# THE WATERSHED MANAGEMENT AND ASSESSMENT USING GIS BASED ON HYDROLOGICAL AND LANDSCAPE ECOLOGICAL ANALYSIS

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**Abstract:** The watersheds are functional geographical areas that integrate a variety of environ-mental and ecological processes and human impacts on landscapes. Geographical assessments using GIS recognize the relationship between interdependence of resources and ecological/environmental components in watersheds. They are useful methodology for viable long term natural resource man-agement. This paper performs through the using hydrological analyses, landscape ecological analyses, remote sensing, and GIS. Indicators are items or measures that represent key components of the small watersheds, and they are developed to be evaluated. Some indicators are described that they represent watershed condition and trend as well as focus on physical, biological and chemical properties of small watershed. Also, ecological functions such as stability, resilience, and sensitivity are inferred from them. The model implemented in GIS allows to reflect the ecological and hydrological func-tioning of watershed. Methodology from image analysis, landscape ecological analysis, spatial inter-polation, and numerical process modeling are integrated within GIS to provide assessment for eco-logical/environmental condition. Results are described from the small watershed of Gwynns Falls in Baltimore County and Baltimore City, Maryland, an area of about 66.5 square miles. The small wa-tershed within Gwynns Falls watershed are subject to a number of land-use. But it is predominantly urban, with significantly lesser amounts of forest and agriculture. The increasing urbanization is ass-coiated with ecological/environmental impacts and citizen conflicts.

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**Keywords**: GIS, watershed, eco-hydrological analyses, landscape ecological analyses, remote sensing

## 1. INTRODUCTION

This paper develops methodology of ecological/environmental restoration using Geographic Information System. Geographical information from small watershed needs for decision making. And this objective is making plan for the water conservation, management, and use of indicators and the water resources of the Gwynns Falls watershed in an efficient, economical, and environmentally sound method so as to provide the maximum benefits for both present and future residents of the watershed.

The focus on information needs for decision making coupled with integrated assessment leads to development of models whose output is a series of indicators of watershed condition; the focus on watershed as hydrological systems leads to development of indicators based on analysis of spatial patterns and processes in the landscape. Indicators from both landscape ecology and water environment are investigated, they are used for assessment of socio-economic and environmental systems, watersheds as a land management and spatial unit, interaction of decision making processes with scientific information, and approaches to coupling GIS. A case study is used to evaluate environmental/ecological assessment within watershed.

### 1.1 Assessment using GIS

There is growing recognition that environmental, ecological, social and economic watershed management require integrated assessment as the basis for decision making (Rhind, 1991; Clayton and Radcliffe, 1996). Watersheds provide a logical conceptual unit for ecosystem management because they are based on the physical, chemical, biological, and geographical characteristics associated with a given ecosystem's hydrology. As such, a watershed includes not only the water resources of an area, but also all the land that drains into that resource. Because many of the problems leading to flood and water pollution are complex and interrelated. Assessment of flooding must be prepared for minimizing problems of flooding along the main stream and major tributaries. Many researches attempt many times and their results are not satisfied. Using watersheds as a basis for water resource assessment offers a more integrated way, as well as providing a framework for more comprehensive management approaches. Problem solving using this approach may offer a more effective means of determining way to protect the chemical, physical, and biological components of the aquatic ecosystems, protect human and environmental health, and allow for sustainable economic growth. Benefits include improved water quality and water supply, flood control, sediment control, improved recreational opportunities, and preservation of bio-diversity and habits.

### 1.2 Decision-making processes

An understanding of decision-making processes is needed to provide the context for developing the role of spatial data handling technologies (Bennett *et al.*, 2000), and to facilitate links between interpretation and use of scientific information (Bellamy *et al.*, 1999). Decision-making is a continual process of consultation, decision evaluation and revision. The main stages identified in the process of decision-making are identified in Table 1.

