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新竹海岸環境資源管理最適化模式建立之研究
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新竹海岸環境資源管理最適化模式建立之研究

Establishment of Optimal Resource Management Models for Coastal Environment in Hsin-Chu

計畫類別：☑ 個別型計畫　　□ 整合型計畫
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計畫參與人員：黃威鈞、陳柏仲

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中英文摘要

一、中文摘要

台灣為海島型國家海岸涵蓋範圍大，各項開發行為皆直接或間接與海岸有關。在倡導經濟與環保並重的口號下，海岸資源的保育與土地開發間的兩難爭議勢所難免。而海岸環境之發展，除了必須兼顧水利工程技術及經濟功能價值之外，對於生態環境、景觀人文與區域發展等層面之影響，亦需進行適當的瞭解，以作為政策研擬時決策分析之依據，因此結合生態規劃理論與多準則決策法來統整土地開發與管理政策，將更易於尋得合理有效之永續發展策略。然而，目前對於海岸環境規劃方面的研究，多在海岸的功能價值上有所著墨，更進一步的研究則是對於政府的管理態度及目前海岸發展現況進行定性的描述，對於土地開發方式及土地使用類別的量化計算較少觸及。本研究將以生態規劃理論為基礎，發展一海岸環境資源管理模式，在環境資源平衡利用的前提下，尋求生態保育、水域污染、景觀價值及經濟功能四項目標函數的最佳解，再藉由敏感度分析推論不同環境變數對各種土地利用的影響程度。本研究延續先前研究計畫，將以新竹海岸地區作為案例進行實證研究，以提供決策者進行海岸環境資源規劃時之參考。研究結果將在海岸土地開發面積的最適化安排上呈現顯著的成效，可以為台灣海岸環境管理與資源利用提出適當的建議。
關鍵詞：海岸環境、資源管理、生態規劃、多準則決策、地理資訊系統

二、英文摘要

Taiwan is comprised of a number of islands. Most developments in Taiwan are, to some degree, related to the coastline. Given the guidelines for economic development and environmental protection, conflict between coastal resource preservation and coastal land development is inevitable. The development of coastal environments, in addition to considering techniques for hydraulic engineering and economic benefits, should also effectively evaluate the impacts of development on the environment, landscape, and regional development, thereby providing a reference for policy decisions. Moreover, given the unstable characteristics of coastal environments, the concepts of ecological planning and multiple criteria decision-making can be adopted when evaluating land development and management policy, enhancing the ease with which one can identify reasonable and effective strategies for sustainable development. However, most studies of coastal environment planning are primarily related to the value of the coastal areas, with further studies elaborating on qualitative descriptions and applying land use suitability analysis to the managerial measure of coastal development. Quantitative investigations of land development and land use are rarely pursued. This study applies analytical methodology based on ecological planning theories to generate a comprehensive system for planning and evaluating coastal environments. Given the premise of striking a balance between ecological conservation and economic development, the four goals—ecological conservation, water pollution prevention, landscape and economic benefits—are adopted as four functions, whereas the solution, thereby achieving a balanced utilization of environmental resources. The coastal area in Hsin Chu, is adopted as an example for the empirical study, with the aim of providing a reference for policy decision makers when planning coastal development. Finally, this dissertation illustrates the applicability of the comprehensive system in the dominance of land use and the optimization of land use development, allow the data to serve as an appropriate reference for management and utilization of environmental resources along coastal Taiwan.
Key Words: Coastal Environment, Resource Management, Ecological Planning, Multiple Criteria Decision Making, Geographic Information System (GIS)

報告內容

一、緒論

一般位於海島之國家或地區，如：日本、台灣等地，因其地理條件較為特殊，水域環境的發展條件與其他大陸地區大有不同，在經濟開發與生態保育必須兼籌並顧的前提下，如何考量水域或水岸地理、水文、生態、人文等條件的特質，適當地規劃出適度利用區、環境共生區、自然復育或保育區等發展方式，以利開發工作的進行及保護規範的建立，實為課不容緩的議題。台灣屬於海島型國家，海岸濕地面積約 11,846 公頃，涵蓋的範圍相當大，因而絕大部分的沿岸開發行為皆直接或間接與海岸有關，經常引發資源保育與經濟開發間的兩難爭議。海岸地區的本質是許多不同領域之組成，海岸土地之消失及沈淪並不僅是區域性之問題，往往可能是經濟與社會整體變遷之一環(Dearden, 1990)。要解決海岸的開發問題就必須先釐清海岸環境之基本特性，特別是其整合性的特質。

