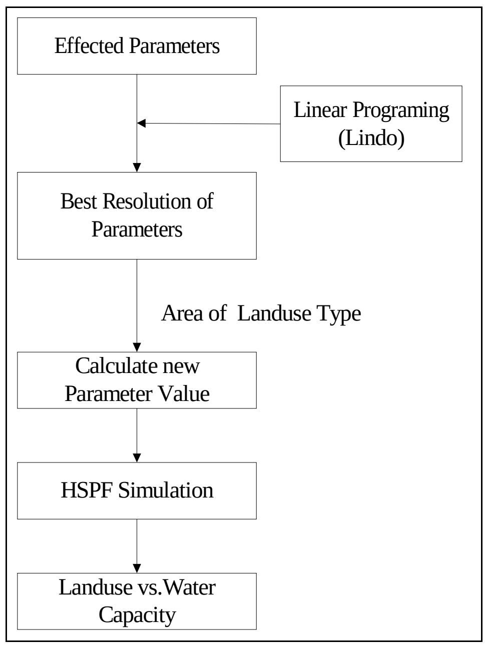

Figure5. Flowchart of land use change *vs*. water capacities

Table 4. Run off estimation from land use changes for study area

Land use change	Run off Volume (CMS)	Run off Coefficient
contrastive area	4260.22	0.74
Orchard	4347.16	0.75
Paddy Rice	4453.62	0.77
Crop field	4414.99	0.76
Grass land	4510.93	0.78
Bare land / landslide	4543.38	0.79
Road	4598.34	0.80
Build up area	4634.44	0.80