**Table 1. Summary of decision-making process and role of scientific information**

| Stage in decision making process | GIS and modeling, Scientific Info. |
|---|---|
| 1. Defining the problem | |
| 2.Establishing goals and setting objectives | |
| 3.Collecting data & other objective info. | Sampling & Survey<br>Databases and data warehouse<br>Scale issues<br>Content<br>Logical consisitency<br>Temporal characteristics<br>Knowledge base |
| 4. Establishing & evaluating alternative scena | Modelling<br>Analysis<br>Error & uncertainty<br>Environmental economic & Sustainability<br>Audits<br>Impact assessment<br>Visualisation |
| 5.Selecting between alternative | Visualisation<br>Communication<br>Sampling, Monitoring<br>Inventory<br>Indicators State/Trend<br>Accounting |

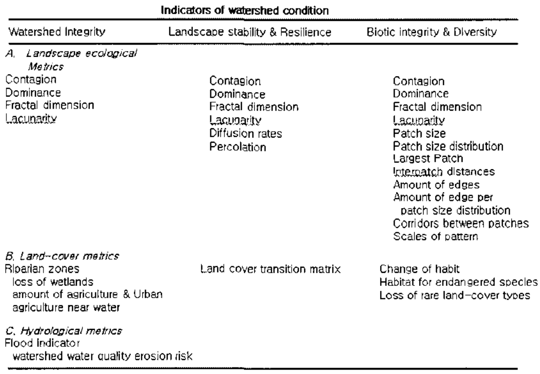
Table 1 shows that using GIS and remote sensing including database making, spatial data handling and analysis is opportunities for exploring and evaluating alternative scenarios. Specially, GIS can also contribute to integration and management of data, and presentation of alternative scenarios through scientific visualization, and monitoring. They are stages for decision making processes. They are necessary for improving data and management of uncertainty (Conroy, 2000).

### 1.3 Indicators for small watershed management.

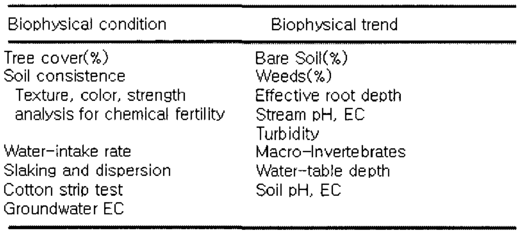
A variety of potential indicators are identified in small watershed (EPA, 1994; Walker and Reuter, 1996; Walker, 1997; Ludwig *et al.*, 1997; Hamblin, 1998; Whitehead and Gorman, 1999). Environmental Protection Agency (EPA) proposed and classified indicators according to following their application; (i) watershed integrity; (ii) landscape stability and resilience, and (iii) biotic integrity and diversity. Further, EPA evaluated and ranked according to an assessment of their suitability for application compared with the need for further development (EPA, 1994). Table 2 shows that EPA proposes potential indicators based on characteristics of landscape, water environment, and ecosystem. Also, Walker and Reuter (1996) identify characteristics for watershed, O'Neill et al and Turner listed as following. For example, subwatershed size or patch size, number of patches or subwatershed, and contagion. For contagion and other fractal dimension, Frohn (1998) has described that it has sensitivity according to spatial resolution and geometric properties of raster datasets.

Land-cover data are used to develop indicators in two main ways (Haines-Young, 1999); (i) measures of amount and distribution of a particular land-cover type; and measures of the spatial organization and structure of land-cover types recorded with landscape ecological matrics, and (ii) land-cover data from stock through time and develop indicators (Haines-Young, 1999). Land-cover changes are described in a transition matrix which is explained as indicator of landscape stability and resilience in Table 2 and 3 (EPA, 1994). Other potential indicators of watershed condition can be found throughout the fluvial geomorphology. In particular, geometric characteristics of watershed provide relationship between the hydraulic geometry of channels and characteristics of the watershed area as drainage area. In addition, biophysical condition and trend are complement indicators based in landscape ecology.

**Table 2. Indicators of watershed condition (source: EPA, 1994)**



| Indicators of watershed condition | | |
|---|---|---|
| Watershed Integrity | Landscape stability & Resilience | Biotic integrity & Diversity |
| *A. Landscape ecological Metrics* | | |
| Contagion | Contagion | Contagion |
| Dominance | Dominance | Dominance |
| Fractal dimension | Fractal dimension | Fractal dimension |
| Lacunarity | Lacunarity | Lacunarity |
| | Diffusion rates | Patch size |
| | Percolation | Patch size distribution |
| | | Largest Patch |
| | | Interpatch distances |
| | | Amount of edges |
| | | Amount of edge per patch size distribution |
| | | Corridors between patches |
| | | Scales of pattern |
| *B. Land-cover metrics* | | |
| Riparian zones | Land cover transition matrix | Change of habit |
| loss of wetlands | | Habitat for endangered species |
| amount of agriculture & Urban agriculture near water | | Loss of rare land-cover types |
| *C. Hydrological metrics* | | |
| Flood Indicator | | |
| watershed water quality erosion risk | | |



| Biophysical condition | Biophysical trend |
|---|---|
| Tree cover(%) | Bare Soil(%) |
| Soil consistence | Weeds(%) |
| Texture, color, strength | Effective root depth |
| analysis for chemical fertility | Stream pH, EC |
| | Turbidity |
| Water-intake rate | Macro-Invertebrates |
| Slaking and dispersion | Water-table depth |
| Cotton strip test | Soil pH, EC |
| Groundwater EC | |