海岸地區資源之開發與利用，除了必須兼顧經濟效益、資源限制與環境特質之考量外，對於工程的可回復性、環境的再發展能力，以及生態、景觀的維護等永續發展層面之影響，亦需進行適當的評估，以作為政策研擬時決策分析之依據。現今在海岸環境資源管理的執行上，並無一套完整明確的標準及制度，這與海岸生態與環境相關資料的難以取得，以及地方基礎性研究的缺乏有很大的關係(張長義，1998)。因此，本研究將由多目標規劃的角度，結合生態環境與人文經濟環境，建立一易於操作且簡明的管理分析模式，以期能符合海岸環境的永續發展。

海岸是大自然孕育的天然緩衝區，是生態環境維護的重要關鍵，其重要性早已為各國所肯定。因此在海岸環境的管理上，美、加、日等先進國家皆採取「永續管理」[1]之制度(山下弘文，1994；韓乃鎮，1998; Broll et al., 2002)，針對海岸地區的功能條件以分類分級的方式進行不同程度的管理。英國、荷蘭、瑞典等歐洲國家，更是將生態原則應用在尚未建築的土地上，以半野性景觀(semi-wild landscape)的都市設計原則，從土地既有生物成長條件為出發點的作法，發展一套適宜人與自然共存的調查方式與分類準則，試圖在都市規劃過程中增加自然生態資訊，以分類尚未開發的海岸土地，協助決定未來使用方式(孔憲法，2000；Soderbaum, 2000)。然而多年來國人對台灣海岸之開發利用卻仍多屬土地的外在使用，少有對其潛在特質的資源管理方式進行探討，使得在環境維護上常有顧此失彼的現象發生，也因而產生諸多生態上的環境問題。

「二十一世紀議程(Agenda 21)」[2]中特別重視生態資源利用與環境規劃管理等議題，並以永續發展理念解決土地及其資源間使用之衝突，發展有效的管理政策，使之符合生態和經濟效率併存的資源分配原則為主要目標(邱文彥，2001)。目前國內海岸環境資源的管理制度仍採傳統土地使用分區管制方式，此種以使用型態及強度的管制作為維護環境品質工具的作法，並無法確切的控制土地之利用使之達到環境保育的目的(郭乃文，2000)，尤其更加不適用於有關海岸、濕地等敏感地區資源的管理與保存。

再者，過去一條式的程序性計畫理論與傳統理性規劃方法，應用在水域環境管理計畫的研擬上，早已不符合永續發展理念的潮流與自然生態保育的要求。因此，為使海岸空間的發展定位，更能適當地反應出生態保育的觀念，並且維持地區穩定、平衡且持續的發展，考量生態環境規劃方法，客觀公平的來研擬相關計畫，實為必然的趨勢。

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[1]濕地永續管理的理念乃是將濕地經調查分類後分級管理，重要濕地優先保護，其他濕地在開發時皆應經過許可，並且濕地開發後開發者必須造回等面積之濕地，即所謂的「零損失(no-net-loss)」政策或「濕地復育銀行(wetland mitigation bank)」策略。

[2] 1992 年六月聯合國環境與發展會議(United Nations Conference on Environment and Development, UNCED)在巴西里約熱內盧舉行地球高峰會，會議中通過「二十一世紀議程」內容，進一步將永續發展概念規劃成為具體的行動方案，並提出工作時程。同年十二月，聯合國成立「永續發展委員會」負責推動各國執行二十一世紀議程的情況（行政院經濟建設委員會，2004）。

