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# News Item—

## IEES Newsline and the Ecosummit07 Conference in Beijing

The International Ecological Engineering Society (IEES) has an online news service, which can be accessed through its website: http://www.iees.ch.

On the web-site a reader can find much information by clicking on various icons. Of special interest is the “EcoEng-newsline”, which lists significant news items on ecological engineering from all over the world. A recent news item is about the EcoSummit Conference recently held in Beijing, China.

**The EcoSummit 2007 Conference:**

Beijing was holding an EcoSummit 2007 from May 22nd to 27th. There were 1,400 scientists from 70 countries attending the Conference. They discussed how to help mitigate global climate change, ecosystem degradation, to find ways to improve human well-being in general. They sought ways of sharing their knowledge on ecological engineering with the world’s common citizens and especially decision makers. Delegates at the EcoSummit called for the human society to work together to prevent further environment deterioration of the Earth. This will require, among other things, developing and enforcing environmental laws and regulations, and upholding and applying international conventions. It also will demand the widest collaboration between civil societies, governments, and world’s scientists in applying ecological principles to everyday life.

**Reference:**

1. http://www.ecosummit2007.elsevier.com
2. http://www.iees.ch

# Seminar on Stream Ecological Engineering Applications

**Date:** April 27. 2007（Friday）

**Location:** Classroom 202, 2F of Civil Engineering Building, National Taipei University of Technology（NTUT）

**Host:** Water Environment Research Center, NTUT

Table.1 Agenda

| Time | Activity | Speaker/Moderator |
|---|---|---|
| 09:00~9:30 | Check in | |
| 9:30~11:30 | Seminar: Stream Ecological Engineering | Dr. Wen-Sheng Liang, Speaker<br>Capital Engineering Corporation |
| 11:00~12:00 | Discussion | Prof. Jen-Yang Lin (WERC, NTUT)<br>Moderator |


Figure.1 Dr. Wen-Sheng Liang Lecturing

Figure.2 Seminar in Session

**Description**

Dr. Liang Wen-Sheng, Vice president of Capital Engineering Corporation, presented an excellent seminar on stream ecological engineering applications in reservoir watersheds. In attendance were technical staff members from various reservoir management administrations, including planning, design and construction personnel. Some students and private citizens also participated.

Dr. Liang described the many stream engineering projects that he was involved, in which ecological engineering methods were applied. He stated that modern engineering designs should grasp the two important elements that impacting a stream, i.e., natural forces such as climate, topography, hydrology, etc., and impacts caused by man’s activities. The balance between these two considerations should be made even at the preliminary design stage. In order to develop detailed and practical planning and design guideline, more field data will be needed.

## A Brief Resume of Dr. Wen-Sheng Liang

### Education:

B. S. Civil Engineering, National Cheng-Kong University, Taiwan, 1963

M. S. Civil Engineering, University of Saskatchewan, Canada, 1968

Ph. D. Civil Engineering, Colorado State University, USA, 1974

### Experience:

| | |
|---|---|
| Vice president, Capital Engineering Corporation | 2005 to date |
| Director of Business Development, GT International | 1999~2005 |
| President, G T International | 1989~1999 |
| Senior Vice President, Simons Li & Associates | 1980~1989 |
| Associates, Camp Dresser & McKee | 1974~1980 |

### Major projects involved:

1. Study on Water Related Ecological Engineering Methods, 2003~2005
2. The Development of Model and Design Guideline for Ecological Engineering Methods, 2004~2005
3. Establishment of Evaluation Methods for Ecological Engineering Technology, 2005
4. Removal of Micro-Organism and Water Quality Improvement Study for Waste Water Reuse, 2004~2005
5. Drainage System Improvement Planning for Dong-Gang River Basin, 2006

# Workshop—

## on the Application of Buffer Strips and Other BMPs for Source Water Protection in Taiwan and United States

**Date**：March 23. 2007（Friday） 8:30~12:30 am

**Location**：Conference Room, 5F of Civil Engineering Building, National Taipei University of Technology（NTUT）

**Host**：Water Environment Research Center (WERC), NTUT

**Sponsors**：WERC, USEPA/University of Virginia

Table.1 Agenda

| Time | Subject | Speaker | Moderator |
|---|---|---|---|
| 8:30~9:00 | Check in | | |
| 9:00~9:25 | Opening Remarks | Vice-President of NTUT, Ching-Yin Lee<br>Deputy Dir.-General of WRA, Tsung-Shen Liao<br>Chairman of CIEnvE, Kung-Cheh Lee | Prof. Jen-Yang Lin<br>WERC, NTUT |
| 09:25~09:30 | Tea Time | | |
| 09:30~10:00 | U.S. EPA Research on Urban Stormwater Pollution Control | Anthony Tafuri<br>Chief of Urban Watershed Management Branch, U.S. EPA | Prof. Pen-Chi Chiang<br>Graduate Institute of Environmental Engineering, NTU |
| 10:00~10:30 | Combined Sewerage System Optimization | Richard Field<br>Leader of Wet-Weather Flow Research Program, U.S. EPA | |
| 10:30~11:00 | A Review of the Application of Buffer Strips for Protecting Drinking Water Sources in the United States | Prof. Shaw L. Yu<br>Civil Engineering, UVa | |
| 11:00~11:10 | Tea Time | | |
| 11:10:11:40 | Conservation on Reservoirs of Buffer Zone and Impounding Zone in Taiwan | Deputy Director Kuang-Chih Chang<br>Conservation Division, Water Resources Agency | Prof. Jan-Tai Kuo<br>Department of Civil Engineering, NTU |
| 11:40~12:10 | 翡翠宣言芻議<br>A Draft of Feitsui Reservoir Declaration | Prof. Shi-Fang Kang<br>Water resources and Environment Engineering, Tamkang University | |

| | | |
|---|---|---|
| 12:10~12:30 | Discussion | Dir. Cheng-Daw Hsieh (Taipei Water Management Office)<br>Prof. Shaw L. Yu (Civil Engineering, UVa)<br>Prof. Jen-Yang Lin (WERC, NTUT) |

Figure.1Tsung-Shen Liao, Deputy Director-General of WRA, giving an opening remark.

Figure.2 Kung-Cheh Lee, Chairman of CIEnvE, giving an opening remark.

Figure.3 U.S. EPA's Anthony Tafuri

Figure.4 U.S. EPA's Richard Field

Figure.6 Workshop in session.

**Description**

The workshop was organized in a comfortable and beautiful day by Water Environment Research Center (WERC).

The workshop invited scholars and experts, who are professionals in the water resource and management, from U.S EPA, University of Virginia and Taiwan to report on their experience and discuss with fieldworkers and local scholars to exchange their comment in the workshop. The audience asked some interesting question in the differ fields thinking. The audiences are from differ fields, such as ecology, landscape architecture and aquaculture etc. The workshop was very successful.

# Pursuing a Nature-Systems Approach to Stormwater Management in Seattle

**Neil Thibert**[1]

[1] *Performance Manager, Seattle Public Utilities, Utility Systems Management Branch E-mail:* neil.thibert@seattle.gov

## Introduction

The City of Seattle, located in the Pacific Northwest section of the United States, has a unique combination of physical and regulatory attributes that pose a significant challenge to stormwater managers. In response to this challenge, Seattle Public Utilities is pursuing a natural systems approach to stormwater management. This paper describes:

1. The overall goals of the approach to stormwater management being pursued by Seattle,
2. The major constraints that the natural features of Seattle, historical choices, the regulatory systems, and political factors impose on any solutions, and
3. Elements of the program with areas of ongoing success and areas of difficulty in creating integrated and more natural solutions in an urban area with many constraints.

Seattle's drainage infrastructure is comprised of three configurations; a combined wastewater and stormwater system, a separated storm drain and sanitary sewer system, and an informal ditch and culvert system that feeds into creeks scattered throughout the city. Each system serves roughly one third of the city and each necessitates a different approach to handling stormwater. To add to this complexity, there are several receiving water types within Seattle including the Pacific Ocean (Puget Sound), a major river (the Duwamish River), numerous creeks, three small lakes, and one large lake (Lake Washington). The needs and beneficial uses of these varied receiving water body types must be incorporated into any water quality protection plan.

Seattle's great challenges and best opportunities lie in creating an integrated and environmentally responsive stormwater management system that builds on historical and enhanced natural drainage systems where possible, and integrates these processes with more conventional urban stormwater approaches. The recent listing of Chinook salmon as endangered under the federal Endangered Species Act (ESA) has expanded both the challenges and opportunities. Seattle is among the first highly developed metropolitan areas that will be required to meet all the regulatory requirements as a result of the ESA listing. All receiving waters that are potential Chinook rearing grounds will be viewed from a perspective of whether the water quality and habitat are sufficient to support the species. This is obviously a much tougher standard than historical regulation would

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have required.

This paper describes an evolutionary approach that Seattle Public Utilities, who is charged with stormwater responsibility for the City of Seattle, is undertaking to create an integrated and environmentally responsive stormwater management program that is compliant with the requirements of the Clean Water Act and the Endangered Species Act.

# 西雅圖利用自然系統管理暴雨之策略

位於美國西北太平洋岸的西雅圖市，由於獨特的天然條件及環保法令規章之需求，在暴雨管理工作上面臨相當大的挑戰。為應付這個挑戰西雅圖市政府公共事業處以追求自然系統方式來作暴雨管理。本文內容大致如下：

1. 西雅圖市進行暴雨管理策略之主要目標；
2. 任何解決辦法所需要考慮西雅圖在自然地形、水域等以及人文、歷史、法令規章和政治等因素的各種限至；
3. 在城市中有許多限制情況下，推動整體性而較”自然性”暴雨管理策略所遭遇到成功及困難的案例。

**關鍵詞**：城市暴雨管理、自然系統、生態系統保護、民眾參與

## Goals

The goals of Seattle's natural-systems approach to stormwater management are to work more harmoniously with the systems that we are trying to preserve. We will be more successful and more efficient preserving aquatic resources than trying to replace them. Structural best management practices are, at best, compromises that are limited in applicability. Some can even have detrimental effects on streams. We want to:

- Improve water quality and enhance riparian habitat through natural means,
- Convey stormwater to prevent flooding cost-effectively without simply moving the problem,
- Preserve open space in an urban setting in a way that connects people to water and the environment,
- Increase stewardship and appreciation for the environment by providing an aesthetic amenity,

## Background

Most of Seattle was originally developed with a combined sewer system and fully improved streets with curbs, gutters, and sidewalks. In the 1950's, the City annexed areas at the north and south ends from King County, which had no development standards. Most of these areas still have unimproved streets with ditches and culverts or no drainage infrastructure at all. Beginning in the 1960's, about half of the combined sewer areas were separated by building storm drains to remove stormwater from the sewers and prevent combined sewer overflows. Much of this early sewer separation was done in residential areas tributary to swimming beaches along Lake Washington and Puget Sound shorelines.

In the late 1980's, the City studied the effects of storm drain discharges and concluded that the persistent contaminants discharged continuously from storm drains posed more harm to the environment than the occasional discharges of diluted sewage. We changed our combined sewer overflow policy from sewer separation to storage and treatment by building large underground storage tanks instead of new storm drains. This achieved the goal of keeping bacteria out of receiving waters without increasing the loading of metals and hydrocarbons. These remaining areas to be controlled tended to be commercial and industrial areas with heavy traffic where contaminant loadings in stormwater would be highest. In those areas that still have combined sewers, stormwater receives secondary treatment at a regional wastewater treatment plant operated by King County before discharge to Puget Sound. The County administers an industrial pretreatment program to deal with high strength discharges to that system. Both the City and the County have to deal with combined sewer overflows caused by excess stormwater in the system during rainstorms.

In those areas now served by a formal storm drain system, we are working to keep contaminants out of runoff and looking for innovative ways to treat stormwater. Source control programs include development regulations, public education, and business inspections. We have a number of staff who visit businesses to identify problems that can be addressed by better housekeeping practices or structural best management practices if needed. The emphasis is on education, with pamphlets provided to explain requirements and follow-up visits. We've hired private businesses to make the inspections in some areas. In some cases, stormwater from particularly dirty industries has been collected and discharged to the sewer system. Because this can affect the County's combined sewer overflows, this is only done in rare instances and with their cooperation. Inspection of private detention systems is also done to ensure that they are maintained and functioning as designed. Street runoff is collected by inlets and catch basins that are equipped with traps to hold floatable. These are inspected and cleaned regularly to keep sediment out of waterways. We are preparing to install several different stormwater treatment devices developed by various manufacturers in order to test their effectiveness and overall cost in actual field conditions. The results of this testing may lead to installation of similar devices in heavily urbanized parts of the city where natural systems are incompatible.

In those areas served by ditch, culvert, and creek drainage systems, the City is attempting to address stormwater management by working with the natural systems. Seattle created a drainage utility in 1987 following a 100-year storm that did millions of dollars worth of property damage to private property, roads, and utilities. We built a constituency for charging a drainage fee by working with a citizen's advisory committee during development of a comprehensive drainage plan. The committee was selected to represent a broad range of environmental, neighborhood, and business interests. They helped us put together a message for presenting at public meetings in every part of the city. Together, we developed the policy ideas that would guide the utility. The Pacific Northwest has a very strong environmental ethic, so protection of water quality emerged as a major policy consideration, along with flood control.

For the next several years, we managed stormwater in pretty conventional ways. We built storm drains and detention ponds, conducted water quality sampling, increased our maintenance funding, and developed a public education program. The capital improvement focus was on building a trunk system to serve the most critical needs in ten drainage basins. As a large city, we also acquired a federal National Pollutant Discharge Elimination System (NPDES) municipal stormwater permit as required by the Clean Water Act. An element of that permit was creation of a stormwater management plan, which guided our water quality program from 1995 to the present time. That permit is up for renewal this year.

Following major landslides in January 1997, we initiated a drainage policy study that resulted in strengthening the City's role in the areas of landslide protection, neighborhood drainage improvements, and restoration of the city's creeks. Once again, constituency was created through public meetings and community involvement. A strong public education program has been part of the utility from the beginning.

With citizen input, Seattle has shifted its focus and its performance measures from just keeping contaminants out of stormwater to managing receiving water quality and quantity for beneficial uses. This means flow reduction to prevent erosion and sedimentation in creeks. It means increasing infiltration of stormwater to maintain dry weather flows. In addition to sampling for water chemistry, we conduct biological sampling of the biota that live in the soil under our creeks, lakes, and Puget Sound as well as counts of the fish that live in these waters. We divided the City into six receiving water zones with the water quality emphasis in each zone tailored to the needs of that water body.