### 1.4 Hydrological indicators

It provides discharge-area relationship between fluvial geomorphology system and hydrological characteristics (Leopold et al., 1964). The relationship between river discharge and drainage area of a watershed is well specified for most watershed for which discharge has been measured. The discharge-area relationship is calculated for mean annual discharge and for

**Table 3. Watershed condition indicators implemented in GIS**

| Indicator | Condition (State) | Change through time | | Spatial Unit | Source |
|---|---|---|---|---|---|
| | | Trend | Account | | |
| Hydrological | | | | | |
| Discharge-area relationship & residuals | X | X | | Regional water catchment & system | Leopold et al (1964) |
| Discharge-precipitation relationship & residuals | X | X | | Regional water catchment & system | Leopold et al (1964) |
| River sinuosity | X | X | | River channel | Leopold et al |
| Riparian vegetation | X | X | X | Riparian buffer area | EPA(1994) |
| Land-cover | X | X | X | | |
| Amount of agriculture | X | X | X | Various | EPA(1994) |
| Amount of urban | X | X | X | Various | EPA(1994) |
| Amount of forest | X | X | X | Various | EPA(1994) |
| Riparian vegetation | X | X | X | Riparian buffer area | EPA(1994) |
| Land-cover change | | Transition matrix | Account | Various | Haines-Young (1999) |

**Table 4. Datasets for the Gwynns Falls watershed**

| Dataset | Description | Source |
|---|---|---|
| **Digital Elevation model** | **30m raster digital elevation representation Of USGS** | **http://www.usgs.gov (USGS)** |
| **Precipitation measured At meteorological stations** | **Point locations and tables of attributes<br>Raster data using interpolation** | **http://www.nws.noaa.gov (NOAA)<br>http://www.usgs.gov (USGS)<br>PRISM dataset** |
| **Stream gauge network** | **Point locations and tables of attributes** | **http://wwwrvares.er.usgs.gov (USGS)** |
| **LANDSAT thematic map 5 (1985)** | **30m spatial resolution, 6 spectral band imagery** | **NASA** |
| **LANDSAT thematic map 7 (1999)** | **30m spatial resolution, 6 spectral band imagery** | **NASA** |
| **Roads** | **TIGER FILES<br>Baltimore Ecological Study** | **TIGER<br>BES( Baltimore Ecological Study)** |
| **Population Census (Various dates)** | **Census data for Counties Overlapping in extent with watershed** | **BES( Baltimore Ecological Study)** |

maximum discharge measured during the recording period. A discharge-area relationship established for an area provides a simple mechanism for estimating the discharge that may be expected for any unmeasured subwatershed from measurement of drainage area. Log discharge plotted against log subwatershed area typically has a strong linear relationship. This relationship provides the basis for an indicator of watershed condition through examination of of the geographic pattern of residuals from the fitted relationship. Precipitation input data and land-cover also influence discharge. A precipitation-discharge relationship is used to relate input and output within watershed and summarizes the basic input-output components of watershed water balance. Precipitation input is measured at meteorological gauging stations and interpolated to provide representations of the geographic variability of rainfall across the watershed using geostatistical methods (Oliver et al., 1989 a, b). As for the discharge-area relationship, log discharge plotted against log precipitation input is typically a linear relationship and the net difference between input and output is informative about the geographic pattern of within watershed hydrological function, in particular, storage and evapotranspiration. Sinuosity of a river is a measure that summarizes the pattern of a river channel and is calculated as the ratio of channel length to down valley distance (Leopold et al., 1964). Sinuosity is defined as the total stream length divided by its valley length. For the survey data, the total stream length was equal to the cumulative distance of the stream thalweg survey. The valley length was equivalent to the as-the-crow-files distance from the first point in the survey to the last point. Stream length and valley lengths were determined from the survey data output file through the use of an Arc/Info GIS procedure (Figure 2). Channel pattern is linked to channel gradient and valley cross-section and, under natural condition, reflects a dynamic equilibrium with processes operating through the fluvial system (Leopold et al., 1964).