目前國外有關推動海岸管理方面的研究計畫，多為海岸功能價值及保存維護政策的探討，對於海岸資源的利用多以定性的描述分類為主，較少觸及數量化的綜合性評估。例如美國國家濕地研究中心偏重探討及檢視社會經濟和政治的改變對美國各州海岸地區管理計畫的影響(La Peyre et al., 2000; Davies and Claridge, 1993)，以及各州政府對海岸濕地的保護決策將如何影響海岸地區的永續發展(Mitsch and Gosselink, l993; Price and Probert, 1997)；英國、瑞典等歐洲國家則將海岸地區視為永久保護的自然區域，在研究上偏重探討海岸功能的永續發展及管理，協調「開發」與「保護」兩者間互動及競爭的態勢(Price and Probert, 1997; 劉靜榆，2000)；日本環境廳的海岸保護運動，則強調海岸濕地的生態功能及環境價值，相關研究則著重探討政府及民間在海岸保護運動過程中應扮演的角色及地位，以及利用信託運動保護未來可能遭受破壞的環境之可行性(山下弘文，1994)。而國內的相關研究則多延續美日的環境保護觀念，在海岸的功能價值上多有所著墨，更進一步的研究則是對於政府的管理態度及目前海岸地區的發展現況進行定性的描述和土地使用適宜性分析(曾明遜，1998；臧效義，1999；邱文彥，2001)，對於土地開發的評估及土地使用類別的量化較少觸及。

台灣以往的土地使用規劃通常都只考慮到單一目標問題，而在目標確立以後，決策者僅能依其運算出來的結果，決定是接受或放棄(蕭再安、王隆昌，1992；莊金霖，1993；樓邦儒、曾國雄，2000）。即使是將土地使用規劃與多目標決策理論結合應用，卻仍多以經濟議題為導向，缺乏將環境及生態目標納入衡量的決策分析研究(曾國雄等，1998b；樓邦儒、曾國雄，2000)。然而，偏向單一經濟目標的規劃或研究，將因缺乏針對環境資源管理的整盤考量，而較易造成環境開發的主觀偏頗，導致生態與經濟發展因素的相互衝突。海岸地區屬於高度敏感地區，且未來又是人類活動的發展重心，過去以經濟發展作為單一發展目標的開發方式，明顯缺乏多重目標之考慮與權衡。因此，未來對於海岸地區的開發決策，勢必應朝向經濟、社會、人文及生態等發展目標的共同達成，進行一整合性之海岸土地使用規劃來努力。而在多目標規劃中，有許多目標是在決策過程中被考慮的，又能同時兼顧多個衝突性目標間的最佳平衡問題，分析者提供決策者許多資訊及可行性方案，最後依決策者的評定，做出最適結論(曾國雄，1992)。

本研究即欲建立一海岸生態環境與合理的土地使用方案相互整合的決策方式，可透過多目標數學規劃法，讓經營者在滿足生態保育、社會心理、經濟效益、環境保護各目標下，求出海岸各土地使用之開發量，以作為經營者投資開發之參考。在藉由生態環境及社會心理目標之引進以及模式之建立，追求合理性之解決方案之後，將使海岸開發對生態環境、社會心理之衝擊減至最低，卻同時能符合開發效益與滿足海岸發展需求。

本研究首先藉由功能指標的篩選分析界定出海岸所具備的功能價值，並以此為依據綜合出生態、水質、景觀與經濟四項目標函數，最後利用多目標規劃法求得各類土地使用面積的最佳解。以此分析結果為基礎，可依據決策者對目標的偏好程度來決定各類土地使用項目在最適承載量限制下的最佳使用面積，作為海岸環境資源管理的依據。將其應用在以新竹市海岸地區作為案例的研究之後，將可得到在各種偏好下各類土地使用面積的最佳解。其結果反應在生態規劃理論上可發現：住宅、工業、遊憩、交通等人為開發用地可視為海岸地區的適度利用區，其與以農業使用為主的環境緩衝區及保護生態環境取向的自然保存區，恰可形成各約三分之一的環境保護態勢，以此來進行海岸土地的總量管制，將更具有彈性且符合生態保護的基本精神。