**Challenges**

Seattle is situated between two large water bodies, so there is no room for expansion. As a result, the city is almost fully developed, and growth occurs mainly by redevelopment. New development is mostly infill on sites previously considered unbuildable. The high value of view property is now causing houses to be built on steep hillsides and in ravines. In order to preserve some of the remaining green space, Seattle's citizens have voted on more than one occasion to purchase property through open space bond sales. Much of the land acquired is on steep hillsides along Puget Sound shorelines or along creeks. Although these properties are under the jurisdiction of the Parks Department, the community looks to Seattle Public Utilities to enhance these open space acquisitions by restoring the creeks that cross these parcels. For the utility, these properties are an opportunity to construct habitat and water quality improvements. The creeks form the backbone of the stormwater conveyance system in part of the city. In addition to providing a neighborhood amenity, the creeks are a cost-effective way to handle the runoff. Development has greatly affected the creeks, so the City is working to mitigate those effects.

Development has encroached on our creeks as houses, apartment buildings, and lawns have been built right up to the stream banks. Street crossings were built with small culverts that no longer can pass the flow during storms. Downcutting of streambeds has left many of these culverts with drops of several feet on the downstream end. This makes it impossible for fish to move up and down the creeks. Salmon cannot get up into the creeks to spawn. Urbanization has made the creeks wide and shallow with bottoms that resemble concrete. To prevent loss of property, residents have armored the banks against erosion with concrete or rock. This eliminates the natural recruitment of gravel that's needed for fish eggs and insects. People dump yard waste along the stream banks. This contributes to low dissolved oxygen levels and clogs trash racks with debris when the creeks rise and carry the material away. A change in behavior is needed, and that is being addressed through public education efforts, including a Salmon in the Classroom program that reaches 20,000 fifth grade students each year.

## Approach

The following examples illustrate some of the methods Seattle is using to manage stormwater using natural systems:

### *Citizen Involvement*

Following guidelines from the Washington State Department of Ecology, the City has worked with a committee of watershed residents and businesses to develop a Watershed Action Plan for each of Seattle's three largest creeks. These plans identify specific actions that the City and community can take to reduce non-point or diffuse sources of pollution.

We celebrated the Millennium with several creek restoration projects. These were kicked off with huge celebrations on Earth Day 2000 that included children's activities, live music, and information booths. Hundreds of people signed up as volunteers to help remove weeds, plant trees, or become creek stewards for their neighborhoods.

### *Wetland Detention*

Meadowbrook Pond is a multi-use detention facility constructed at the site of a former wastewater treatment plant owned by the utility. This project uses a series of ponds on a nine-acre site to remove sediment and reduce peak flows in Thornton Creek. During heavy rains, stormwater flows from the creek through these wetland ponds, and back to the creek through a control weir. When the level of the ponds reaches a certain height, excess water flows over a weir and into the old outfall pipe from the treatment plant. The outfall conveys the water directly to Lake Washington, thus protecting the lower mile of the creek from flooding and erosion. The site incorporates public art, interpretive signage, bridges and overlooks for viewing wildlife including salmon, beavers, and numerous species of waterfowl. The entire site is landscaped with native vegetation. Creek restoration work on the site has improved the ability of fish to travel up the creek during both high and low flows. Part of the site contains classrooms and a greenhouse that are used by a local high school for an urban horticulture class. There is space for a nursery to propagate wetland plants and other native plant species for use on our projects. This stormwater detention project is so attractive that a number of weddings have taken place here.

We recently renovated one of the older detention basins in Seattle by excavating some material from the bottom to create a permanent pool of water and planting a variety of wetland plants and trees to provide filtering and shade. The outlet structure was also modified to reduce flows for the more frequent storms that are the biggest problem for fish. Previously, the basin was designed to reduce flooding during the 25-year and 100-year storm events, but storms up to the 2-year flow passed right through with no detention. One side of the basin was also excavated back to make up for volume lost by the low-level storage during the major events.

The Utility constructed another wetland detention facility on property owned by a local community college. In addition to stormwater detention and treatment, the project is an outdoor classroom for biology students who use it to observe the many species of birds and other wildlife that the site attracts along with the many plants that were incorporated into the project. A rare species of orchid also occurs naturally on the site.

Becker's Pond is a project that's still in the planning phase. We purchased a property adjacent to a large City park that contains a creek with a good salmon run. The success of the salmon returns in this creek has been largely due to extensive community involvement over many years. One detriment to the salmon is the high peak flows that occur during rainstorms. These create high velocities that the fish must swim against and cause erosion and sedimentation that smothers the salmon eggs in the bottom of the creek. Flooding in this park is not a problem, because there are no structures along the creek to be damaged. Most of the park is wooded, and there is a grassy field along one side of the stream. Instead of a typical flood control basin, we want to build a detention facility that will reduce flows in this tributary by as much as possible during a two-year storm event.

### *Golf Course Detention*

Because Seattle Public Utilities does not own many large tracts of land for constructing regional detention facilities, we are looking for large vacant parcels owned by others. The Seattle Parks Department is the largest landowner along the creeks, and their largest holdings are two golf courses. We have already built one detention pond on a golf course and will begin construction of additional ponds next year. These provide amenities for the golfers in the form of water hazards and more attractive courses. They also provide wetland habitat for fish and wildlife as well as food sources for the entire creek downstream. Along with mitigating storm flows in the winter, the ponds will serve as an irrigation source during the summer to moderate the sudden drawdown of the creek during watering.

In order to accommodate the ponds within the area currently occupied by golf course fairways, we will have to relocate the creek and reconfigure a portion of the golf course. To do this, we have hired fisheries biologists and stream restoration experts, as well as a golf course architect. The final product will be consistent with the golf course master plan and provide safe refuge and habitat for fish in addition to detention. Details that had to be worked out included screening to avoid sucking fish into irrigation pumps and a way to keep them from being stranded in the ponds during low flow periods. Maintenance responsibilities, access during construction, site restoration, and mitigation for lost play during construction had to be worked out between the two City Departments and the private vendor that manages the golf course.

Another golf course has a long culvert under a fairway that prevents fish passage and cuts migrating salmon off from the upper two miles of creek. Immediately upstream of this culvert is an old rockery dam built during the Great Depression by the Works Progress Administration. It constitutes another fish passage obstruction. We are beginning design of a project to replace the culvert with one that will allow fish to swim upstream. Because of the historical significance of the dam and the fact that the area above it has completely silted in to form a large wetland, we will build a fish ladder around the dam. We will construct other habitat improvements throughout the golf course, including additional tree planting along the creek and also replace a couple of failing culverts that act as golf cart bridges.

### *Fauntleroy Fish Ladder*

In 1997, an inspection showed that a long culvert under a street near Puget Sound was failing. We decided to replace it in a way that would allow salmon to swim up into Fauntleroy Creek for the first time since 1914. Because the original culvert had a very steep slope, we installed two fish ladders. One was located under a parking lot with a conventional rectangular design. The other was placed alongside a private home where it is visible from the sidewalk. We formed this one with an S-shape and hired people who create imitation rocks at places like the zoo to make it look like a natural rock channel built into the landscaping in a small ravine. We built a viewing platform for people to watch the salmon swimming up through the fish ladder and hired an artist to incorporate public art into the design. Most of the creek upstream runs through a City park. The communities is thrilled with the design, and have donated countless hours of time restoring the creek, planting trees and shrubs, removing invasive plants, and using the site as a training site for school children. We developed an award-winning video about the design, construction, and community involvement of this project, which is used to recruit new volunteers and get people excited about the possibilities in our urban area. Within two weeks of project completion, over 200 salmon successfully swam up the culvert from Puget Sound to spawn – the first ones to reach Fauntleroy Creek in 85 years.

### *Swales*

We use grassed swales like many jurisdictions, but they are often hard to fit into a built environment. In one location, we regarded an alley down the center of a long residential block that had a ditch running through it. We planted the alley with grass and prepared to measure the sediment removal achieved by stormwater flowing through the grass. We found that spreading the water out allowed it to soak into the ground so it never reached the downstream end of the block. On another street with a steeper slope, we widened a ditch to about fifteen feet and created a series of shallow ponds with concrete weirs and landscaping. During storms, it can be clearly seen that the water entering the first pond is very muddy and the water in each succeeding pond is cleaner. Again, much of the water infiltrates the ground to recharge the creeks during low flows rather than increase high flows.

These experiments led to a concept that we call S.E.A. Streets (for street edge alternative). We achieved multiple benefits by creating a new look for one of our residential streets. In order to slow traffic and reduce impervious surfaces, we narrowed the pavement and introduced a gentle curve to a straight street. Instead of parallel parking, we have a few angled parking spots. Instead of ditches, we have a series of small, connected ponds and swales with wetland vegetation and other native landscaping. A meandering stone path is used instead of a sidewalk. Much of the right-of-way is now taken up with green space. The street is much more pleasant aesthetically. Some filtration and infiltration have enhanced the function of conveying stormwater. Future projects will attempt to build on this by incorporating porous pavement where the soils are suitable. We are beginning to experiment with porous paving for sidewalks to determine their effectiveness and maintenance needs.

This project did provide some challenges. During the design phase, we gave the property owners construction drawings to show them what the project would look like and obtain their approval. Not being engineers, they didn’t understand the drawings. When the project was under construction, the results weren’t what they expected, and we had to do some redesign to address their concerns. This pointed out the need for more up-front education and visual materials that the public can understand.

### *Gray to Green*

We are working with the Parks Department and the Seattle School District on what we call our Gray to Green Program. There are many asphalt or soggy grass playfields in Seattle. We are paying a portion of the cost to replace these with grass over layers of specially designed soil mixes and gravel. Rainfall drains down through soil and either infiltrates into the ground or drains slowly through the gravel to the drainage system. This is more effective than conventional detention at a similar cost and without taking up space. The result is a playfield that stays playable in all weather and is easier to maintain. Eliminating impervious surfaces also reduces the drainage fees we charge these properties.

Trees provide many functions in a natural stormwater system. They provide shade on the water and a canopy overhead to keep the air in riparian corridors cool during the summer. This is critical to cold-water species such as trout and salmon. The leaf litter and other falling debris provide a layer of duff on the ground that absorbs and slows runoff on its way to receiving waters. They capture and detain water on their leaves and branches. They stabilize steep hillsides and stream banks. For all of these reasons, Seattle Public Utilities works with volunteer groups to plant native trees and shrubs along creeks and on utility or open space property.

In addition to planting trees in less urbanized areas of the City, Seattle has long had a program to plant trees along streets. These are typically planted in a square pit dug in the sidewalk with a metal grate over the soil. Seattle Public Utilities is working with our Transportation Department to build extended tree pits with specially designed soil mixes to capture and treat runoff. The water would be infiltrated into the ground, absorbed by the tree roots, or could overflow to the drainage system.

### *Duwamish River Habitat Restoration*

The lower Duwamish River, which runs through Seattle's industrial district, is an estuary emptying into Elliott Bay. This area is critical to the development of salmon smolts during their migration to the Pacific Ocean. Seattle and King County are working with tribes and other agencies to develop areas of shallow mudflat habitat along the river for these juvenile salmon to escape from predators and find food as they spend time changing from the freshwater to saltwater environment.

### *Maintenance of Natural Systems*

ESA is a hot topic. As we build facilities to protect endangered salmon species, we need to be sure that not only the design but also the maintenance practices are done in conformance with ESA requirements. Drainage utility crews are very good at maintaining storm drains, culverts, and ditches. They know how to clean inlets, catch basins, and trash racks efficiently. Existing sewer and drainage utility crews may not be equipped to handle the maintenance of these unique natural-systems type facilities. They maintain some natural features such as roadside ditches, but that usually means mowing everything down and gouging out the bottom.

New facilities sometimes require types of work that haven't been needed up until now. This includes dredging of settling basins, removal of floating debris from ponds, working on golf courses, pruning trees and bushes on creek restoration sites, working in the water, relocating fish from a creek and bypassing the flows during maintenance, and proper cleaning of fish ladders. How do they know when maintenance is needed? These new facilities are designed for a purpose and with an intended function that may not be readily apparent to maintenance personnel. Staff is often reluctant to take over these new and unique facilities.

Sewer workers like cleaning sewers. They aren't interesting in landscaping or litter removal.

To address these issues, Seattle Public Utilities is developing operation and maintenance manuals for all new facilities that have unique or natural-systems features. Each manual contains a description of the facility and its intended purpose, along with the location and a vicinity map. Photos and diagrams help illustrate the sites. The manual contains a list of the project's components, an indicator of the condition that would require care, and the procedures to follow for maintenance. A detailed narrative of maintenance procedures for each component explains the steps for inspection, cleaning, and repair. It includes a list of any special requirements such as permits, access agreements, the equipment, tools, and materials needed, crew size, and frequency and estimated annual cost of maintenance. Each facility is added to the Utility's Infrastructure Management System for automatic maintenance scheduling and cost tracking.

The utility is beginning to assess the total maintenance needs for all of this work and then evaluate options for getting it accomplished. Because existing forces aren't trained or equipped to perform much of this work, the utility is looking at options. These might include hiring other City departments to do part of the work such as landscape maintenance, contracting with other agencies or private companies, or hiring and training staff and purchasing the needed special equipment. Volunteer groups or youth conservation corps workers can also do some of the work, such as removal of invasive plant species or litter and debris removal. The O & M Manuals, together with some initial experience carrying out the required maintenance, will help document the costs to facilitate obtaining needed resource.

## Conclusions

Seattle Public Utilities has shown, through a number of example projects, that a natural-systems approach to stormwater management can reduce flooding and improve water quality while improving habitat conditions. As we learn more about the species we are trying to protect, we continue to adopt our programs to meet those needs. These projects also soften the urban environment and make the city a nicer place to live and work.

Natural projects also create challenges. Wetland ponds attract wildlife. This can include waterfowl that add to the bacteria counts in the stream. Beavers may move into the site and begin cutting down newly planted trees to construct their lodges. Eventually, they may go after trees on neighboring properties, resulting in a public relations problem for the utility. Thousands of fish may swim into the ponds and become stranded there during low flows. Water in open ponds may increase water temperatures and lower dissolved oxygen levels. Wetlands will reduce many contaminants in stormwater, but may increase nutrients if not managed properly. Careful design has to take all of these things into consideration.

Citizen involvement is critical to our success. Residents want infrastructure upgrades. Our challenge is to have them accept natural systems in place of curbs, gutters, and storm drains. We must also design these facilities for ease of maintenance and work with Operations staff to incorporate their concerns into the design. Learning to create a new natural systems ethic will require changing the way we do business.