GIS can also be used to identify sub-watershed to calculate indicators for these areas to better understand the construction of different sub-watershed to the ecolcgical and hydrological function of the whole geographic area. Watershed can be identified from digital elevation models (Moore and Gallant, 1991).

### 1.5 Spatial interpolation, hydrological land-cover and landscape ecological models in GIS

The models for indicators are developed in GIS as a series of tools and presented in the GIS interface. Figure 1 shows the work flow for interpolation of climatic data using geostatistical methods. Interpolated precipitation data, as output from Figure 1, is one input to the sequence of operations described in Figure 2 to produce discharge-area and discharge-precipitation relationships. Figure 2 includes the model for watershed delimitation that is the basis of a number of analyses of geographical organization of watershed into sub-watershed. Brown (1998 a, b) suggests that Figure 3 describes the model that produces a fuzzy membership classification of satellite imagery. Fuzzy membership function are calculated using the method described by Brown (1998 a, b) and the model also explains issue of uncertainty for class identification, class heterogeneity and boundary position in land—cover mapping (Aspinall and Pearson, 1995).

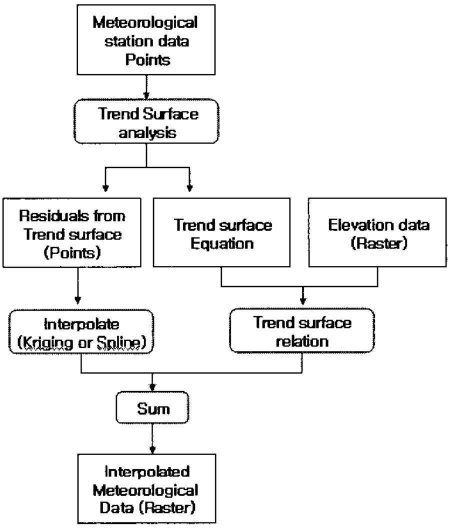


**Figure 1. Process flow for modeling climate data using spatial interpolation (Brown (a), 1998)**

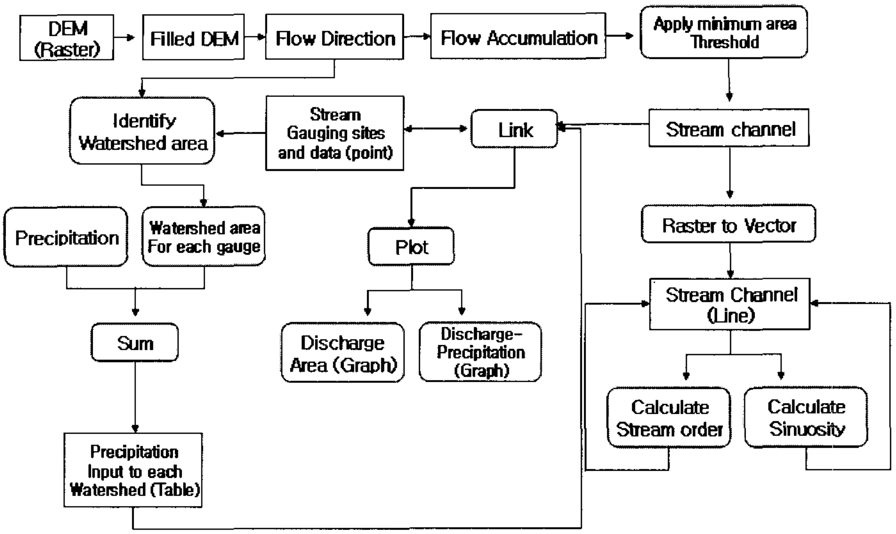


**Figure 2. Process flow for modeling watershed, discharge-area and discharge-precipitation relationships and channel sinuosity (Brown (b), 1998)**