二、模式架構之建立

本研究針對海岸資源的特性，建構出海岸環境之目標，將之整合於海岸土地使用開發模式中，並在各目標相互衝突的狀況下，求取海岸環境與土地使用之相應開發量。以下針對本研究所研擬出的四項目標式以及五種限制條件之基本構想做一詳細的敘述。

（一）目標函數

就私部門之開發而言，海岸開發之動機與目的大多以追求最大經濟效益為目標，鮮有考慮到開發後對週遭生態環境所造成之衝擊。然而隨著大眾對環境之要求水準日益提高，公部門對私部門的開發行為，在政策考量上必須加以因應之。

海岸地區之開發，多以擁有自然資源或具有發展潛力之地區為主，為達到資源的保護和永續性，海岸資源的利用應以保育重於開發為原則，以環境供給面作為開發的限制條件，以減少海岸開發對海岸資源造成負面的影響。

本研究依據「生態工法國家型科技計畫規劃」過程中環境規劃、海岸工程、生態系統、濕地復育等相關領域專家學者之建議(行政院國家科學委員會，2004)，以及先前針對海岸及濕地環境功能指標之研究結果(閻克勤等，2005；閻克勤等，2007)綜合而得，海岸具有水文及化學循環上的功能，例如：淨化水質、防範洪水、保護海岸線、補注地下水含水層等功能。且海岸被稱為「生物超級市場」(Mitsch and Gosselink, 1993)，是廣大食物鏈場所，具有豐富的生物多樣性，因此，又具有生態上的功能。而近年來海岸土地大量的使用，再加上週休二日的實行，海岸不僅是一般民眾活動中心，更是外來遊客休閒遊憩的最佳場所，在遊憩功能上的地位日益重要(各項海岸功能綜理如表一)。

綜合上述，海岸地區開發時不應僅以單一的經濟目標為導向，還應滿足生態保育、水文淨化，以及提升海岸週邊民眾之安全感與遊客滿意度等目標。依此，本研究乃歸納整理出生態保育功能、水質污染程度、景觀知覺偏好、經濟功能價值做為建構海岸生態環境與土地使用整合模式之四大目標函數。其內容如下：

1.最大生態保育功能

就物種棲息地而言，將一個較大的嵌塊體(patch)分成較小的嵌塊體過程，會改變內部棲地，並導致內部族群的大小和數量的減少，因此嵌塊體的大小，是研究景觀要素特徵的主要參數，其直接影響單位面積的生物量、生產力和養分貯量，以及物種組成和物種多樣性(Forman and Godron, 1986; Marsh, 1991; Forman, 1995; Bourgeron et al., 2001)。而對於一個特定物種，在較大的嵌塊體比較小的嵌塊體通常會有較大的群體，這也使得較大的嵌塊體較不容易發生區域性滅絕；反之，如果嵌塊體過小，則會增加物種區域性滅絕的機率，主要是因為一個大的嵌塊體會擁有更多的棲地，所以大嵌塊體會比一個小的嵌塊體包含了更多數量的物種，不容易造成滅絕（Forman and Godron, 1986; Forman, 1995; 張俊彥等譯，1997；鄔建國，2003）。綜合以上所述可得知，嵌塊體面積越大，保育能力越強；反之若嵌塊體越小，其保育功能相對較低。因此，本研究參考了 Forman (1995)對景觀生態指數所做的研究，選擇與土地利用面積有關的嵌塊體指標中的「平均嵌塊體大小（Mean Patch Size, MPS）」，來作為評量海岸地區生態保育功能的指標。

本研究目標式中之最大生態保育功能目標函數，乃應用平均嵌塊體大小作為生態保育能力的評量標準，由於平均嵌塊體面積愈大，相對生態影響範圍會愈集中，則保育能力將愈好，因此將其訂為望大特性。

2.最小水質污染程度

海岸水質的污染程度，是評估海岸地區環境品質的重要性指標。評估水質污染程度的方法相當多，如溶氧量 DO、生化需氧量 BOD、化學需氧量 COD、總磷、氨氮、懸浮固體、大腸桿菌群等（黃光輝譯，1992；孫儒泳等，1999）。其中溶解於水中氧的量稱為溶氧量，水中的魚貝類就靠溶解於水的氧呼吸；而水中微生物亦會利用水中一部份溶解的氧，將有機物分解成簡單的物質，微生物在分解有機物時所消耗的氧氣量就稱為生化需氧量(BOD)。水中污染物越多，生化需氧量也會越高，一個良好的水域須具有高的溶氧量及低的生化需氧量。