**Figure 1.** Seattle Streets – Before Construction

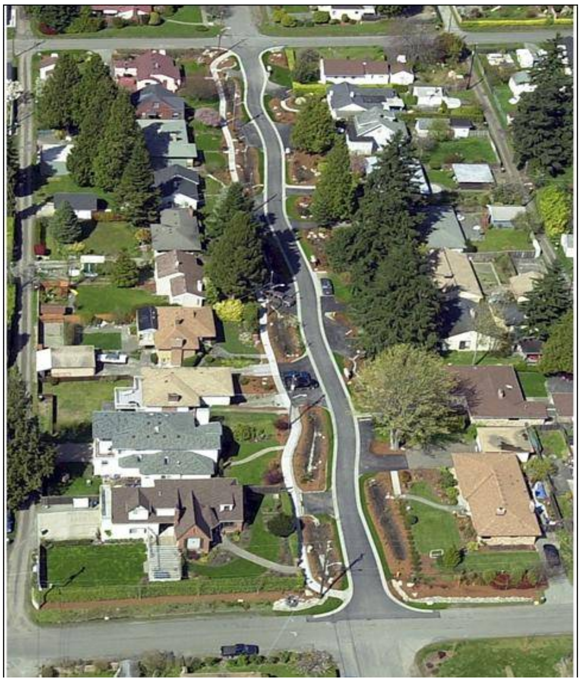

**Figure 2.** Seattle Streets – After Construction

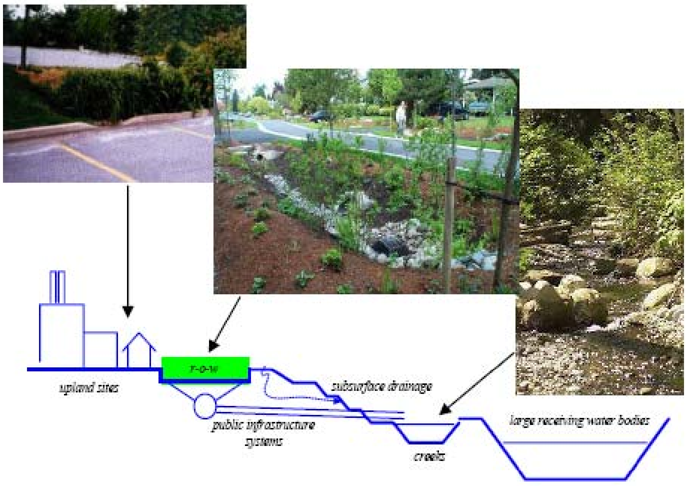


**Figure 3.** Opportunities within a watershed

WERC

Technical Paper

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# Preliminary Study on the Change of Landscape and Ecology in Sitou Tract of NTU Experimental Forest

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## Abstract

Due to natural disasters and human disturbances in recent years, the landscape in Central Taiwan suffered certain kind of changes. In particular, landslides caused by earthquake and heavy rainfall, improper use and development in hill slope areas enlarge and speed up the change of forest landscape. Several studies on the change of forest landscape by integrating remotely sensed data and Geographic Information System (GIS) informatics were published after the great Chi-Chi earthquake in 1999 and Typhoon Toraji in 2001. However, few studies were focused on the interactions and relationships between change of ecosystem and landscape. In this paper, a pioneering research is accomplished by using Landscape Pattern Metrics (LPM) derived from Satellite Imagery and GIS spatial coverage to model the possible pattern of change between landscape and ecology. Located at the mountainous area in central Taiwan, ranging from 800 to 1,800 meter and comprising 2,349 hectares in size, Sitou Tract of the National Taiwan University Experimental Forest is selected as the study site. Three FORMOSAT II images through 2004 to 2006 are used to compute LPM and analyzed with ecological investigation collected from seven ground sample sites. The preliminary result shows that by using remotely sensed data and ground investigation, it is feasible to monitor and assess the relationship between change of landscape and ecology in forests. It indicates that the recovery and restoration of vegetation after the human and natural disturbances highly correlates with the value of NDVI (Normalized Differential Vegetation Index), bird composition and diversity are highly correlated with the diversity of patches. The values of SHDI(Shannon Diversity Index), SIDI(Simpson Diversity Index）, SHEI(Shannon Evenness Index） and SIEI(Simpson Evenness Index）show that the diversity of landscape is growing while the evenness of landscape remains stable from 2004 to 2006. The proof for the obvious relationship between the change of ecology and landscape metrics is yet to be verified by subsequent ecological investigations.

**Keywords:** landscape, ecology, Landscape Pattern Metrics, satellite imagery, GIS

# 臺大實驗林溪頭營林區森林地景與生態變遷之初步研究

近年因天然與人為之干擾臺灣中部之森林地景遭受一定程度之改變，尤其在崩塌地因颱風及地震及人為不當利用更加速了森林地景之變化。自 1999 年集集大地震及 2001 年桃芝颱風後，利用遙測與地理資訊系統進行森林地景變遷之研究逐漸增多，然而較少研究針對生態系統與地景變化之交互作用與相關性進行探討。本研究利用遙測衛星影像及地理資訊系統空間圖資所推導之地景指標來建立地景與生態可能之相關性。研究地區選定臺大實驗林管理處之溪頭營林區，其面積為 2,349 公頃，高程介於 800 與 1800 公尺。研究中搜集 2004 至 2006 年福衛二號影像及七個地面樣區之生態調查資料，初步研究結果顯示利用遙測資料與地面調查資料來監督與評估森林地景與生態變遷之關係是可行的，在天然與人為干擾後植生之恢復與復育狀況與 NDVI 值呈現高相關；鳥種組成及多樣性與嵌塊體之多樣性亦呈高相關。Shannon 與 Simpson 之多樣性指標逐漸增高顯示其溪頭營林區之森林地景更加多樣化，Shannon 與 Simpson 之均勻度指標值穩定顯示其地景中之嵌塊體逐漸維持穩定。而生態變遷與地景指數之定量變化關係仍有待後續生態調查資料之持續搜集方能予以驗証。

**關鍵詞：**地景、生態、地景指標、衛星影像、地理資訊系統

## Introduction

After the natural disturbance such as earthquakes and typhoons in recent years, forest managers of the authorities need to assess and evaluate the restoration and recovery condition of forestland, in particular at the surrounding areas in Central Taiwan which were severely damaged by 921 Chi-Chi earthquake in 1999, typhoon Herb in 1996, typhoon Toraji in 2001 and typhoon Mindulle in 2004. All these natural disturbances cause landscape changes at different degrees. As the awareness of the protection and conservation for ecological restoration drawn by the public, there is an urgent need to model the relationship between the change of ecology and landscape. In this study, we propose a technique combined with remotely sensed data with the ground ecological investigation, to establish the relationship of landscape change and ecosystem. First the Landscape Pattern Metrics (LPM) is generated from satellite imagery using FRAGSTATS (McGarigal and Marks, 1995). Meanwhile, we collect the bio-resources of seven locations to get the ecological information on the changeable area by natural and human disturbances. It is believed that bird communities can stand as the indicators on the disturbed area (Raman etc., 1998). Therefore, investigations of vegetation and bird communities are represented as the bio-resources in this study. Finally the composition and configuration of LPM together with vegetation index are analyzed with corresponding bio-resources.

Since landscape ecology was introduced by C. Troll in 1939, researchers and managers for forest science had been used this new theory to understand how landscape reacts in the spatial configuration, internal functions and mutual interactions of their components between the interchange process of material and energy (Forman and Gordon, 1986; Turner, 1989; Christina et al., 1998; Lech, 2002; Maile, 2002). McGarigal and McComb (1995) investigated the relationship between landscape structure and breeding bird abundance in the central Oregon Coast Range. They quantified the independent effects of habitat area and configuration on 15 birds species associated with late-seral forest. Cheng et al. (1999a) presented that from the perspectives of spatial and temporal changes, the fractal dimension is a useful indicator for monitoring forest landscapes. Cheng (1999b) also recommended the use of the Shannon diversity index for representing landscape composition. In addition, the matrix, which is commonly made of natural broadleaf forests, should be included when quantifying landscape structures. Chen et al. (2005) used SPOT images to establish the spatial distributions of vegetation types that were used to estimate the indices of landscape structure and dynamics, and the result showed that the growth season images can be used to build vegetation distribution maps in Ken-Ting National Park by the Maximum Likelihood classification method. Chang et al. (2005) also use SPOT images to analyze the landscape metrics of Central Taiwan after the natural disturbances in recent years.

As the rapid development of Geographic Information System (GIS) and remote sensing technology in recent decades, hundreds of LPM had been proposed to describe the pattern-process relationship between landscape and ecology (Turner and Gardner, 1991). Maile et al. (2004) indicated the importance of the thorough understanding the theoretical behavior of landscape metrics and argued that understanding expected metric behavior could aid in selecting and interpreting metrics that are sensitive to changes resulting from a phenomenon of interest. Kearns et al. (2005) adopted multivariate factor analysis to reduce the redundancy of metrics to get important contextual information between landscape and freshwater in urban area.

## Methods and Material

This study can divide into four stages shown at Figure.1. At first stage the GIS spatial coverage and Digital Elevation Model (DEM) together with FORMOSAT II satellite imagery is collected. By the auxiliary information we can set suitable sample sites. Meanwhile, the ground investigation of vegetation and bird resources are also collected at this stage. Next the categorized land use types and training sample area are selected and satellite imagery classified by using Maximum Likelihood Method. At the third stage, the result of classification is input to the FRAGSTAT 3.3 software to compute LPM and values of NDVI and VRR are obtained from the satellite imagery. At the last stage, ground investigation is analyzed with the LPM, NDVI and VRR obtained at the previous stage to see if there exists certain relationship between the change of landscape and ecology.

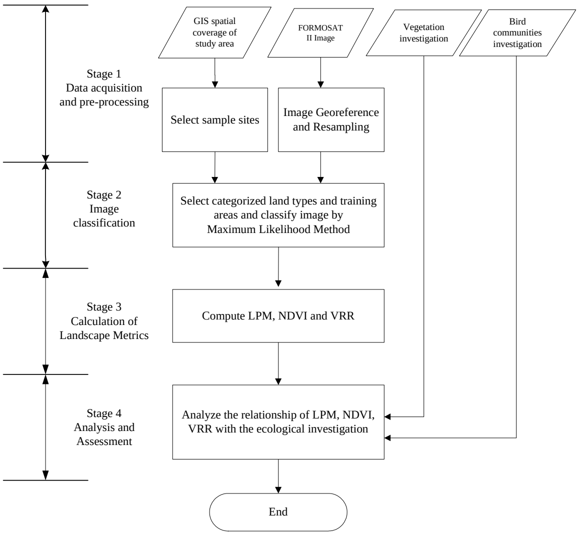


**Figure 1.** Flowchart of the study on the change of landscape and ecology using remotely sensed data and ground investigation

### *Study area*

The study area Sitou Tract comprises of 2,349 hectares of forestland, located at Lugu Township of Nantou which is under the jurisdiction of National Taiwan University Experimental Forest (NTUEF). Ranging from 800 to 1,500 meter, study area is in a dustpan valley surrounded by mountains with an open exit in northwestern direction. The location is shown at Figure.2. Due to the geomorphic characteristics, the study area is often mantled with fog both in autumn and winter while its average humidity is around 90% together with 2,611 mm of average annual rainfall. (Data from Sitou Nursery Agricultural Weather Station, 1941-2002) The typical tree species among the study area are *Cryptomeria japonica, Taiwania cryptomerioides* and natural evergreen broad-leaf trees like *Cinnamomum camphora* and *Lithocarpus castanopsisifolius* etc. Land use is distinguished from the topographic and environmental restraints, while its composition illustrated as Figure.3. After the Chi-Chi earthquake in 1999, the forestland in Sitou Tract was disturbed especially in the slope land, a lot of gullies and landslides were formed by rocks fallen from loosen ridges and peaks. According to the interpretation and estimation by aerial photo and ground survey, the damaged area exceeded 1,000 hectares. Except for natural forest and contract forest cultivated by residents, 254 hectares of plantation forest was collapsed. Among the damaged area, 30% was restored by artificial plantation, 30% was done by spreading the seeds of trees while the rest of areas near ridge and cliff was left to recover naturally. Unfortunately, there is not enough time for forestland to rest and restore. Within two years these gullies and landslides were further eroded due to the heavy rainfall of Typhoon Toraji in 2001 and resulted in disaster of debris flow. After these two natural disturbances, the authorities of NTUEF implemented over 100 projects by using ecological engineering methods. The project included filling up the fissures on the landslides and ridges, making corrections and management on upper watersheds and recovering and restoring the damaged forestland. (National Taiwan University Experimental Forest, 2003)

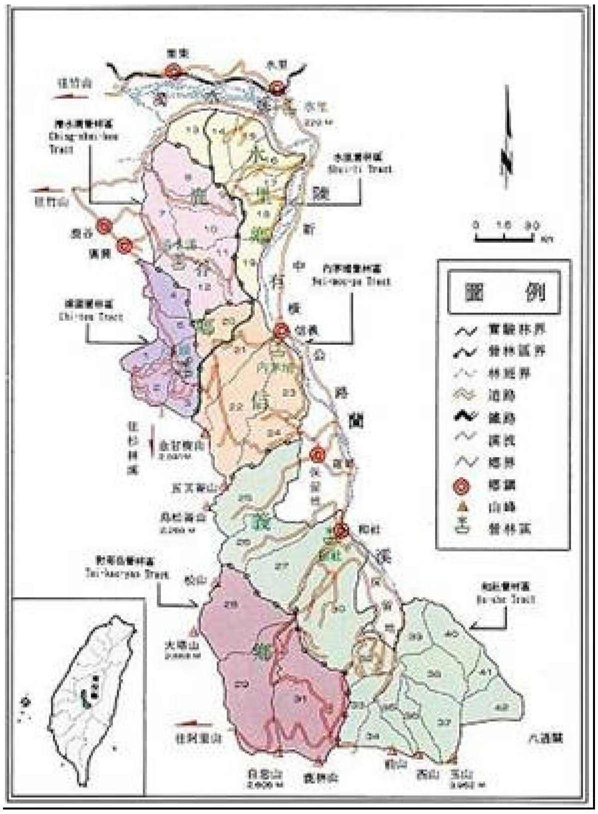

**Figure 2.** location of Sitou Tract

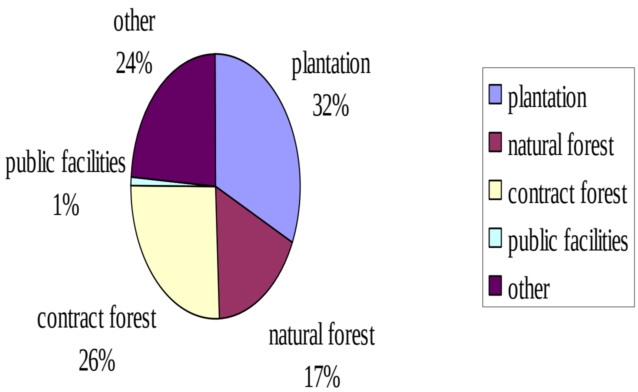


**Figure 3** Composition of land use in Sitou Tract

***Remotely sensed data***

In this study, satellite imagery, aerial photo, DEM and digital map for land use are used to categorize the land use then obtain LPM. The FORMOSAT II satellite passes the space above Taiwan twice a day to capture imagery with resolution 8 meter in multi-spectral and 2 meter in panchromatic band, the characteristics of these channels also shown as Table 1. Due to the high resolution in space and short revisit time interval, three FORMOSAT II images acquired from Spatial Information Research Center (SIRC) of National Taiwan University are selected to represent land cover information from 2004 to 2006, while the acquisition date depends on weather and atmospheric condition, in particular with no cloud cover. The detailed attribute data are shown in Table 2. With the satellite imagery and digital map, in addition to the field investigation, training samples of different land type are selected for land use classification.