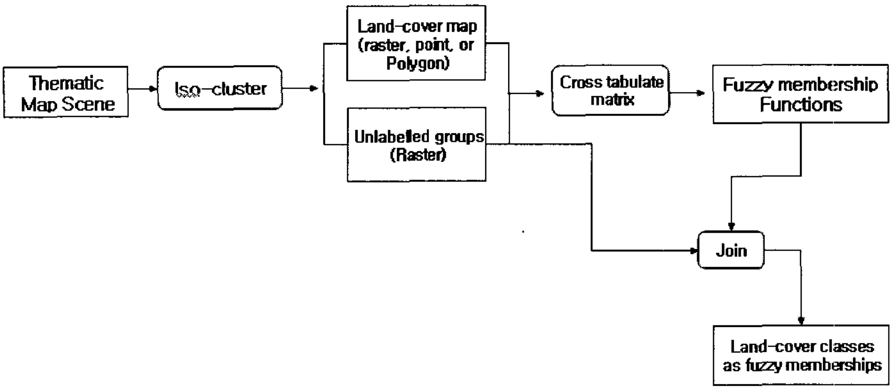


**Figure 3. Process flow for modeling land-cover as fuzzy membership function (Brown, 1998)**

In addition, land-cover data were used to create Gwynns Falls site for maximum likelihood supervised classification and fuzzy classification of Landsat 7 ETM+ imagery. Seven based images and indices(PVI, NDVI, SAVI, tasseled cap greenness, tasseled cap moistness, Landsat 7 band 5, and PCA composite 2) were created with this imagery. The method can be used to allocate fuzzy membership functions for imagery using any existing land-cover or habitat data represented as points, polygons or raster cells. Figure 4 shows the model for calculating land-cover transition matrices and land-cover accounts from multi-date imagery.

In this study, land-cover matrix is used. A change matrix is a table like table 5 and table 6 that quantifies the amount of change that occurs between all of the land cover types. The matrix shows the 1985 classes as row and the 1999 classes as columns. The number of rows and

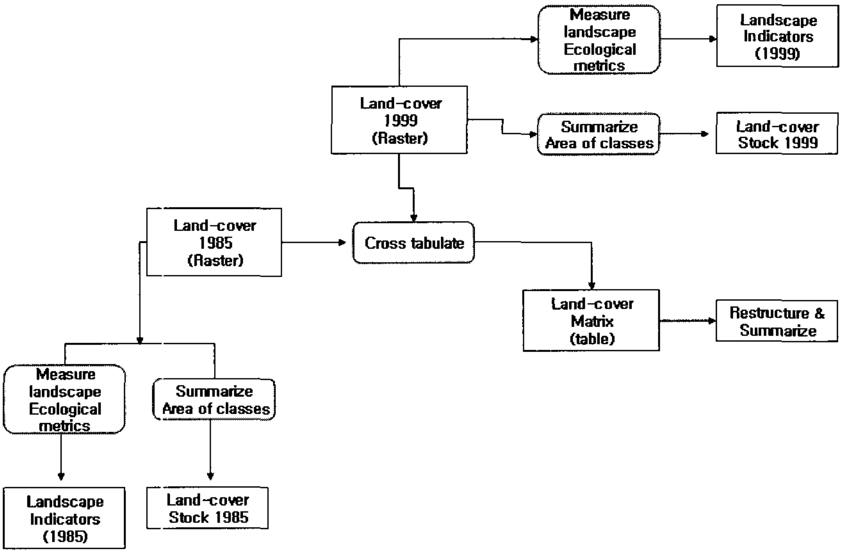


**Figure 4. Process flow for modeling land-cover change transition matrix, land-cover accounts & landscape ecological metrics (Aspinall and Pearson, 1995).**

**Table 5. Land-cover transition matrix for between 1985 and 1999 for the Gwynns Falls watershed**

| | Landcover type | | | 1999 | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Urban | Agricultur | Gassland | Forest | Lake/River | Rock | Tundra | Total |
| 1985 | Urban | 10 | 3,88 | 0 | 0,1 | 1,3 | 0 | 0 | 15,28 |
| | Agriculture | 7 | 4,22 | 0 | 2,51 | 0 | 0 | 0 | 13,73 |
| | Grassland | 0 | 3,1 | 0,14 | 2,14 | 2,1 | 0 | 0 | 7,48 |
| | Forest | 6,2 | 1,3 | 0,11 | 3,3 | 2,4 | 0,42 | 0 | 13,73 |
| | Lake/River | 4,2 | 0 | 0,05 | 2,6 | 1,2 | 0 | 0 | 8,05 |
| | Rock | 0 | 0,79 | 0 | 1,83 | 1,7 | 0 | 0 | 4,32 |
| | Tundra | 0 | 0,31 | 0 | 2,23 | 0,6 | 0,67 | 0 | 3,81 |
| | Total | 27,4 | 13,6 | 0,3 | 14,71 | 9,3 | 1,09 | 0 | 66,4 |

Unit: (sq mi)

columns is determined by the number of classes in land cover image. Each number represents the area(square miles) of land cover change. Moreover, the matrix can be used during data development to identify changes that are unlikely to occur.