建立函數時，需考慮到資料是否容易取得，以及水質模式是否可信等因素，而本研究在評估各項水質參數後，選擇了較為完整可信及普遍使用的水質模式 BOD-DO 模式（黃光輝譯，1992），但考慮到台灣河川水流湍急、西部海岸沿岸流流速大，DO 多可保持在水體水質標準之上，因此本研究乃以 BOD 作為水污染指標，並且取其為

望小特性。

表一 海岸功能內容一覽表

功能	項目	內容
生態功能	生產作用	海岸地區為高生產力地區並為許多經濟性海洋生物之生育舞台。此外海岸地區往往成為候鳥遷徙途經之路線，亦為鳥類之重要棲息地。
	承載作用	可容納人類活動，並儲藏、稀釋、過濾有機與無機之污染物質。
水文功能	制衡作用	海岸地區地下水層淡水與海水之交界維持著動態平衡，可防止鹽水入侵，避免沿海生態環境造成突變或惡化。
	淨化作用	廢棄物之化學淨化作用及生物體或生態系之新陳代謝作用，可淨化水質，維持水文正常循環。
經濟功能	經濟作用	具海洋生物資源、礦物資源、能源、淺海養殖資源及土地資源等。而海岸地區的陸域因其自然特性，則可供工業及能源設施、居住及建築發展、產業開發與經營、港埠與運輸、觀光遊憩、軍事設備等土地利用。
遊憩功能	遊憩作用	提供大眾親水空間與紓解身心之休閒場所。
	教育作用	為活生生的自然教室，提供實察、標本採集等研究資源。

3.最大景觀知覺偏好

海岸開發往往不會考慮到社會心理層面的問題，而本研究將針對外來遊客以「情境感受度」的調查方式，來探討遊客對於海岸環境的景觀偏好程度。景觀偏好的評估方法中最為人熟知與應用廣泛的就是「景觀美質評估法（Scenic Beauty Estimation, SBE）」。SBE 法是 1976 年由 Daniel 和 Boster 所提出，其認為人類對於景觀的知覺反應，取決於觀賞者對景觀的美感經驗與觀賞者的美感判斷標準(Schroeder, 1984)。其中，美感經驗受景觀美質所影響，判斷標準則因個人以往經驗與環境背景的影響而有所差異。為消除觀賞者因使用不同的判斷標準發生之誤差，於是提出此景觀美質評估模式。

本研究根據 Schroeder 於 1984 年建立的環境知覺尺度作為景觀美質評估的標準，藉由分類量表（category scales）法，直接從受試者的判斷建立心理屬性的等距量表，即要求受試者將所測試的景觀圖片，按照問卷設計的類別或等級加以分類或評分。最後由建立的量表來推算各土地使用項目之景觀知覺偏好函數，偏好值愈大代表景觀價值愈高，因此取其為望大特性。

4.最大經濟功能價值

海岸土地開發因環境資源會產生外部效果，因此較難直接由成本衡量其經濟效益。由於價值(value) V 是外部功能(function) F 與內在成本(cost) C 的比值(即 $V=F/C$)，且外部功能價值，即為目標成本價值(李杰，1995)。因此若能藉由目標成本的估算將土地開發之外部功能數量化，即可藉由其與土地開發的單位成本的比值來估算各種土地開發的單位價值，此一價值可視為一種土地開發的經濟效益，亦即投入單位成本所能獲得的單位開發效益。因其為一單位比值，因此本研究乃將其作為開發單位面積的經濟功能價值係數，將其與土地使用面積變數相乘後，即可得到各種土地使用開發之經濟效益，加總後的目標式即為土地開發之總「經濟功能價值」。本研究將以各土地使用類別之功能價值總和，來作為海岸開發經濟效益評估的目標函數。此目標函數取其為望大特性。