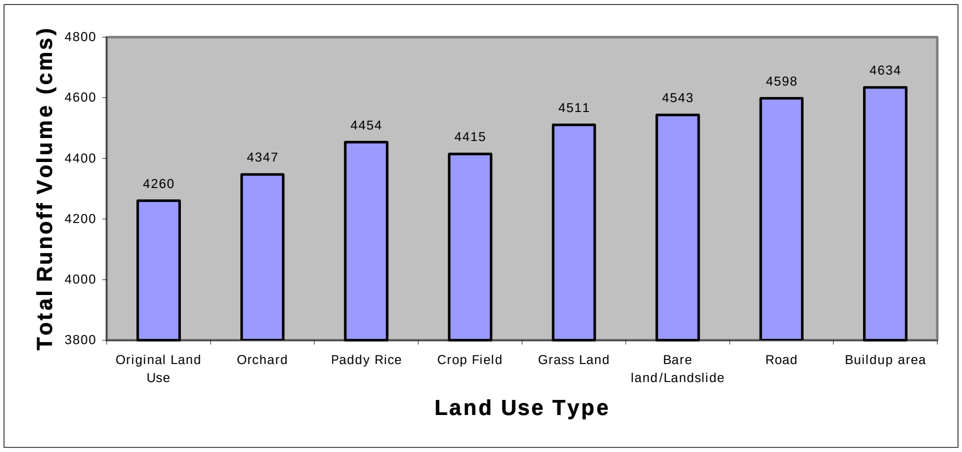

Figure 6. The diagram of run off estimation from land use changes

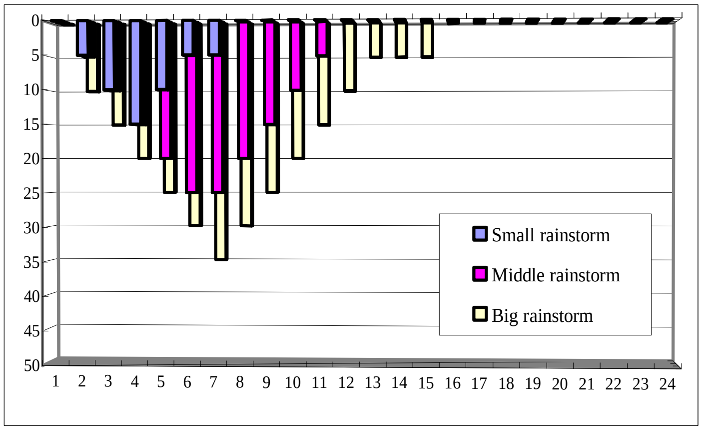

Figure 7. Designed rainstorm hyetograph

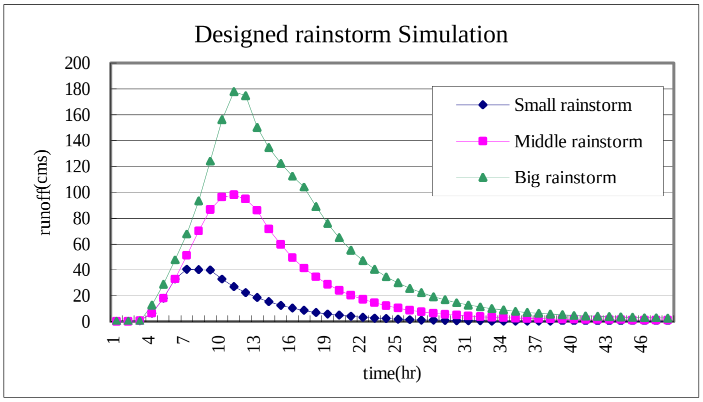

Figure 8. Designed rainstorm simulation results

3.5 User Interface Establishment

This system is developed in Window 2000 Chinese and ArcView GIS 3.2, programming language are ArcView Avenue script and Borland C++ Builder. This program use DDE or DLL to link to ArcView and expend the interface designing capability. Through the graphic user interface (GUI), the linkage flowchart of models and GIS system is showing as Figure 10.

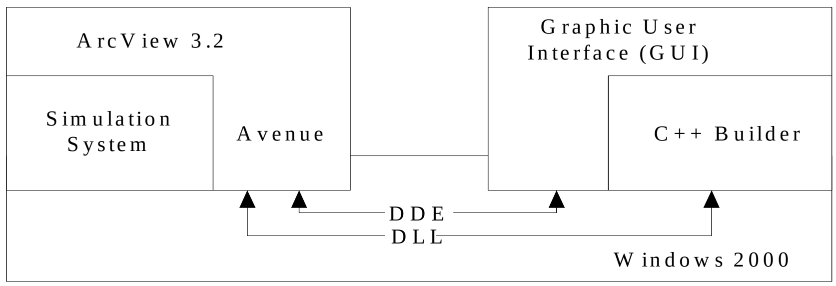

Figure 9. System framework

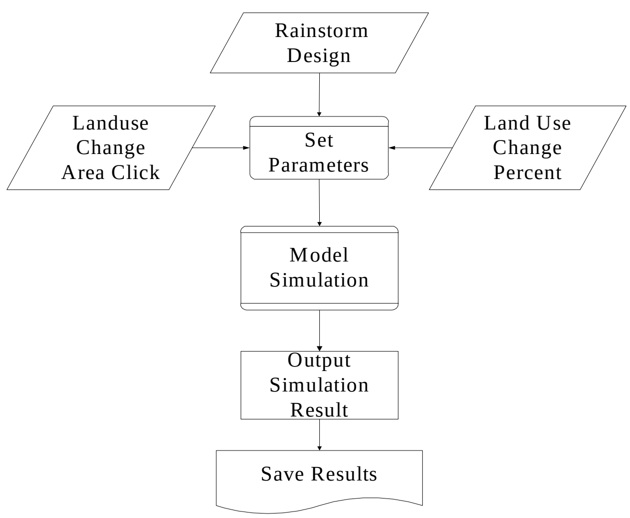

Figure 10. System simulation linkage flowchart

3.6 System Illustration Display

Water capacity analysis interface is the same with soil erosion analysis and added with rainstorm chosen option. The input and output interface shown as below. By the results of HSPF simulation can bring out, it can get the discharge hydrograph of a rainstorm before and after land use changed. The discharge hydrograph is showing as Figure 12. The green line is the discharge hydrograph before land use changed, and the red one is the discharge hydrograph after land use changed. From this result, it is conspicuous to see that when the area of development increases, the flood peak will increase and the time to peak will be shortened. This is the whys of watershed flood calamity.