**Table 1** Band characteristics of FORMOSAT II imagery

| | Band | Band width( $\mu m$ ) | Ground resolution (m) |
|---|---|---|---|
| MSS | B | 0.45-0.52 | 8 |
| | G | 0.52-0.60 | |
| | R | 0.63-0.69 | |
| | Near IR | 0.76-0.90 | |
| PAN | | 0.45-0.90 | 2 |

**Table 2** Attribute data of acquired FORMOSAT II imagery

| No. | Date of Acquired | Ground Resolution (m) MSS | Level of Georeference |
|---|---|---|---|
| 1 | 2004.11.12 | 8 | II |
| 2 | 2005.12.20 | 8 | II |
| 3 | 2006.11.10 | 8 | II |

### *Land use classification*

The land type is based on classification of the third forest resources investigation by Forestry Bureau (Forestry Bureau, 1995). Due to the limitation of spatial and spectral resolution of the imagery, it seems impractical to categorize the land type as fine as even the different broadleaf trees can be distinguished as a single land use. Hence, the classification has to be combined and simplified according to the similar properties of the land type on the spectrum. Seven land types are categorized: forest, bamboo, grassland, farmland, road and building, water and bare land. Digital map of land use, which is made after Typhoon Toraji by Chiou (2003), is used as the reference map for selecting training samples. Besides, GIS spatial coverage such as the boundary of forest compartment, DEM, aerial photos and photos taken at study sites are also auxiliary information for locating the correct sites of training samples. We use commonly supervised Maximum Likelihood Method to classify the satellite imagery into seven land types. After the classification is done, the classified land use is converted to raster grid type, which is the input item for calculating LPM. The whole imagery process is operated under the working environment of TNT MIPS software.

### *Landscape Pattern Metrics*

FRAGSTATS (McGarigal and Marks, 1995) software is used to compute LPM. The software computes the landscape in three different scales: patch, class and landscape. LPM is divided into eight groups for describing the composition and configuration of landscape. Those groups contain properties of patches such as area, density, edge, shape, core area, isolation and proximity, contrast, contagion and interspersion, connectivity and diversity. Landscape Pattern Metrics, except some of them like the core area and contrast are used in this study. Detailed definitions of LPM, readers are referred to the context of analysis program on the internet (McGarigal et al., 2002) and only LPMs at landscape scale are listed in equation (1) to (6). Some parameters such as edge depth and weighted edge of core area and contrast, however, are needed to be initialized the adequate values in subsequent study. After the classification grid data and its basic information, such as the cell size, columns and rows of imagery have been input to the user's interface, FRAGSTAT will start to compute all the LPM. The computation time required depends on the size, number of patches and class types and also processing ability of the computer hardware.

Shannon Diversity Index (SHDI)

$$SHDI = -\sum_{i=1}^{m}\left(p_i \ln p_i\right) \quad (1)$$

$p_i$ =proportion of the landscape occupied by patch type (class) i.

Shannon Evenness Index (SHEI)

$$SHEI = \frac{-\sum_{i=1}^{m}\left(p_i \ln p_i\right)}{\ln m} \quad (2)$$

$p_i$ =proportion of the landscape occupied by patch type (class) i.
$m$ =number of patch types (classes) present in the landscape, excluding the landscape border if present.

Simpson Diversity Index (SIDI)

$$SIDI = 1 - \sum_{i=1}^{m} p_i^{\,2} \quad (3)$$

$p_i$ =proportion of the landscape occupied by patch type (class) i.

Simpson Evenness Index (SIEI)

$$SIEI = \frac{1 - \sum_{i=1}^{m} p_i^{\,2}}{1 - \left(\frac{1}{m}\right)} \quad (4)$$

$p_i$ =proportion of the landscape occupied by patch type (class) i.
$m$ =number of patch types (classes) present in the landscape, excluding the landscape border if present.

Modified Simpson Diversity Index (MSIDI)

$$MSIDI = -\ln \sum_{i=1}^{m} p_i^{\,2} \quad (5)$$

$p_i$ =proportion of the landscape occupied by patch type (class) i.

Modified Simpson Evenness Index (MSIEI) (6)

$p_i$ =proportion of the landscape occupied by patch type (class) i
$m$ =number of patch types (classes) present in

$$MSIEI = \frac{-\sum_{i=1}^{m} p_i^{\ 2}}{\ln m}$$

the landscape, excluding the landscape border if present.

### *Vegetation Evaluation on sample sites*

Normalized Difference Vegetation Index (NDVI) is commonly used as an indicator for the change of ground vegetation (Cohen, 1991). Due to the characteristic of reflecting infrared light but absorbing red light for green vegetation, when NDVI decreases after natural or human disturbance, it can be referred the vegetation area shrinks. On the contrary, the vegetation area expands when NDVI increases. We define a new index, VRR, which stands for Vegetation Remnant Rate for evaluating the recovery of vegetation. If the VRR value equals 100%, it represents that the vegetation turns back to the same original condition before the disturbance. If the NDVI value only reaches 50% of the condition before the disturbance, the VRR value will be 50%. The VRR value may exceed 100% or be negative if the recovery condition is even better or worse than before. The calculated form for NDVI and VRR are expressed as equation (7) and (8).

$$NDVI = \frac{(IR - R)}{(IR + R)} \quad (7)$$

where $R$ is the reflectance of red light and

$IR$ is the reflectance of infrared light

$$VRR(\%) = \left(1 - \frac{(NDVI_0 - NDVI_1)}{|NDVI_0|}\right) \times 100\% \quad while \quad NDVI_0 \neq 0 \quad (8)$$

where $NDVI_0$ stands for the NDVI value before the disturbance

$NDVI_1$ stands for the NDVI value after the disturbance

Since there are three satellite imagery used in this study, the imagery of 2004 will be regarded as the base year for vegetation, the change for next two years can be obtained using equation (8).

### *Ecological Investigation*

We select seven sample sites for ecological investigation (See Table 3). The sites are located in second, third and fourth compartment in Sitou Tract as shown in Figure.4. Ranging from 800 to 1,500 meters high, these sites suffered severe landslide and debris flow damage in recent years except the seventh site. The sample sites reveal the significant forming factors for the change of forest landscape. The first sample site is located at the down slope land of Sun-Link-Sea Road where one is up-stream of Bei-Shi River. It was loosen by the heavy 921 Chi-Chi earthquakes and surface soil and rocks of slope land were pulled down and expanded the bare area by subsequent typhoons. The second, third, fourth and fifth sites are located at the transitional path of debris flow passed during Typhoon Toraji and Nalie. The sixth site, as the first site, was also located at the slope land near ridges. This site is unique because the stratum in situ is along the same direction as the surface slope which causes the slope land is very vulnerable and easy to collapse and slide. On the other hand, the seventh site is far from the disturbance of earthquake and typhoon that is suitable as the comparison set of the typical condition of forestland before disturbance in Sitou Tract.

The ecological investigation was divided into two parts: vegetation and bird communities. We set seven sample sites for investigation of vegetation which each one contains 20 meters by 20 meters square area. Each region was be divided into sixteen sub-regions which accommodate 5 meters by 5 meters for investigating three factor including relative dominance, relative frequency and relative density. Important Value Index (IVI) will be the average percentage of these three factors for representing the composition of society of flora. If the vegetation inside the sub-region were herbaceous plants, the IVI will be the average percentage of relative coverage and relative frequency. The computational form for IVI is as Equation (9). The time interval for investigating the vegetation will be once a year, considering there is no significant seasonal change.

**Table 3** Attribute data of samples sites

| Site No. | Name | Compartment No. | Plantation No. | TM2 X (m) | TM2 Y (m) | Elevation (m) | Slope (%) | Aspect (°) |
|---|---|---|---|---|---|---|---|---|
| 1 | Landslide below the Sun Link Sea Road | 2 | 74-2 | 226454 | 2618016 | 1448 | 35.5 | 317.9 |
| 2 | University Gully upstream | 2 | 49-1 | 227354 | 2617984 | 1277 | 18.1 | 41.3 |
| 3 | University Gully downstream | 2 | 49-1 | 227412 | 2618245 | 1241 | 9.8 | 46.5 |
| 4 | Liu-Long Gully upstream | 3 | 76-10 | 227925 | 2618176 | 1251 | 14.9 | 21.3 |
| 5 | Liu-Long Gully downstream | 3 | 76-10 | 228005 | 2618287 | 1229 | 12.1 | 87.6 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 6 | Landslide beside Nei-Hu Elementary School | 4 | 93-3* | 227186 | 2623187 | 802 | 33.3 | 19.5 |
| 7 | No.166 Plantation | 3 | 166 | 228433 | 2618421 | 1188 | 13.5 | 324.5 |
| | * just beside the plantation site | | | | | | | |

For wooden plants (9)

$$IVI = (relative\ density + relative\ dominace + relative\ frequency)/3$$

while $relative\ density = density\ of\ certain\ kind / total\ density \times 100$

$$relative\ dominance = bottom\ area\ of\ certain\ kind / total\ bottom\ area \times 100$$

bottom area is computed by DBH (Diameter of Breast Height) curve

$$relative\ frequency = numbers\ of\ sample\ area\ for\ certain\ kind / numbers\ of\ total\ area \times 100$$

for herbaceous plants

$$IVI = (relative\ coverage + relative\ frequency)/2$$

while

$$relative\ coverage = coverage\ of\ certain\ kind / total\ coverage\ of\ all\ kinds \times 100$$

$$relative\ frequency = numbers\ of\ sample\ area\ for\ certain\ kind / numbers\ of\ total\ area \times 100$$

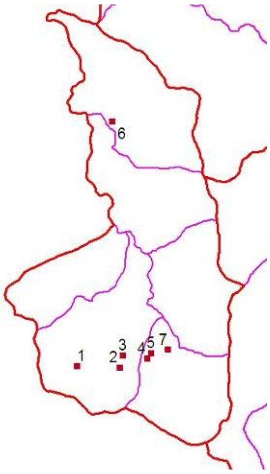


**Figure.4** Location of sample sites

The fixed-distance circular-plot method was used to estimate bird density. We counted all birds seen or heard within 50 m at the center of samples sites, and bird species and number of individuals were recorded. When we heard, but unable to see, more than one bird of flocking species, we assumed it was a single group of that species. In this case, we used the average group size for that species during the season in question (breeding or non-breeding) to

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estimate the number of individuals. Bird density can be represented as equation (10).

$$D = \left[ \frac{N}{\left(P \times R^2 \times 3.14 \times C\right)} \right] \times 10000$$

(No./ha)

While $N$ donates the total number of birds recorded (10)

$P$ number of sample points

$C$ number for investigations

### *Model the relationship between LPM, NDVI, VRR and Ecological Data*

Since the ecological data were only investigated in 2006, therefore, the ecological change will be obtained in subsequent years. However, from the results of investigation, the flora and fauna still may exhibit certain relationship reflected on the LPM, NDVI and VRR. In particular, the first six sample sites located on landslide area was compared with the undisturbed seventh sample site. The variation of these parameters derived from remotely sensed data will be reflected on the ecological change.

## Results

### *Land use classification*

The results for classification of imagery between 2004 and 2006 are shown in Figure 5 Figure 6 and Figure 7. The whole imagery is distinguished into seven pre-defined land use type. The overall accuracy and kappa value of each year is 90.57%, 86.33%, 87.71% and 0.814, 0.686, 0.677 respectively. From the error matrix of classification, we can see that the most misclassification occurs at the bamboo and forest type, water with road and building. The possible reason is that there are some mixed area containing forest and bamboo, due to the limitation of the spatial resolution of satellite imagery, it is not possible to categorize the mixed pixel into correct land type. On the other hand, the upper stream of study area most eroded by the debris flow, the riverbed still filled with a lot of rocks, which cause the reflectance very similar with the paved road and building on the spectrum. Meanwhile, the discharge of the gullies streams eroded by the debris flow is not much in most time of the year, not to mention the date of satellite imagery acquired is on November and December, which falls on dry season of streams in Taiwan.