（二）限制條件

藉由目標函數，規劃者所尋求之海岸土地開發效益將可在各目標之權衡下達成。但在現實情況中，海岸土地開發規模通常必須取決於法規容許之上限及其他實質限制

之條件。因此，本研究乃基於規劃目標之訂定，考慮客觀環境的影響，依照海岸土地使用面積、土地使用類別規範，以及生態保育、遊憩計畫等因素，在決定其土地使用分區及許可使用類別後，尋求最適合的開發規模，以獲致各目標的平衡。

本研究係以海岸地區為主要研究對象，因此針對開發地區之實質限制條件與開發者之客觀條件，分別就海岸地區總面積、總允許開發面積上限、各土地面積使用上限及各土地面積使用下限等層面加以考量。現分別說明如下：

1.海岸地區總面積

研究範圍內各分區土地面積的加總，應該等於研究範圍內海岸地區之土地總面積大小，因此將海岸地區總面積列為限制條件。

2.總允許開發面積上限

為了避免過度開發，需限制總允許的開發面積（如：住宅用地、工業用地、遊憩用地、農業用地、交通用地等）上限，以減少不相容土地使用對特殊生態資源之破壞而導致環境品質降低、天然災害發生、資源耗竭及物種滅絕等環境負效果(黃書禮，1986)。本研究將海岸研究範圍地區之總面積減去限制發展面積（環境敏感地區），來作為總允許開發面積之上限。

3.各土地使用分區面積上、下限

海岸地區各類土地使用分區的總面積，依其發展現況、地區特性及未來政策需求導向，應有其上、下限的條件限制，此一限制除可符合實際發展需求之外，亦可避免目標函數的無限變大或變小。

三、模式整合之構想

根據前段之定義說明，建立海岸環境與土地使用整合多目標規劃模式之目標函數為：最大生態保育功能、最小水質污染程度、最大景觀知覺偏好、最大經濟功能價值，而模式之限制式包括：海岸地區總面積、總允許開發面積上限、各土地使用分區面積上限及各土地使用分區面積下限。現將上述目標函數與限制條件，運用數學符號構建基本模式說明如下：

（一）目標函數架構

1.最大生態保育功能

平均嵌塊體（MPS）的面積越大，保育能力越強；反之，若嵌塊體越小，其保育功能相對較低。海岸地區嵌塊體之形成主要乃是因為開發體單元的切割所造成，尤其是道路路網的切割最為明顯。依嵌塊體的計算公式建立目標式如下所示：

$$\max Z_1 = \frac{\sum_{j=1}^{n} x_j}{\sum_{j=1}^{n} N_j} \qquad (1)$$

其中：

Z_1 為平均嵌塊體面積函數(ha)

x_j 為第 j 種土地使用（開發體）面積(ha)， $j = 1,...,n$

N_j 為開發體數目， $j = 1,...,n$

2.最小水質污染程度

本研究以生化需氧量 BOD 作為水污染指標。各開發項目單位面積生化需氧量污染輸出量與海岸各分區土地面積乘積之總和即為總生化需氧量污染輸出量，其值愈小水質污染程度愈小。目標函數如下：

$$\min Z_2 = \sum_{j=1}^{n} \left(p_j \times x_j \right) \qquad (2)$$

其中：

Z_2 為總 BOD 污染輸出量函數(kg/year)

p_j 為第 j 種土地使用型態之單位面積 BOD 污染輸出量(kg/year ‧ha)

x_j 為第 j 種土地使用面積(ha)， $j = 1,...,n$

3.最大景觀知覺偏好

海岸開發往往不會考慮到景觀心理層面的問題，本研究將針對外來遊客進行海岸景觀情境感受度的調查，將遊客對於海岸環境的平均感受度與各土地使用分區的面積，利用迴歸公式建立各類土地使用分區的景觀知覺偏好函數，再將其總和作為景觀知覺偏好的目標函數值，其值愈大代表景觀價值愈高。目標式如下所示：