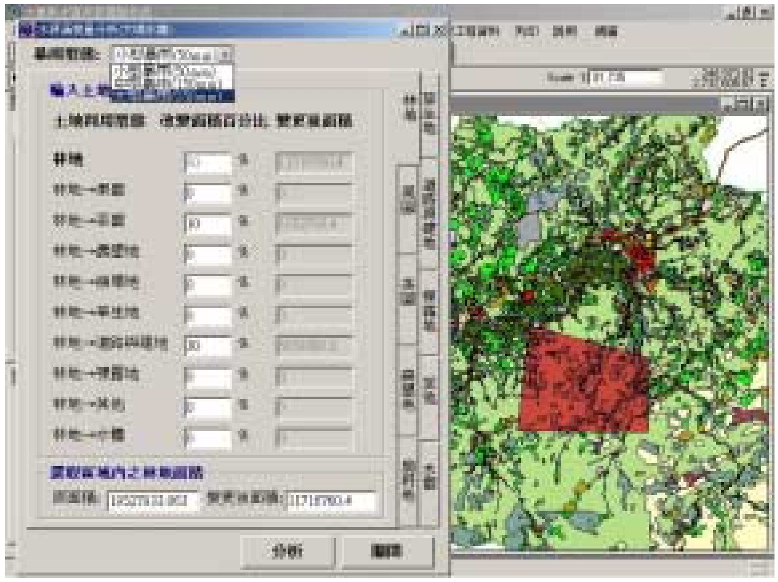

Figure 11. Water capacity analysis input interface

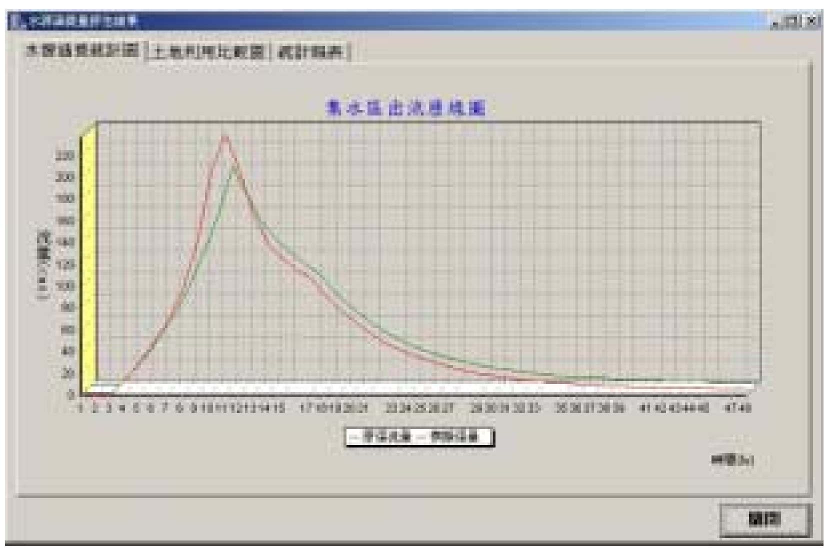

Figure 12 Watershed discharge hydrograph compartment

4. Conclusion

The integration of GIS and Remote Sensing technologies can provide a powerful tool in assisting watershed management. HSPF model and GIS database were linked to analyze the impact to water conservation capacity from land use changes. The final resulted numerical figures for watershed conservation capacity estimation can assist the government in managing the controversy of economics development and resources conservation issues.

Using GIS to link the geographic database and models can calculate the models parameters directly from the topology and attributes by graphic user interface. This mode provides information of strategic decisions for the management agency as watershed conservation and management policy making.

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References

Cheng ,J. D. , W. K. Lin and R. R. Su, 1994: A Study on Rainfall-Runoff Relationships of an Upstream Watershed in Central Taiwan with Geographical Information System and HEC-1 Hydrograph Package. J. Chinese Soil and Water Conservation, 25(3), 143-150.

Chen, W. F. and H. C. Liao, 1996: Runoff Characteristic of Land Use Change in Urban Rim Area - Jing-Mei Watershed, J. Chinese Soil and Water Conservation, 27(4), 311-324.

Chen, M. C and T.Y. Chou, 1998: The Impact of Land Use Changes on Water Conservation for Reservoir Watershed Area. 1998 ACSM Symposium, 517-525.

Hsu , S. K., etc., 1998:Quantitative Model For Land Use Impact on Catchment Water Conservation Capacity, Symposium on Science and Policy Working Together in Catchment Management Proceedings. 177-199.

Chou, T. Y. and M. H., Chen, 1999: Estimation Of Water Conservation Capacity For Reservoir Watersheds by Integrated GIS/RS Technologies. Geoinformatics and Socioinformatics The Proceedings of Geoinformatics'99 Conference, pp.43-55.

Mark, A. R., and D. T. Patrick,1992: Integrated Hydrologic Modeling with Geographic Information Systems. J.Water Resources Planning and Management, 119(2), 129-140.

Portmann, F. T.,1997: Hydrological Runoff Modeling by the Use of Remote Sensing Data with Reference to The 1993-1994 and 1995 Floods in the River Rhine Catchment", Hydrological Processes. 11, 1377-1381.

Shih S. F.,1990: Satellite Data and Geographic Information System for Rainfall Estimation. J. Irrigation and Drainage Engineering. 11(3), 319?331.