Error Matrix

Ground Truth Raster... \formosat2\5-classify\2004\20041112.rvc / CATEGORIES Help Close

| Classificat | Ground Truth Data | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Name | forest | bamboo | grass | farmland | roadbuil | water | bareland | Total | Accuracy |
| forest | 41358 | 755 | 0 | 14 | 33 | 7 | 6 | 42173 | 98.07% |
| bamboo | 1880 | 18354 | 3 | 275 | 137 | 105 | 62 | 20816 | 88.17% |
| grass | 10 | 177 | 83 | 69 | 60 | 48 | 192 | 639 | 30.05% |
| farmland | 388 | 1414 | 0 | 755 | 150 | 51 | 60 | 2818 | 50.18% |
| roadbuil | 127 | 20 | 5 | 27 | 480 | 50 | 32 | 741 | 64.78% |
| water | 134 | 117 | 3 | 98 | 434 | 246 | 96 | 1128 | 38.48% |
| bareland | 5 | 129 | 8 | 36 | 136 | 111 | 294 | 719 | 40.89% |
| Total | 43902 | 20966 | 102 | 1274 | 1430 | 618 | 742 | 69034 | |
| Accuracy | 94.21% | 94.29% | 0.00% | 0.00% | 63.92% | 0.00% | 65.50% | | |

Overall Accuracy = 90.57% Khat Statistic = 81.40%

**Figure 5** The error matrix for land use classification of 2004 imagery

Error Matrix

Ground Truth Raster... C:\formosat2\5-classify\20051220.rvc / CATEGORIES  Help  Close

| Classificat: Name | forest | bamboo | grass | farmland | roadbuil | water | bareland | Total | Accuracy |
|---|---|---|---|---|---|---|---|---|---|
| | Ground Truth Data | | | | | | | | |
| forest | 28323 | 562 | 0 | 0 | 56 | 119 | 7 | 29067 | 97.44% |
| bamboo | 1480 | 6495 | 8 | 40 | 54 | 319 | 61 | 8457 | 76.80% |
| grass | 555 | 335 | 83 | 36 | 71 | 67 | 157 | 1304 | 42.56% |
| farmland | 4 | 530 | 1 | 586 | 255 | 228 | 63 | 1667 | 35.15% |
| roadbuil | 8 | 7 | 0 | 7 | 455 | 51 | 114 | 642 | 70.87% |
| water | 486 | 400 | 3 | 46 | 182 | 284 | 70 | 1471 | 33.04% |
| bareland | 2 | 17 | 3 | 0 | 120 | 63 | 439 | 644 | 68.17% |
| Total | 30858 | 8346 | 98 | 715 | 1193 | 1131 | 911 | 43252 | |
| Accuracy | 95.16% | 77.82% | 0.00% | 81.96% | 38.14% | 0.00% | 48.19% | | |

Overall Accuracy = 86.33%  Khat Statistic = 68.62%

**Figure 6** The error matrix for land use classification of 2005 imagery

Error Matrix

Ground Truth Raster... 5-classify\20061110\20061110-classi.rvc / CATEGORIES  Help  Close

| Classificat: Name | forest | bamboo | grass | farmland | roadbuil | water | bareland | Total | Accuracy |
|---|---|---|---|---|---|---|---|---|---|
| | Ground Truth Data | | | | | | | | |
| forest | 37842 | 257 | 2 | 27 | 61 | 392 | 18 | 38599 | 98.04% |
| bamboo | 1211 | 7401 | 24 | 99 | 70 | 478 | 109 | 9392 | 78.80% |
| grass | 29 | 541 | 101 | 1 | 13 | 78 | 156 | 919 | 58.87% |
| farmland | 2900 | 1206 | 0 | 406 | 267 | 260 | 16 | 5055 | 57.37% |
| roadbuil | 24 | 32 | 3 | 6 | 793 | 81 | 20 | 959 | 82.69% |
| water | 935 | 216 | 7 | 42 | 364 | 533 | 39 | 2136 | 43.77% |
| bareland | 14 | 113 | 42 | 26 | 72 | 190 | 295 | 752 | 39.23% |
| Total | 42955 | 9766 | 179 | 607 | 1640 | 2012 | 653 | 57812 | |
| Accuracy | 97.02% | 81.32% | 0.00% | 0.00% | 48.35% | 0.00% | 45.18% | | |

Overall Accuracy = 87.71%  Khat Statistic = 67.72%

**Figure 7** The error matrix for land use classification of 2006 imagery

### *Computation of Landscape Pattern Metrics*

The LPM at class level is calculated by FRAGSTATS software for three satellite imagery. Forest, bamboo and farmland are three major land use types in the study area. Due to the limited context in this paper, the results of LPM between 2004 and 2006 are not listed here. From the LPM value of CA (Total Class Area), NP (Number of Pathces), AREA_MN (Average Area) and GYRATE_MN( Average Radius of Gyration), it is obvious that number of forest patch is less than bamboo and farmland, and the average area of each forest patch is significant larger than the other two types. From the LPM value of AI (Aggregation Index) and CLUMPY (Clumpiness Index), we can tell that the forest is more aggregated and clumpy than the other two types, which is satisfied with the expectation that the forest land is the dominant patch type in study area. LPM value at landscape level shown in Table 4, among the values PR(Patch Richness), PRD (Patch Richness Density) and RPR (Relative Patch Richness) are all the same because every patch in three satellite imagery are categorized into different land types. SHDI and SIDI increase gradually which represents the diversity of landscape is growing after the natural and human disturbance. SHEI and SIEI increase from 2004 to 2005 and almost equal with value of 2005 in 2006 which also reflects the evenness of landscape remains stable.

**Table 4** LPM values at landscape level between 2004 and 2006

| LPM | 2004 | 2005 | 2006 |
|---|---|---|---|
| PR | 7 | 7 | 7 |
| PRD | 0.1513 | 0.1513 | 0.1513 |

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| | | | |
|---|---|---|---|
| RPR | 100 | 100 | 100 |
| SHDI | 1.2246 | 1.3766 | 1.4092 |
| SHEI | 0.6293 | 0.7074 | 0.6911 |
| SIDI | 0.6335 | 0.6794 | 0.7242 |
| SIEI | 0.7391 | 0.7926 | 0.8063 |
| MSIDI | 1.0038 | 1.1376 | 1.1749 |
| MSIEI | 0.5158 | 0.5846 | 0.6038 |

Due to the location of pre-assigned sample sites, we pay more attention on the LPM change of bare land. In Table 5, we observe that the area of bare land shrinks to almost a half of 2004 in 2005 but expands in 2006. The possible reason is that there is no significant natural disaster in 2005. Geological and hydrological conditions at bare lands make it possible for vegetation to recover and restore without much disturbance. However, a heavy rainfall occurred on June 9 2006, according the record of Sitou Office rain gauge, the total amount was 769 mm in 72 hours. Although no debris flow disaster happened, there is still a lot of soil and rocks carried by water flow from upstream towards downstream. An obvious evidence at downstream of third sample site of University Gully shown as Figure.8, riverbed near the newly built sabo dam made of Japanese Fir was filled with sands and little rocks after the heavy rainfall event. The area of bare land (AREA) in Sitou Tract expands from 21.42 hectare to 33.27 hectare, number of patches (NP) increases from 1062 to 2168 and average patch area shrinks from 0.0202 hectare to 0.0153 hectare. The fractal dimension (FRAC) decreases a little from 1.0396 of 2004, 1.0373 of 2005 to 1.0327 of 2006. The FRAC value approaches 1, as Turner (1993) stated, the self-similarity will be stronger while the shape and configuration of patches will be more regular and simple. From the result of FRAC value, the landscape configuration of bare land becomes simple during these three years. The LPM of AREA_MN, GYRATE, CONTIG (Contiguity Index), ENN (Euclidean Nearest-Neighbor Distance), CLUMPY, PLADJ (Percentage of Like Adjacencies), IJI (Interspersion and Juxtaposition Index), CONNECT (Connectance Index), COHESION(Patch Cohesion Index), AI also shows similar trends: As the area of patches shrinks, these LPM values increase; on the contrary, the area of patches expands, LPM values decrease. These results imply that the less area of bare land exists, the patches become more aggregated and simple in shape. That also means the total length (TE) and edge density (ED) of patches will be less which causes the interaction and interchange between patches will also be lower than other patch types.

**Table 5** LPM values of bare land class between 2004 and 2006

| LPM | 2004 | 2005 | 2006 |
|---|---|---|---|
| CA | 42.7392 | 21.4208 | 33.2736 |
| PLAND | 0.9225 | 0.4631 | 0.7194 |
| NP | 2656 | 1062 | 2168 |
| PD | 57.3307 | 22.9601 | 46.8715 |
| LPI | 0.0209 | 0.0257 | 0.0249 |
| TE | 153808 | 66024 | 118680 |
| ED | 33.2 | 14.2742 | 25.6582 |
| LSI | 59.189 | 35.9483 | 51.4345 |

| | | | |
|---|---|---|---|
| AREA_MN | 0.0161 | 0.0202 | 0.0153 |
| AREA_AM | 0.0977 | 0.1688 | 0.1355 |
| AREA_MD | 0.0064 | 0.0064 | 0.0064 |
| AREA_RA | 0.96 | 1.184 | 1.1456 |
| AREA_SD | 0.0362 | 0.0547 | 0.0429 |
| AREA_CV | 225.142 | 271.4335 | 279.8253 |
| GYRATE_MN | 5.355 | 5.6428 | 5.1047 |
| SHAPE_MN | 1.1184 | 1.1144 | 1.0941 |
| FRAC_MN | 1.0396 | 1.0373 | 1.0327 |
| PARA_MN | 4519.86 | 4397.593 | 4549.025 |
| CIRCLE_MN | 0.4555 | 0.4539 | 0.4428 |
| CONTIG_MN | 0.0844 | 0.1025 | 0.0772 |
| PAFRAC | 1.5699 | 1.4914 | 1.544 |

| | | | |
|---|---|---|---|
| PROX_MN | 1.3695 | 1.3672 | 1.4274 |
| ENN_MN | 29.9878 | 41.0805 | 34.5019 |
| CLUMPY | 0.2699 | 0.3808 | 0.2816 |
| PLADJ | 27.3211 | 37.7054 | 28.2747 |
| IJI | 88.58 | 94.0423 | 89.4408 |
| CONNECT | 0.2226 | 0.3779 | 0.2577 |
| COHESION | 58.5828 | 64.4913 | 60.0105 |
| DIVISION | 1 | 1 | 1 |
| MESH | 0.0009 | 0.0008 | 0.001 |
| SPLIT | 5142176 | 5917698 | 4744490 |
| AI | 27.6607 | 38.3703 | 28.6745 |
| NLSI | 0.7234 | 0.6163 | 0.7133 |

a) sabo dam made of Japanese Fir just finished on Feb 8 2006

b) after the heavy rainfall event on Jun 26 2006

**Figure 8.** Photos taken before and after the heavy rainfall on June 9 2006 at University Gully

### *Ecological investigation*

Result of Vegetation Investigation is shown as Table 6. We find 165 species of vegetation in all seven sample sites. From the calculation of IVI, due to the limitation of the context, we only list the first ten largest IVI values of vegetation species in Table 7. *Miscanthus floridulus*, which is very common pioneering herbaceous specie especially on bare land, its IVI is 31.62 with the coverage of 26.23%. The other dominant species, including *Pueraria Montana, Elatostema edule, Debregeasia edulis, Hibiscus taiwanensis* are also common vegetation species on bare lands. The IVI ranges from 3.68 to 31.62 and coverage ranges from 2.11 % to 26.23% for the first ten largest species. The IVI and coverage shows positive relationship except for *Alocasia macrorrhiza*. The possible reason is that this specie is dominant at the seventh sample site, at the shadow bottom below canopy of Japanese Fir where the environment is very humid, its IVI is as high as 24.81 at the seventh site instead of only 5.60 for overall sample sites.

**Table 6** Investigation result of vegetation at sample sites in 2006

| | pteridophyte | gymnosperm | angiosperm | | Sum |
|---|---|---|---|---|---|
| | | | monocotyledon | dicotyledon | |
| No. of family | 13 | 2 | 43 | 7 | 65 |
| No. of genus | 21 | 3 | 86 | 27 | 137 |
| No. of specie | 31 | 3 | 98 | 33 | 165 |

**Table 7** First ten largest IVI vegetation species at samples sites in 2006

| Scientific Name | Chinese Name | IVI | Coverage (%) | Relative frequency (%) |
|---|---|---|---|---|
| *Miscanthus floridulus* | 五節芒 | 31.62 | 26.23 | 37.01 |
| *Pueraria montana* | 葛藤 | 14.48 | 11.35 | 17.61 |
| *Elatostema edule* | 闊葉樓梯草 | 11.82 | 9.88 | 13.76 |
| *Debregeasia edulis* | 水麻 | 9.45 | 6.06 | 12.84 |
| *Hibiscus taiwanensis* | 山芙蓉 | 8.91 | 5.96 | 11.86 |
| *Gonostegia hirta* | 糯米團 | 8.29 | 3.65 | 12.93 |
| *Diplazium dilatatum* | 廣葉鋸齒雙蓋蕨 | 8.17 | 3.09 | 13.25 |
| *Alocasia macrorrhiza* | 姑婆芋 | 8.11 | 5.60 | 10.62 |
| *Equisetum ramosissimum* | 木賊 | 5.41 | 2.91 | 7.91 |
| *Angiopteris lygodiifolia* | 觀音座蓮 | 3.68 | 2.11 | 5.25 |

Investigation results of bird communities are listed as Table 8 (the overall of 35 bird species for 17 families). We observed 23, 24, and 19 bird species of birds in the three seasons in 2006 respectively. Among the overall sites, the first sample site which is located at landslide below the Sun Link Sea Road, contains 16 species and highest relative abundance of 50.8 No/ha. From table 8, it is referred that the first sample site and fourth site contains more species and higher relative abundance than other sites. The sixth sample site, located at landslide beside Nei-Hu Elementary School, contains less species and lower relative abundance. The species and relative abundance is comparative higher in winter season with spring and summer, while the latter contains the lowest value. It is likely that first site is progressing the succession of vegetation, which represents the pioneering plants has turned into the next dominant tree species. The biodiversity of vegetation provides a suitable habitat for birds. On the other hand, the fourth site is located at the edge of Liu-Long Gully, which used to be the well-covered Japanese Fir forest but destroyed by the debris flow. The width of Liu-Long Gully is within the diameter for counting birds which also provides the transition area for the birds to breed and to find shelters. The edge along the patch of pure forest type and bare land also provides diverse habitat for aquatic vegetation, insects, amphibians to live in, which is also the important factor to attract birds to stay. The seventh site, located in No.166 Plantation, contains almost the least species and lower relative abundance. As the typical man-made Japanese fir forest, this site is free from the severe disturbances of natural disasters. Despite there is still limited thinning cutting for nurturing operation, the area is very small compared with the forest patch and the influence on landscape can be negligible. The pure patch provides simple and homogeneous habitat for birds to stay somehow makes the environment without much interaction with the surroundings.