$$\max Z_3 = \sum_{j=1}^{n} z_j\left(x_j\right) \qquad (3)$$

其中：

Z_3 為景觀知覺偏好函數

$z_j\left(x_j\right)$ 為第 j 種土地使用之景觀知覺偏好函數， $j = 1,...,n$

x_j 為第 j 種土地使用面積(ha)， $j = 1,...,n$

4.最大經濟功能價值

海岸各土地使用分區之經濟功能價值係數，為各類土地使用之外部功能評價值 F_j 與海岸土地開發現實成本 C_j 之比值，藉由各類土地使用分區之經濟功能價值係數與其土地面積乘積之總和來建立最大經濟功能價值函數如下，其值愈大代表經濟功能價值愈高：

$$\max Z_4 = \sum_{j=1}^{n} \left(\frac{F_j}{C_j} \times x_j\right) \qquad (4)$$

其中：

Z_4 為經濟功能總價值函數

F_j 為外部功能評價值（元）， $j = 1,...,n$

C_j 為第 j 種土地使用之土地開發現實成本（元）， $j = 1,...,n$

x_j 為第 j 種土地使用面積(ha)， $j = 1,...,n$

（二）限制式之考量

1.海岸地區總面積

各土地使用分區面積的加總等於研究範圍內之土地總面積。

$$\sum_{j=1}^{n} x_j = T \qquad (5)$$

其中：

x_j 為第 j 種土地使用面積(ha)， $j = 1,...,n$

T 為海岸地區總面積(ha)

2.總允許開發面積上限

總允許開發面積必須限制低於海岸研究範圍地區總面積減去限制發展區面積後之值。

$$S(x_j) \le T - t \qquad (6)$$

其中：

$S(x_j)$ 為總允許開發面積函數， x_j 為第 j 種可開發之土地使用面積

T 為海岸地區總面積(ha)

t 為限制發展區面積(ha)

3.各土地使用分區面積上限

參考相關研究計畫中，針對海岸地區土地之發展所進行的適宜性分析及建議，對各類土地使用面積設定發展上限。

$$x_j \le P_j \quad （7）$$

其中：

x_j 為第 j 種土地使用面積(ha)， $j = 1,...,n$

P_j 為第 j 種土地使用開發面積上限(ha)， $j = 1,...,n$

4.各土地使用分區面積下限

依照海岸地區發展的特性及地區需求趨勢，訂定各分區之開發面積下限。

$$x_j \ge B_j \quad （8）$$

其中：

x_j 為第 j 種土地使用面積(ha)， $j = 1,...,n$

B_j 為第 j 種土地使用開發面積下限(ha)， $j = 1,...,n$

四、案例實證—以新竹市海岸地區為例

針對前節構建出的四項目標函數（最大生態保育功能、最小水質污染程度、最大景觀知覺偏好、最大經濟功能價值），以及四種限制函數（海岸地區總面積、總允許開發面積上限、各土地使用分區面積上限、各土地使用分區面積下限），選擇濕地面積廣大的新竹市海岸地區進行案例實證，在將相關係數導出後，建立完整之目標式及限制式。