## 2. Materials and Methods

### 2.1 Gwynns Falls watershed and data preparation.

In Figure 5, Gwynns Falls watershed located in middle of Baltimore County and Baltimore City, Maryland. The Gwynns Falls watershed is composed of 17 major sub-watersheds that range in size from 1.8 square miles to 7.16 square miles. The headwaters of Gwynns Falls are located in the town of Glyndon in west-central Baltimore County. The stream drains several residual communities in west-central Baltimore County before entering the south-western corridor of Baltimore City. Gwynns Falls discharges into the middle branch of the patapsco River, which comprises the

**Table 6. Land-cover account for change between 1985 and 1999 for the Gwynns Falls watershed**

| Land-cover type | 1985 Stock (sq mi) | Urban development (sq mi) | Afforestation (sq mi) | Agricultural intensification Irrigation (sq mi) | Agricultural extensification (sq mi) | Misclassification of imagery (sq mi) | 1999 Stock | Net change (sq mi) | Net change (%) | Loss (sq mi) | % 1985 stock lost | Reliability of change estimate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Urban/Built-up | 15.28 | 8.8 | | | | 1.1 | 27.4 | 12.12 | 79.3 | 1.2 | 7.9 | High |
| Agriculture | 13.73 | -2.4 | | | | 0.1 | 13.6 | -0.13 | -0.94 | 2.4 | 17.5 | High |
| Grassland/ Rangeland | 7.48 | -3.1 | -24.4 | | | 0.3 | 0.3 | -7.18 | -95 | 1.4 | 18.7 | High |
| Forest | 13.73 | -0.8 | 28.1 | | | 13.4 | 14.71 | 0.98 | 7.14 | 1.9 | 13.8 | Low |
| Lakes/Rivers | 8.05 | 0.1 | | | | 9.2 | 9.3 | 1.25 | 15.5 | 3.7 | 45.9 | Low |
| Rock | 4.32 | 0 | | | | 30.3 | 1.09 | -3.23 | -74.8 | 1 | 23.1 | Very Low |
| Tundra | 3.81 | 0 | | | | 22.2 | 0 | -3.81 | -100 | 1.2 | 31.5 | Very Low |

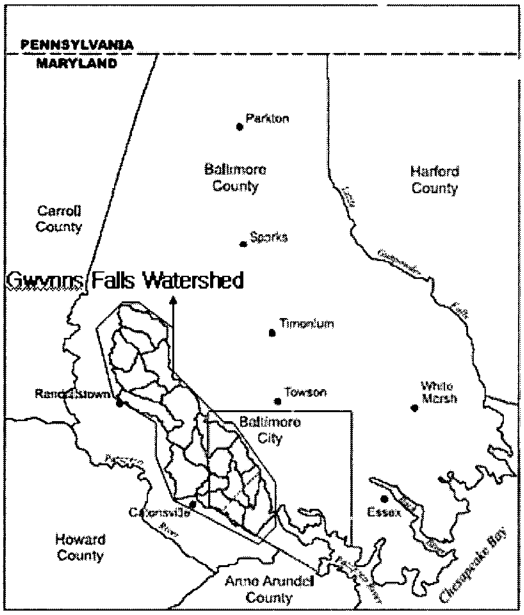


Figure 5. Gwynns Falls Watershed

western part of Baltimore Harbor. The middle branch of the Patapsco River ultimately drains into the Chesapeake Bay. Annual-mean precipitation in the Gwynns Falls watershed is about 43 inches, and the annual-mean runoff is about 16 inches(http://baltimore.umbc.edu/lter/description/working/description.htm). Based on the annual mean discharge for 34 years of continuous record and the drainage area(1970~2004), the annual-mean runoff at the continuous-record streamflow-gaging station on Gwynns Falls at Villa Nova, Md., is 16.5 inches. The difference between annual-mean precipitation and annual mean runoff is almost entirely due to evapotranspiration losses. Because of variations in seasonal rates of evapotranspiration and seasonal changes in ground-water discharge to streams, monthly mean stream discharges generally decline from highs in March to lows occurring in September and October. This pattern reverses as evapotranspiration losses decrease after growing season, resulting in increased ground-water discharge to streams. For this paper, the majority of these data are available over the Internet under USGS, TIGER and Baltimore ecology study (BES). The developing role of spatial data and digital data libraries on the Internet provides an opportunity for developing GIS and models to support decision-making and also inclusion of a wide public community in decision-making.