**Table 8** Investigation results of bird communities at sample sites in 2006

| | | | | | |
|---|---|---|---|---|---|
| 1st season (winter) | | | | | |
| sample site | Landslide below the Sun Link Sea Road | University Gully | Liu-Long Gully | Landslide beside Nei-Hu Elementary School | No.166 Plantation |
| No. of specie | 16 | 13 | 13 | * | 11 |
| Relative density (D) | 50.8 | 31.2 | 43.3 | * | 30.9 |
| | number of family=10<br>number of specie=23 | | | | |
| 2nd season (spring) | | | | | |
| No. of specie | 15 | 13 | 9 | 12 | 9 |
| Relative density (D) | 37.5 | 31.2 | 30.3 | 31.3 | 21.6 |
| | number of family=11<br>number of specie=24 | | | | |
| 3rd season (summer) | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| No. of specie | 11 | 10 | 7 | 5 | 11 |
| Relative density (D) | 31 | 29.8 | 33.1 | 24.2 | 22.4 |
| number of family=8<br>number of specie=19 | | | | | |
| Total No. of specie | 21 | 18 | 20 | 24 | 14 |
| Average relative density (D) | 39.8 | 30.7 | 35.6 | 27.8 | 25.0 |
| * data were not investigated<br>4th season data were not investigated | | | | | |

### *Relationship between LPM, NDVI, VRR and ecological investigation*

Though the ecological investigation was done in 2006, the relationship between change of ecological resources and LPM could be analyzed by the following investigation of next two years. However, LPM calculated from 2004 to 2006 especially for bare land, shows that patches become simpler and more aggregated in these three years. From Table 9 and Figure.9, we can observe that NDVI of the majority of sample sites is increasing except for sites located at upstream and downstream of University Gully. The possible reason is that this site was eroded by the sands and rocks and became the movement zone for debris, so the gullies itself remain unstable for vegetation to recover and restore. The NDVI at upstream sample site of University Gully decreases from 0.097 in 2004 to 0.055 in 2005 and 0.078 in 2006, while at downstream site NDVI also decreases from 0.157 in 2004 to 0.007 in 2005 and 0.092 in 2006. The trend supports that this site is quite unstable and is vulnerable to be disturbed by the interference. Nevertheless, the specie of bird resources in situ remains good but has lower relative abundance. The possible reason is that the situation at University Gully is quite similar to the fourth sample site Liu-Long Gully. It was originally a man-made plantation site of Japanese Fir and Taiwan. The difference between the two sites is that the width of University Gully is much wider compared to that of Liu-Long Gully. The widest part of University can reach 120 meters than within 50 meters at Liu-Long Gully. The wider width causes birds to be exposing in the spacious space to its natural enemy. That reduces the appearance of the birds, though the species are still good due to the diversity of the habitat. The fourth sample site located at Liu-Long Gully, though the NDVI is comparatively low with other sites, the value grows significantly to 0.307 in upstream and 0.134 in downstream and exhibits the highest VRR value with 767.5% and 297.8%. The first sample site, despite exists the lowest NDVI values of all samples sites, the slope land becomes stable and the recovering condition of vegetation is good. The trend of increasing NDVI coincides with the analysis of the landslide monitoring by Wei (2006). The seventh site, though NDVI obtained from the reflectance of the canopy, which fails to represent the ground vegetation, the values remain stable around 0.2 and VRR values around 100%. Compared with the other six samples sites, the seventh site represents the undisturbed, typical forest condition and contains almost the least bird species and lower relative abundance.

**Table 9** NDVI and VRR value at sample sites between 2004 and 2006

| No. | Sample site | NDVI | | | VRR (%) | |
|---|---|---|---|---|---|---|
| | | 2004 | 2005 | 2006 | 2004-2005 | 2004-2006 |
| 1 | Landslide below the Sun Link Sea Road | -0.429 | -0.348 | -0.200 | 118.8 | 153.3 |
| 2 | University Gully upstream | 0.097 | 0.055 | 0.078 | 56.8 | 80.6 |
| 3 | University Gully downstream | 0.157 | 0.007 | 0.092 | 4.5 | 58.7 |
| 4 | Liu-Long Gully upstream | 0.040 | 0.055 | 0.307 | 137.5 | 767.5 |
| 5 | Liu-Long Gully downstrem | 0.045 | 0.047 | 0.134 | 104.4 | 297.8 |
| 6 | Landslide beside Nei-Hu Elementary School | 0.075 | 0.126 | 0.189 | 168.0 | 252.0 |
| 7 | No.166 Plantation | 0.203 | 0.205 | 0.202 | 101.0 | 99.5 |

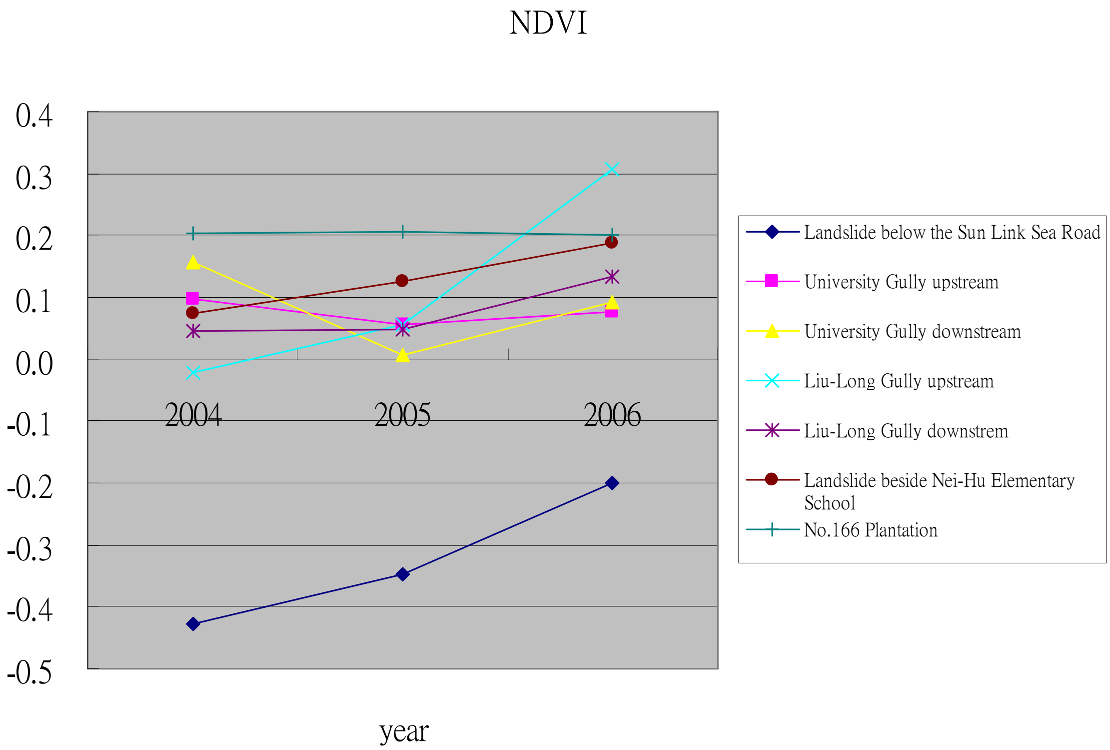


**Figure 9.** Change of NDVI at seven sample sites between 2004 and 2006

## Discussion

The overall accuracy and kappa value for classification of 2004 to 2006 satellite imagery is 90.57%, 86.33%, 87.71% and 0.814, 0.686, 0.677 respectively. Three issues for the classification accuracy are yet to be discussed: the accuracy of image georeference, classification and the suitable time for imagery acquired. The georeference level for the acquired satellite imagery is only Level II, which still not satisfy the standard of image orthorectification. That leaves the possibility of image pixel corresponds to the actual terrain site with displacements. Secondly, due to the limitation of spatial and spectral resolution of FORMOSAT II, 8 meters and 4 bands in multi-spectral bands, different land use types or mixed types are not possible to be distinguished from each other from the imagery. That leads to the selection and combination for different land use types should be more concise by the theories of classification. The seven land types in this study are selected in terms of the land use types of the third forest resources investigation by the Bureau of Forestry and combined with similar reflectance on spectrum. The quantitative value is still required for delineating the suitable land use types. Furthermore, the time for imagery acquired is another important issue for analysis using remotely sensed data. Due to the variation of solar radiation within a year, imagery acquired at different seasons may exhibit the minor difference of radiation, which has to be calibrated. Chen et al. (2005) used twelve SPOT satellite images to classify the vegetation types in National Kenting Park and concluded that October is recommended as the suitable month for image acquisition. The study site, Sitou Tract, is often mantled with fog both in autumn and winter time and suffers typhoons and monsoon events during summer. These limitations make it is very difficult to select the fixed time correspondent with ground investigation. From experiences to select the cloud-free satellite imagery, we suggest the imagery from November to December may be the most suitable time for data acquisition. The three almost cloud-free imagery used in this study were obtained during this time period.

Since calculated from the result of image classification, the values of LPM are dependent on the accuracy of image georeference and image pixels being classified into the correct land type. LPM introduced in this study shows the variation of forest landscape, which is crucial to the ecological change. At the class level, we can find the patches of seven land types fluctuate at different values of LPM. Among the seven land types, the bare land is discussed in particular in terms of most significant landscape change. The change between 2004 and 2006 reflects on the trends of several values of LPM mentioned above. From the landscape scale, the LPM of SHDI and SIDI increase gradually which represents the diversity of landscape is growing after the natural and human disturbance. The LPM of SHEI and SIEI in 2005 equal with values in 2006 also reflects the evenness of landscape remains stable. However, no matter at the class or landscape scale, the variance and capability explained by various LPM still needs to be further analyzed in the future.

The preliminary results for ecological investigation indicate that the recovery of vegetation is highly correlated with the NDVI value at sample sites and the bird communities show significant correlation with the diversity of the habitat. Due to the landscape metrics reflect the whole patches of land types in study area, LPM values of each sample site in situ is not indicated individually, that means specific properties of each sample site can not be reflected from values of LPM. However, the values of LPM still can provide valuable information of the patches, which is crucial to the understandings of the changeable landscape. For example, the change of fractal dimension (FRAC), provides the information whether shape and configuration of the patches become regular and simple or not. On the other hand, due to the limited manpower and material resources, number and size of sample sites together with the frequency for ecological investigation also arises the issue for the representative characteristics for the landscape. This study provides the preliminary result for analyzing the relationship between landscape and ecology, which yields detailed and more accurate procedures and methodology need to be thoroughly reviewed and analyzed in the following studies.

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## Conclusion and future work

We conclude that by using remotely sensed data and ground investigation, it is feasible to monitor and assess the relationship between change of landscape and ecology in forests. The preliminary results in Sitou Tract indicates, though only ecological investigation done at the different sample sites for one year, the recovery and restoration of vegetation after the human and natural disturbances highly correlates with the value of NDVI; the bird composition and diversity are highly correlated with the diversity of patches. The values of SHDI, SIDI, SHEI and SIEI show that the diversity of landscape is growing while the evenness of landscape remains stable from 2004 to 2006.

The geological stratum, soil and aspect are not particularly discussed in this study. However, the environmental factors may affect conditions of the restoration and recovery. These factors should be considered in the following studies.

Because the ecological investigation only began in 2006, more quantitative and definitive proof for the relationship between the change of ecology and landscape metrics is yet to be verified. Meanwhile, ecological investigations will add insects both on riparian and bare land at sample sites in the following years. We believe adding the insects collected near bare land and riparian areas at sample sites where also influenced by the natural and human disturbances and it will be more representative for biodiversity and offer more information on the change of landscape.

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# Has Ecological Engineering Failed Taiwan

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A few years ago, Typhoon Mindulle tested modern engineering in Taiwan. Some were saying that the new Ecological Engineering approaches had failed this test and should be abandoned or restricted. But has Ecological Engineering failed? Should these new approaches to sustainability be abandoned? To answer these questions we must first understand what Ecological Engineering is, and then evaluate the relative success or failure of projects completed based on Ecological Engineering practices.

Ecological Engineering is a new development in engineering; an approach intended to sustain ecosystems while also building facilities. Ecological Engineering principles recognize that past engineering practices, which emphasized protection of humans from the environment, must now be changed to include practices that will protect the environment as well as humans. If good engineering practice is viewed as building structures that have a demonstrated utility, cost effectiveness, and performance, then Ecological Engineering is simply good engineering practice that now considers both the environment and human needs. It should be recognized, for example, flood control structures designed with Ecological Engineering principles should provide protection to both humans and the ecosystem from impact of floods.

Today, the looming loss of biodiversity and the clear consequence of development without environmental protection have called upon the engineering profession to move quickly to provide local, regional, and global responses to environmental damage. Ecological Engineering is a response to this need, but as a new engineering discipline it is different because new designs, codes, and practices must be developed under an accelerated schedule. Today, not all Ecological Engineering designs have been as thoroughly tested as the traditional designs for infrastructures. One should not therefore have the misconception that Ecological Engineering can be a “cure-all” solution to all our engineering problems.

Another critical factor in Ecological Engineering is the materials used in a project, and the capability of those materials to meet the rigors of Taiwan’s earthquakes and typhoons. In Ecological

Engineering, natural materials are commonly used in what is termed bioengineering. Where traditional engineering practice builds structures with materials such as concrete that have known strength and reliability, bioengineered materials gain strength over time as natural materials grow The test of an Ecological Engineering design then is in long-term sustainability rather than in short term strength. What should be apparent is that a balance between immediate strength and long term sustainability will be a mixture of traditional engineering and Ecological Engineering. We should also remember that the time line of ecosystem changes is usually a long one. It may take years, or even decades, for an ecosystem to fully recover from degradation caused by its stressors. The success of Ecological Engineering may take a long time to be realized.

It is now possible to consider an answer to the question "Has Ecological Engineering Failed Taiwan?" Our answer would be emphatically "No"! Projects developing Ecological Engineering practices may not have performed as expected, but what we learn from these "failures" is the basis for improving practice. There has been no complete accounting as yet of actual practice performance following typhoon Mindulle. When that accounting is done, analysis should consider whether the project incorporated only modifications to an existing design, or incorporated Ecological Engineering principles in an integrated design. There are reports of the success of sustainable design projects in Taiwan that suggest the application of Ecological Engineering deign principles met typhoon Mindulle's test. Public Construction Commission has reported that in Wufeng Township, Taichung County, only 3 of more than 60 sites that were bioengineered failed. In Tungshih Township only 2 of 150 sites failed. A 97% success is impressive!

At the same time that this success is acknowledged, efforts should be made to determine the performance of all Ecological Engineering practices in Taiwan. We should remember that all engineering designs have a design limit! For example the drainage system for a major highway in the U.S. is usually designed for a 25-50 year storm. We expect the system will likely be overcharged when a larger storm occurs, but accept the risk for obvious fiscal reasons. When we consider how typhoon Mindulle tested Taiwan, it appears this typhoon went well beyond common engineering design limits. Rainfalls in excess of 2,100 mm were recorded at several locations in central Taiwan due to Mindulle. This rainfall intensity places Mindulle in the class of "100 year" storms and likely exceeded the 100-year designs of even traditional engineering projects in central Taiwan.

When considering this rainfall amount, there has been much discussion about Taiwan's unique conditions that call for careful development and even abandoning developed areas. To put these ideas in perspective, a recent article in Nature noted that Taiwan has the world's leading production of sediment being carried to the sea. Between 1970 and 1999, Taiwan supplied 384 million tons per year of suspended sediment to the ocean. This represents 1.9% of estimated global suspended sediment discharge from only 0.024% of earth's surface. Earthquakes, landslides, debris flows, and flooding are major, and continuing, problems in Taiwan. What Ecological Engineering offers to Taiwan is a new, and more sustainable, approach to planning and engineering. Ecological Engineering practices must pass critical natural tests, and if practices fail then we must learn from the failure. Retrofitting existing projects and superficial designs that are more aesthetic than engineering should be avoided. Considering Taiwan's harsh tests, it is clear that sustainable designs will depend on a foundation of good engineering practice where the best use of traditional and bioengineered approaches are mixed to be effective and efficient. Ecological Engineering has not failed Taiwan, but its use must be carefully planned and implemented, especially in such harsh environments of Central Taiwan.

# 台灣推動生態工程錯了嗎

若要回答「台灣生態工程錯了嗎？」我們的答案是「不」！

幾年前的敏督莉颱風侵台，使得台灣生態工程受到檢討，並提出生態工程應用是不恰當的。但是生態工程應用真的錯了嗎？我們必須先知道什麼是生態工程，再來評估成敗與否。

台灣地震與颱風天災因素，使得生態工程受到嚴苛的挑戰。若要回答「台灣生態工程錯了嗎？」我們的答案是「不」！生態工程也許並不如預期，但是從錯誤中學習提升是根本法則。在敏督莉颱風過後行政院公共工程委員會統計，約97％的工程案例是成功的，生態工程在台灣的應用我們必須注意工程設計極限，例如在美國主要高速公路的排水系統，通常以25-50 年洪水頻率為設計準則，可以預期的是如果有超過 25-50 年洪水頻率發生時，則可能有公路淹水或設施損壞的風險，供承設計一般都是在平衡成本效益及風險考量前提下確定的。我們細想傳統工法設計極限可能超過敏督莉颱風的 2100 毫米降雨量嗎？在考量超大雨量情況下也許我們應該對是否在某些地方進行開發行為做仔細評估。

地震、土石流、山崩及洪水仍持續是台灣主要問題，生態工程提供台灣一個新且永續性的設計及工程方法概念。生態工程必須通過自然的考驗並且如果錯誤我們必須從錯誤中學習。生態工程在台灣並沒有錯誤，但是必須在設計及執行上必更用心，尤其是在環境苛刻的中台灣。

Figure 1. A project using ecological engineering methods that withstood Typhoon Mindulle

Figure 2. Another successful case example of ecological engineering applications

Figure 3. A project using ecological engineering methods that failed due to Typhoon Mindulle

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# Evaluation of Watershed Management Strategy Using Emergy Synthesis

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## Abstract

The concept of EMERGY (spelled with an M), developed by Howard T. Odum, revised energy theory of value by incorporating aspects of ecological hierarchy and energy quality to valuate the contribution of natural environment to human economic system. In this paper emergy synthesis was proposed as a tool for studying the watershed management strategies in Taiwan. This paper identified a specific district of a river basin and used a few indices to explain and verify the condition of basin development. One may apply the verified conclusion to reach the economic development of a river basin without confliction on ecological and hydraulic purposes.

**Keywords:** Emergy; watershed management; systems ecology; ecological economics; hierarchy.

# 使用能值綜合評估集水區經營管理

台灣在 2003 年建立了包含環保、生態、社會、經濟、制度等五大範疇的永續發展指標。水利署也指出得以永續發展之流域整體水資源管理應達成治水、利水、保水、親水、活水等五大目標，其實質即為達成「生態流域」的「永續發展」，或可概分為「生態永續」與「水資源發展」兩個相輔相成之課題。

本研究使用能值(emergy)評估流域的經營管理，能值與生態經濟為一種建立在系統太陽能量(solar energy)基礎上的分析方法，可透過計算能值評估各種發展方案之優劣，更可用以建立複雜系統之經營理論。採用能值量化方法有以下優點：(1)能值以永續能量(太陽能)為單位，且考慮產生的過程，適合闡釋或比較不同產品的永續性；(2)所有事物有一共同得以比較的單位；(3)由生態能量觀點出發，適合討論與自然生態有關的議題。

在系統生態學的既有研究成果方面，已有許多能值的分析指標，分別具有其意義及功能。本研究選擇擬定流域經營管理策略上較具參考意義的能值指標，並對單一流域計算其能值後，解釋該等能值指標在流域自然生態環境與經濟開發間的關係與意義。建議未來再對不同流域做能值評估與比較，以由相互比較結果檢討公共政策、建設投資及永續發展的適切性與方向。

**關鍵詞：**流域經營管理、生態階層、能值、生態經濟、系統生態

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## Forward

The natural environment offers resources including food, water and energy. It also helps to reduce pollutants, which is produced by human economic activities, and circulates nutrient to maintain and balance the function of human economics and ecosystems. Still there are so many uncertainties to the true value of human society in the natural environmental system. Under the limit on quantity of various kinds of energy to make the long-term policy to maintain the ecology and economic interface to ensure that the mankind sustainable development are necessary.

Population and land use demand is increasing fast due to economic development. Human picks and fetches the natural environmental resources to change economic worth, but their utilization speed of natural resources exceeding the natural self-repairing speed day by day. So the ecosystem structure decreasing gradually, the ecological species difference is also reducing, and finally the original nature of the environment reducing its material and service to human.

After achieving the complete satisfaction of the material, human begins to pay attention towards comfortable living environment and to the coexistent relation between human and environment because of social economic development. In this regard, a serious impact imposing on the environment by human behavior.

Although water resource in the basin belongs to renewable resources, and because of rainfall type and distributing is different with season and times, it is by storing it in the earth's surface and ground water also the change thereupon. The land resources characteristics such as topography, soil, vegetation or also artificial behavior of river flow and land development can change the hydraulic procedure. Basin water resources availability is different with time and space. Moreover, water consumption rates are different with the purpose, area, and seasonal changes. Therefore, the supply of the water resources for the urban development is a crucial subject that cannot be ignored.

The contradictory perspective of hydraulic engineers and ecologists has long been a dilemma in watershed management issues. A traditional approach to hydraulic engineering is utilizing levees to restrain flooding. It hinders people from getting close to water environment hence the harmonic interactions between people and natures are usually overlooked. Ecologists, on the contrary, usually emphasize more on esthetic issues. They tend to preserve and utilize natural materials instead of using artificial ones, such as concrete, without sufficient consideration on hazard-mitigation. The chance to possibly bring these two conflicting viewpoints into reconciliation seems pessimistic.

In this study Lan-Yang river basin, which is the major river of Yi-Lan county in Taiwan, was taken as a case study to evaluate the sustainable development of basin by using emergy synthesis. From the ecological economics point of view, it was tried to illustrate basin situation through emergy indices. These illustrations could help to observe the feasibility of public decisions on the basin management issues.

## Documents Retrospect

The focal point will be divided into two parts in this section, including land-use changes and ecological energy analysis. This ecological energy analysis is a bit different from the traditional one and it relies mainly on analyzed ecological economic system.

### *Land-use change*

Water Resources Agency of the Ministry of Economic Affairs of Taiwan has finished investigation within 3 kilometers of each 25 main river basins and coastline of whole province from 2003 to 2006. The investigation includes land-use map, digital terrain model (DTM) at an interval of 5 meters and digital surface model (DSM). Ortho-photo maps were also generated using a representative fraction of 1:5,000. The agency also developed the geographical information system (GIS) for the best use of those 25 main river basins and coastline of whole province data. We compared data changed from 1995 to 2006 which is shown in Table 1.

**Table 1.** Land use change between 1995 and 2006 (area in ‘000 ha)

| Year | Industrial Land | Water Conser-vancy Land | Traffic Land | Archi-tectural Land | Military Land | Agricultural Land | Tourist Land | Mineral Land | Salt Indus-try Land | Others Land | Unknown Land | Total Land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | 15.7 | 83.8 | 19.0 | 58.7 | 10.3 | 520.0 | 2.89 | 1.35 | 3.47 | 28.0 | 6.59 | 750.0 |
| 2006 | 21.1 | 54.6 | 38.4 | 74.3 | 46.4 | 471.0 | 6.38 | 1.47 | 2.77 | 54.2 | 0.0 | 771.0 |

### *Ecological energy analysis*

Ecological economics is a trans-discipline science, which was introduced by system ecologists and economists. The aim of this science was to integrate ecological and economic systems and to encourage new ways of thinking for achieving a sustainable development. The theoretical basis of ecological economics extends from classical approach with emphasis on biophysical processes, which is a bit different from the neoclassical oriented environmental economics. Energy analysis provides methods for representing ecological economic interface and for integrating ecological and economic systems. The concept of emergy (spelled with an M) first developed by Howard T. Odum (1924~2002), who was respected as father of systems ecology. He revised energy theory by incorporating aspects of ecological hierarchy

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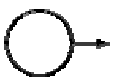
and energy quality to evaluate the contribution of natural environment to human economic system.

From the ecological economics point of view, GNP is unable to measure the national welfare, its main reason is that it neglects tribute like energy, service, etc. that nature offers to produce economy. For example, forest may offer human economic benefits including water and soil conservation, purify air and water, provide wild animal habitat, ecotourism etc. But GNP can only compute the income due to market transaction of the cost, which comes from cut down the forest and the timber.

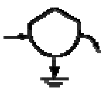
Different kinds of ingredient, interaction of global systems and even human information involve in energy flows, storages, and transformations. The operations of various kinds of ecological function are depending on energy as motive force.

Energy flows can be used as a measure of the nature, which is the datum of various kinds of function. It can also be used as a tool for expressing and understanding the system of people and natural environmental relationship.

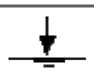
***Energy circuit*****:** A pathway whose flow is proportional to the storage or source upstream.



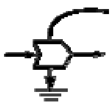
***Source*****:** A forcing function or outside source of energy delivering forces according to a program controlled from outside.



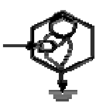
***Tank*****:** A compartment or state variable within the system storing a quantity as the balance of inflows and outflows.



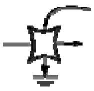
***Heat sink*****:** Dispersion of potential energy into heat accompanies all real transformation processes and storages. This energy is no longer usable by the system.



***Interaction*****:** Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; a work gate.

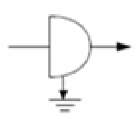


***Consumer*****:** An autocatalytic unit that transforms energy, stores it and feeds it back to improve inflow.

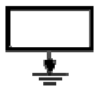


***Switching*****:** ***Action*****:** A symbol that indicates one or more switching actions controlled by a logic program.

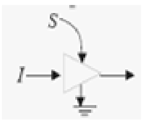
***Producer*****:** Unit that collects and transforms low-quality energy under control of high quality flows.



***Self-limiting energy receiver*:** A unit that has a self-limiting output when input drives are high because there is a limiting constant quantity of material on a circular pathway within.



***Box*:** Miscellaneous symbol to use for whatever unit or function is needed.




***Constant-gain amplifier*:** A unit that delivers an output in proportion to the input *I* but changed by a constant factor as long as the energy source *S* is sufficient.

***Transaction*:** A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed). Price is shown as an external source.

Figure 1. Symbols and definitions of the energy systems language (Odum, 1983)

Diagramming is done with energy systems symbols (Figure 1). Diagrams of our world are called energy systems because everything has some energy. Pathway may indicate causal interactions, which show material cycles, or carry information, but always with some energy. The systems diagram also defines the equations that are used for systems simulation. The symbol language includes some mathematical relationships. Energy systems diagrams have items in order of size and turnover time from left to right. Whether parts are aggregated or disaggregated, energy systems diagrams should have all the known inputs and outputs of the system crossing the selected window.

The quotient of a product's emergy is divided by its energy and is defined as its trasformity. The unit of the transformity is em-joules per joule (Thus it is not a dimensionless ratio). The more the energy transformations to a product, the higher is the transformity. At each transformation, available energy is used up to produce a smaller amount of energy of another form. Thus, the emergy increases but the energy decreases, and therefore the emergy per unit energy increases sharply.

Another property of emergy, self-organization, is the spatial clustering of structure and processes that includes storage and energy transformation into a single unit. Examples are storms, organisms, stars, and industries. Higher values of transformity have larger centers and operate over larger territories. In the hierarchy of the universe, from the very small to the very large, there are various storages at each level. Small storages affect small areas and turn over rapidly. On the other hand, larger storages affect larger areas and have longer replacement times, lower depreciation rates, slower turnover times, larger size, and larger territories of support and influence that go along with higher positions in hierarchies.

It can be concluded that there is a universal energy hierarchy, and it provides transformities for quantitatively relating to energy on one scale to the other. Transformities can be used to put items at different scales on a common basis, which is required for one kind of emergy for a product or service to the other.

## Meaning in the Ecosystem of the Pulsing Incident

The meaning of pulsing is that the burst of enormous dissipation in the system which will cause the material in system to renew and/or to recycle, such dissipation can also cause the gradual increase of productivity of the system. In general ecology, it is often mentioned that a steady system will finally reach the prevailing phase. But after observing different ecosystems, it can be found in a long period or space the whole system may change; then it is needed to force the system to reply such changes.

River pulsing is one important factor to influence the river self-organization. In the field of ecosystem, there are different conclusions from different observation, which can make quite disparity of method in applying and/or re-breeding ecology. When discussing ecology management and/or re-breeding issues, the ecology should be taken as a holism. From the aspect of holism, ecology could be illustrated with three parts namely structure, process, and function.

Inundation pulsing phenomenon may happen because of torrential rain and flood and it is often may defined as natural disaster. In Taiwan, dams and/or dyke are used to prevent natural disaster, which suppressed the mechanism of inundation pulsing, and it is unfavorable to maintain the ecosystem and the re-breeding of the bio-diversity. Meanwhile, once the intensity of torrential rain or intensity of flood exceeded the designed hydrologic recurrence period, the social economic losses will be higher, and it will not be win-win situation.

For sustainable management of the basin, pulsing theory will be a suitable direction as one of the reference indexes. It is believed that set up basin calamity historical data like typhoon or torrential rain is necessary to observe how it will increase or decrease in view of basin emergy benefit using historical pulsing analysis. What would be its role in basin sustainable development and also which kind of indicator should be assessed and be established? It is needed to set basin emergy analyses, and after getting a suitable reference and set up theory structure in the documents retrospect, further study may be done.

## Basin Emergy Analyses

For soil and water resources management, the basin is the important management unit. Upstream conservation basin will control water supply and downstream land development will develop the water requirement, and the equilibrium of supply and demand of water resource will be related to the whole basin. So, for sustainable management, basin upstream conservation and downstream land development is needed as a whole.

Calculating of emergy is needed first to draw out emergy diagram, which is shown in Figure 2. Lan-Yang river basin was taken as a case study to compute and to roughly sum up these categorized classifications which is shown in Table 1. The area was divided into three major classifications as natural area, agricultural area, and urban area.