# 3. Results

## 3.1 Precipitation and discharge relationships in watershed

The least square root or box-muler transform of precipitation measured at meteorological stations in interpolated to reduce the influence of strong skew in the data. Linear regression shows a significant correlation between precipitation and elevation (r=0.823, N=140). The residuals from the regression model are interpolated by kriging using a circular variogram model and the resulting interpolation summed with the trend surface relationship applied to the Digital Elevation Model. Figure 6 shows gauge station sites with mean annual/monthly/daily precipitation mapped for the watershed using this kriging interpolation model like Figure 1. Calculating discharge-area and discharge-precipitation relationships are shown by Figure 2. The results are shown in Figure 7. In Figure 7, deviations from the linear relationships provide information that is used to examine differences between watersheds and can be related to land-cover or other data as required using the GIS.

## 3.2 Land-cover in watershed

Actually, land-cover has been mapped in 1970, 1985 and 1999. But land-cover is mapped from 1985 and 1999 LANDSAT imagery using the model in Figure 3. These land-cover data are intended for environmental assessment of land-use patterns and human reaction of changing circumstance. These environmental assessment of land-use pattern are related with water quality analysis, agricultural/industrial/urban growth management, and other types of environmental impact assessment (USGS, 1990). Change in land-cover between 1985 and 1999 are analyzed using the model in Figure 4. The land-cover transition matrix for the Gwynns Falls watershed is shown in Table 5. Land-cover accounts for the same area and dates are shown in Table 6. Table 5 and 6 include the amount of urban, agricultural and forested land which are themselves indicator like table 2 and 3.

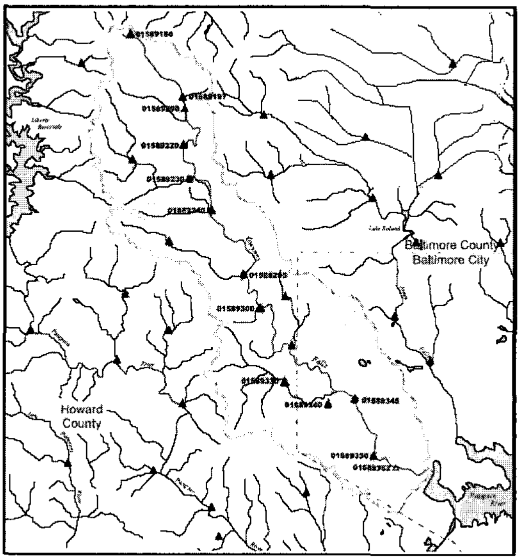
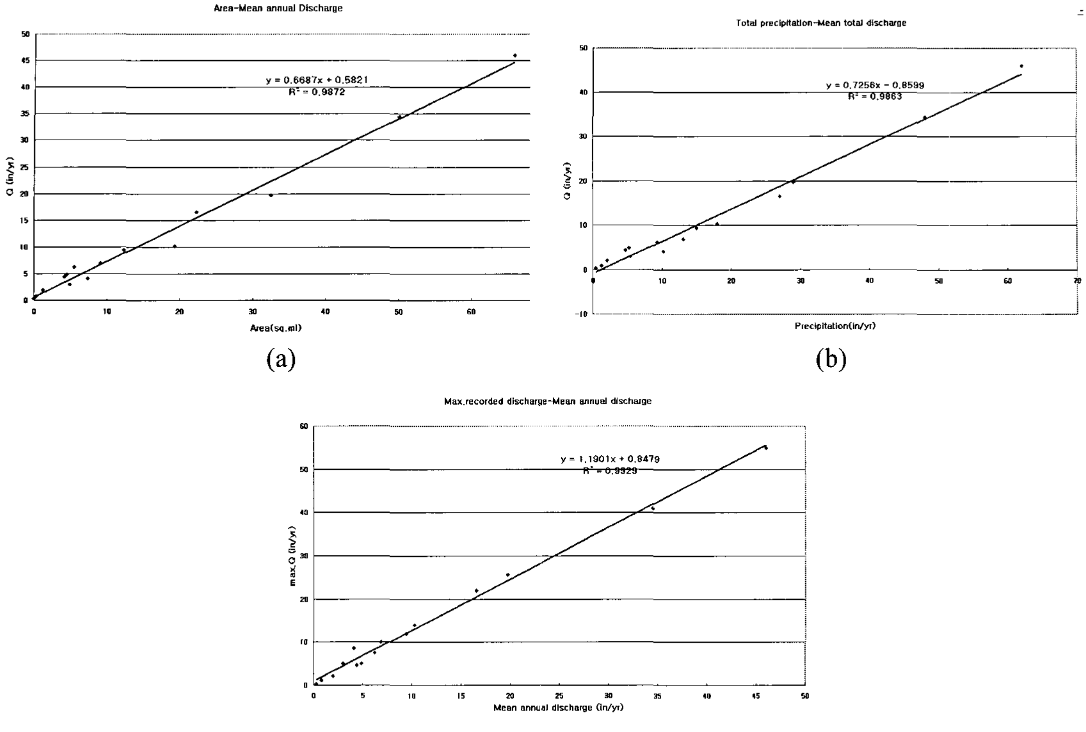