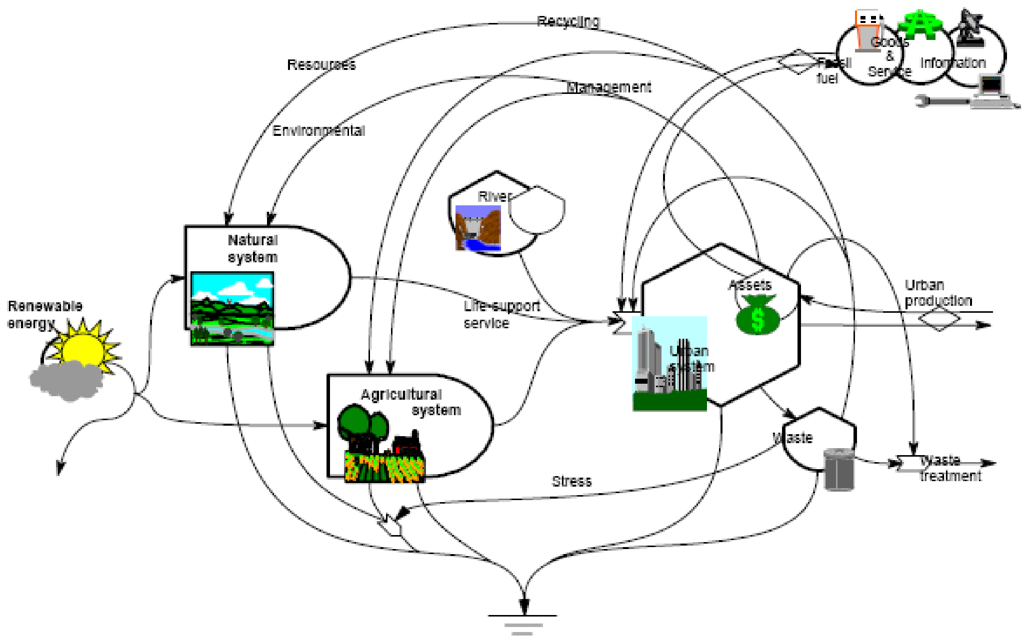



Figure 2. Basin emergy analysis diagram (Shu-Li Huang, 1991)

For emergy analyses sunlight, wind, rain (chemical energy), rain (geo-potential energy), and typhoon was taken as renewable resources; soil loss and net topsoil loss was taken for non-renewable resources. For consumption of the energy and discarded produce amount, soil loss and net top soil loss, electric use and liquid or solid state offal was taken as representative samples. Average statistical data of Taiwan (for 2004) were used to compute the non-renewable resources and consumption and discarded produce amount to the energy.

According to the agricultural statistics annual report (2004), agriculture, livestock and aquatic products in the area of Yi-Lan (Lan-Yang basin) may be shown in Table 2.

**Table 2.** Agriculture, livestock and aquatic products and its percentage of Yi-Lan area for year 2004

| Item | Agriculture products | Livestock products | Aquatic products |
|---|---|---|---|
| Output (million NT$) | 3942.00 | 2363.00 | 4215.00 |
| Percentage | 37.47 | 22.46 | 40.07 |

The major emergies assessed of Lan-Yang river basin is shown in Table 3.

**Table 3.** The main emergy analysis and assessed of Lan-Yang river basin

| Resource classification items | Raw Data (unit) | Transformity (sej/unit) | Solar emergy (sej) | Macroeconomic Em $ (NTD) |
|---|---|---|---|---|
| **Renewable resources:** | | | | |
| 1.sunlight ；J | 3.7957E+19 | 1 | 3.7957E+19 | 8.31E+8 |
| 2.wind；J | 9.2527E+17 | 623 | 5.7644E+20 | 1.26E+10 |
| 3.rain (chemical)；J | 1.5731E+16 | 15444 | 2.4295E+20 | 5.32E+9 |
| 4.rain (geopotential)；J | 2.9022E+10 | 8888 | 2.5795E+14 | 5.64E+3 |
| 5.Typhoon; J | 6.1198E+12 | 41000 | 2.5091E+17 | 5.49E+6 |
| | | | 8.576E+20 | 1.87E+10 |
| **Non-renewable resources** | | | | |
| 6.soil loss；T | 2.3472E+5 | 1.71E+15 | 4.0137E+20 | 8.78E+9 |
| 7.Net topsoil loss；J | 5.9243E+10 | 62500 | 3.7027E+15 | 8.10E+4 |
| | | | 4.014E+20 | 8.78E+9 |
| **Renewable organic energy** | | | | |
| 8.Manpower NT$ | 5.99E+04 | 4.73E+12 | 2.83E+17 | 5.96E+6 |
| 9.irrigated water chemical energy ; J | 1.24E+10 | 41068 | 5.09E+14 | 1.07E+4 |
| 10.organic fertile NT$ | 5.15E+03 | 4.73E+12 | 2.44E+16 | 5.14E+5 |
| 11.seeds NT$ | 5.70E+03 | 4.73E+12 | 2.70E+16 | 5.68E+5 |
| subtotal | | | 3.35E+17 | 7.05E+6 |
| **Energy-consuming** | | | | |
| 12.（fuel）electric use ;J | 1.37E+17 | 66000 | 9.042E+21 | 1.98E+11 |
| | | | 9.042E+21 | 1.98E+11 |
| **Amount of produce discarded：** | | | | |
| 13.Solid state offal；J | 2.89E+16 | 1800000 | 5.202E+22 | 1.14E+12 |

| | | | | |
|---|---|---|---|---|
| 14.liquid offal；J | 1.42E+16 | 665714 | 9.4531E+21 | 2.07E+11 |
| | | | 6.147E+22 | 1.35E+12 |

## Emergy Indicators

Table 4 is the comprehensive form of Lan-Yang river basin which is computed from Table 2 and Table 3.

**Table 4.** Comprehensive form of Lan-Yang River

| Emergy flows | Operation type | Quantity(E+19 sej) |
|---|---|---|
| Renewable environmental emergy | R | 85.76 |
| Non-renewable environmental emergy | N | 40.14 |
| Total emergy of the environment | I = R+N | 125.90 |
| Renewable organic emergy | T | 0.03 |
| Fossil fuel emergy | F | 904.2 |
| Total assist emergy | U = F+T | 904.23 |
| Total emergy invest | U + I | 1030.13 |
| Agricultural output | Y1 | 18.72 |
| Livestock output | Y2 | 11.22 |
| Aquatic output | Y3 | 20.02 |
| Total output | Y = Y1+Y2+Y3 | 49.96 |

According to emergy analysis, a lot of indicators were used and each of the indicators has its meaning and function separately. The data already collected related to emergy computation for this research, was chosen some meaningful indicators which may help in the draft management strategy of the basin. It was also trying to explain the meaning and relationships of those indicators between economic development and that in the natural environment, and those indicators illustrated as follows separately:

(1). Net emergy yield ratio (NEYR): It is an indicator to assess whether resources operations are in economic use or not. It is the ratio of economic emergy output to emergy that put into. If emergy of the production process output is greater than emergy that put the economic system into, i.e., if NEYR>1, have economic benefits.

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Lan-Yang river basin's NEYR was found to be 0.05 which shows that the utilization of natural resources efficiency of the basin was very low, the basin had a lower emergy`s utilization ratio, the production cost was relatively high, therefore under equal conditions, its product had worse competitive power on the market.

(2). Emergy investment ratio (EIR): It is ratio of emergy that puts into the system to the renewable emergy of natural environment. Competitive economic system must have some free and low-quality renewable resource with paid, which is a high-quality of energy. EIR of the Lan-Yang river basin is 11, which are estimated belong to high ratio. More developed area (or country) has higher emergy investment ratio (greater than 7), and area of low developed might far lighter than 1. If emergy of basin mostly come from using urban economic system of importing resource, then this emergy make the investment higher, it cause price rises to be unable to compete in the international market. Besides, higher EIR can regard as natural environment (such as basin of research) must bear a large number of economic activities. So the ratio can also be regarded as determined the load to the economic activity of natural environment indicator.

(3). Emergy dollar ratio (EDR): It is the ration of total emergy`s consumption to gross national product (GNP). To locate development of the area and/or its industrialized condition, EDR value is required. Higher EDR value represent the economic activity of per unit is high. It means that uses of larger percentage of the natural resources are in the production process. On the other hand, when EDR value is lower, its contribution to develop the economy of natural resources is relatively small. It shows that the development of this area is large. Lower development districts may have higher EDR value because those districts may have human energy of economic activity, which may come mostly from natural environmental resources directly. EDR of Lan-Yang river basin is about $4.75 \times 10^{10}\ sej/\$$.

(4). The concentration of indicators of emergy can be computed by the following three ratios:

A. Concentration to rural ratio (CRR): Using CRR it is easy to find the type of resources using in an area. CRR of the Lan-Yang river basin is about $904.2/125.9 = 7.18$.

B. Emergy density (ED): It is the ratio of total emergy's consumption to the area or district studied. If the district studied is highly developed, its economic activity will be frequent and emergy's consumption per unit area of this district must be very high. ED of Lan-Yang river basin is $1.05 \times 10^{19}\ sej/Km^2$ which is very high.

C. Emergy per capita (EPC): It is an indicator to judge resident's living standard level in this area. EPC of Lan-Yang river basin is $2.23\times10^{16}\, sej/man$.

(5). emergy's source indicator: It indicates the structure of that resource which is used in this area. We can analyze it using the following two ratios:

A. Emergy use from home source (EFHS): It is the rate of emergy use which taken from emergy consumption use of this district. The higher value of EFHS shows the more consumption of the natural resource in this area. Because the computation of natural resources have a positive relationship with area, therefore, greater district have higher EFHS.

B. Fraction of purchased emergy (PE): It is the ratio of the buying emergy's consumption to the total emergy's consumption. Using this PE, it is easy to estimate the dependence to external resources of one district.

## Contrasts

We can use those emergy indicators to compute Lan-Yang basin planting emergy's indicators and compare those indicators with Guangdong Province (1993) and Italy (1989) as Table 5.

**Table 5.** Planting's systematic emergy indicator comparison of Lan-Yang river basin

| Emergy Indicators | Operation | Lan-Yang Basin | Guangdong Province (1993) | Italy (1989) |
|---|---|---|---|---|
| Systematic emergy and transformity | I/Y | 2.52 | 3.28E+4sej/J | 4.62E+4sej/J |
| Net emergy's output rate | I/(F+T) | 0.14 | 1.20 | 1.13 |
| Putting into rate of emergy | (F+T) /(R+N) | 7.18 | 5.11 | 7.55 |
| Environmental load strength | (F+T+N) /R | 11.01 | 5.40 | 9.29 |
| Free environmental emergy/total emergy | (R+N) /I | 1 | 0.16 | 0.11 |

Source: Systematic emergy indicator materials source of Italian planting (Ulgiati et al, 1992)

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From Table 5 it is found that the putting into rate of overall emergy of the agricultural system of Guangdong Province is 5.11 which is lower than 7.55 of Italy's corresponding system. The Table 5 also showed that the use of systematic of total emergy of the environment (R+N) of agriculture of Guangdong Province corresponding purchase fossil fuel emergy (F) that invests lower than Italy. From which it is evident that to buy emergy puts into invest for Guangdong Province is still relatively lower level than Italy.

This value showed agricultural products in Guangdong Province will reduce the production cost because of less purchase emergy's input. The economic emergy of agriculture puts into here is less, it can say that Guangdong Province are not in good use of free environmental resources, the best utilization efficiency is not yet to reach.

Therefore, if the input amount of economic emergy of agriculture can increase properly, than it can improve the systematic putting into rate of emergy. The putting into rate of overall emergy of the agricultural system of Lan-Yang river basin is 7.18. From the value we knew that the Lan-Yang river basin's investment is relatively higher in the use of land agriculture systematic of total emergy of the environment (R+N) and the corresponding purchase fossil fuel emergy (F).

The Tabulated value also showed that land agricultural products of Lan-Yang river basin is raised the production cost because of higher purchase of emergy's input. On the other hand, due to more economic emergy of agricultural puts into, the free environmental resources already reached better utilization efficiency.

The environmental load strength of the agricultural system of Lan-Yang river basin is 11.01, which is higher than Italy (9.29) and Guangdong Province (5.40). Analysing these data it is clear that the development level of the agricultural system of Lan-Yang river basin is relatively high compared to the Italy and Guangdong Province. The environmental pressure that the system produces in Lan-Yang basin is high and the potentiality of environmental development and utilization of resources of agriculture is relatively small. On the other hand, if the input in emergy is increased, the feasibility of improving the productivity level may remains low.

Although computation has already been charged to the renewable organic emergy (T), but it could be learnt that free environmental emergy and total emergy would equal to each other. It proves that the agricultural land of Lan-Yang river basin relies on emergy of purchase from economic system, and it also becomes a highly opening goods marketing system at the same time. The agricultural system of Guangdong Province and Italy relies mainly on the purchase emergy puts into, but comparative study clarifies that in the proportion of purchase emergy invests in Guangdong Province is relatively lower than that of Italy. It also shows that the proportion of purchase emergy invests of Lan-Yang river basin are relatively higher.

## Conclusion

The integrated watershed environment undertook the impacts of all human activities. It included the water quantity and quality of streams and related natural resources such as land, forest, ecology, etc. of a river basin. This paper took Lan-Yang river basin of Taiwan as an example to investigate the feasibility of applying emergy synthesis and indicators as an assessment tool for general unified evaluation of development of land use and sustainable measures of streams.

This paper estimated emergies and relevant indicators of Lan-Yang river basin only. To be applied for devising public policy or investment decision making, most indicators need to be computed and compared among different river basins or districts though a few indicators can perform self-criticism independently to a single basin. For better estimation of emergy indicators, it is necessary to understand the ecological economics of all river basins of Taiwan. Many different algorithms, such as multivariate analysis, principle component analysis or fuzzy classification, can be applied to classify basins of the same ecological characteristics. Appropriate policies of preserving ecosystems and pursuing sustainable development for different river basins can be devised.

Emergy transformities are utilized to properly and efficiently evaluate emergies of all river basins. Though Odum et. al. had estimated a large number of different emergy transformities, transformities of system specific output of energy and materials still have to be computed from historical information of the studied watershed. It would be valuable contributions to simplify the estimation algorithm and provide more transformities for being adopted in other analysis.

Flood and typhoon are renewable resources in emergy computation. They can be regarded as one or two of the river basin indicators under pulsing theory. They can also be the basis of developing sustainable management strategies of river basins.

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