**Figure 6. Monitoring stations operated by the U.S.Geological Survey in the Gwynns Falls watershed**

In the table 5, the diagonal of the transition matrix contains 30% of the land area, showing good agreement between the land-cover datasets from the two dates and the large proportion of the total area has changed (70%). The land-cover tabulate as table 5 provides information of land-cover change. It summarizes changes; they include a subjective assessment of the reliability of the measured change by land-cover class. The change of land-cover type and the relationship of changing land-cover would be expected by using indicators through participatory approach (Walker and Reuter, 1996; Walker, 1997, Bellamy et al., 1999; Haines-



(a)

(b)

(c)

**Figure 7. (a) Discharge-area relationship, (b) discharge-precipitation relationship and (c) maximum recorded discharge-mean annual discharge relationship for Gwynns Falls watershed.**

Young, 1999). Table 6 includes an assessment of the reliability of change. This is based on the ratio of potentially misclassified change compare with the amount of net change measured (Aspinall and Hill, 1997). High reliability is allocated to classes for which misclassification is a small proportion of the net change, low reliability for classes that have large misclassification compared to the net change. Rock and Tundra both have very low reliability. The complex of land-cover types in the watershed and sub-watersheds implicates a condition of watershed. Indicators can be calculated for any interesting area using GIS. Also, for more improve analysis and watershed management, the GIS can be an advantage of incorporating the hydrological and ecological interpretation models into GIS environment. In addition, negative numbers represent that 1985 image is subtracted from the 1999 image to identify different pixels. Corresponding pixels that have the same values in both years will have a 0 when subtracted and indicate no change. Pixels with either positive or negative numbers have changed.

## 4. Discussion and Conclusion

The adaptive water resource management and ecological protection require information and criteria to decision-making and integrated assessment of watershed. These information and criteria are exactly evaluated and make more databases. Table 1 shows that decision process is following a number of stages. This paper focuses on data manipulation and integration within a GIS environment that includes evaluated indicators for decision making processes. The GIS with implemented other model are also available for management, analysis and presentation of data and results. The indicator represents key components of a system and has meaning beyond the attributes that are directly measured. It is described in Table 3 that represent state (condition) and trend (changes across space and time) of watersheds focus on the physical, biological, and chemical properties of watersheds, as well as ecological function such as stability, resilience, and sensitivity. Many of these are capable of measurement from remote sensing and GIS with hydrological models. The hydrological and ecological indicators are readily calculated within GIS-modelling framework. Also, Models for spatial interpolation, land-cover change analysis, and land-cover mapping using transition matrices and hydrological modeling are developed within a GIS. The outputs from GIS with models focus on their role as sources of information to support decision making, and develops indicators of watershed condition as output. This encourages use of output for decision-making. Indicators address ecological and hydrological function of watershed and develop both existing indicators from landscape ecology as well as indicators based in hydrological function of watersheds. The geographic analysis capabilities of the GIS are used to calculate indicators for specified geographic areas within a watershed.

## Acknowledgements

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