（一）案例背景說明

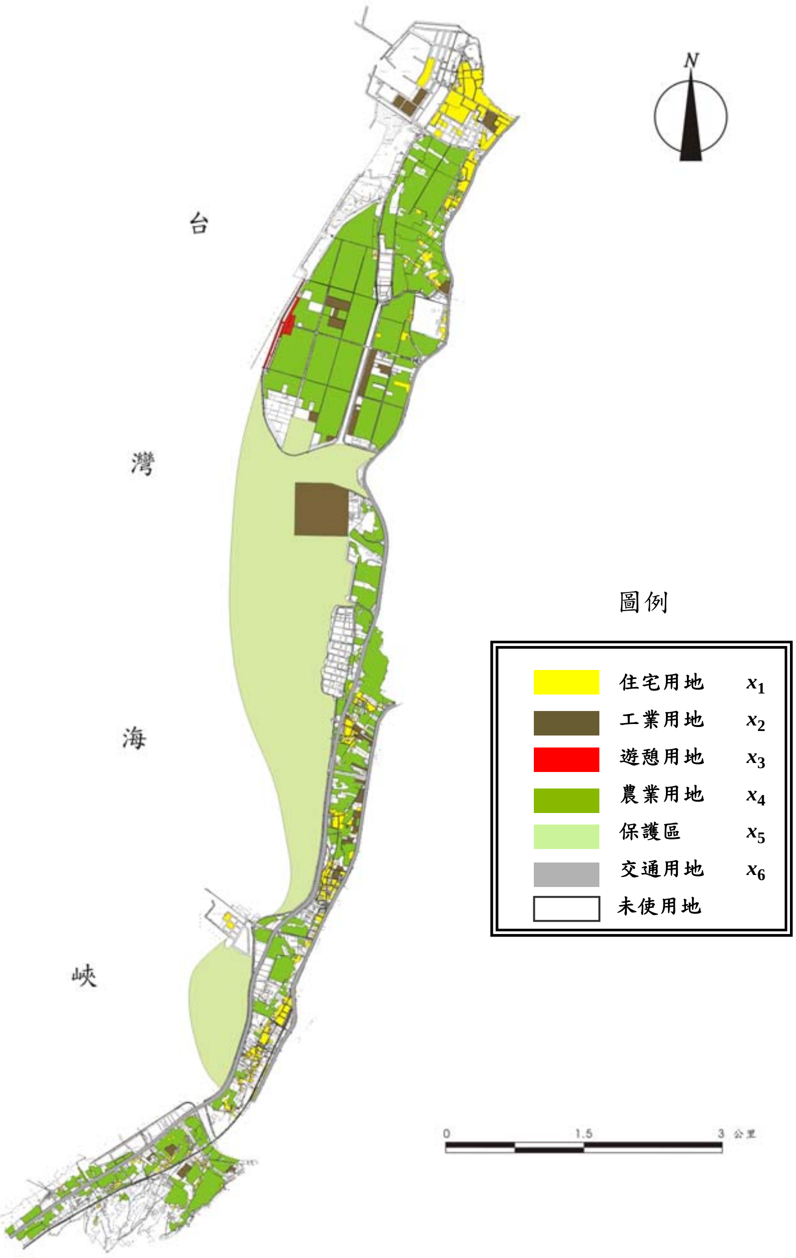
新竹市西臨台灣海峽，海岸線北起南寮，南至南港，長約 17 公里，屬離水堆積海岸。臨海的潮間帶泥灘地是北台灣面積最大的海濱濕地，千餘公頃潮間帶所孕育的大量蝦蟹螺貝，吸引大批水鳥，據統計紀錄的鳥類多達 274 種，螃蟹達 43 種（洪明仕、何平合，1999），尤其介於客雅溪溪口至南港無名溝之間的香山潮間帶，屬於東亞水鳥遷徙分佈網的重要一環(Wetlands International, 1996)，益加突顯此一濕地生態系統平衡的重要性。

新竹市近年推動「沿海 17 公里觀光帶」計畫，以促進民眾體驗生態旅遊及對海岸資源的認知。但由現階段都市發展現況來看，伴隨著經濟大幅成長，以及發展腹地受限因素的驅使，科技與人文並重的新竹市，在都市不斷擴張與龐大人口壓力之下，此一觀光發展計畫卻愈發促使海岸地區的土地漸次開發。加上來自都市地區暴增的污染物，亦隨之擴散至海岸地區，終而造成養殖業沒落、環境污染、資源競用、土地利用不相容等問題的產生，暴露出新竹市海岸地區環境資源管理上的疏漏與失當。如何在自然生態環境與社會經濟效益上求得海岸土地使用的最佳平衡點與空間分配模式，將是未來新竹市海岸規劃決策上必須受到重視的課題。

本研究將以新竹市海岸地區為例，進行海岸生態環境與土地使用整合模式之研究。但海岸地區橫跨海域與陸域兩大體系，地理範圍顯得模糊與複雜，其寬度也會隨時間而有所改變，因此範圍界線之劃設較為困難。本研究參考相關海岸範圍界定之定義，以環境有顯著變化之處作為界線，陸地範圍採「以公路或行政界線、地籍產權界線明顯之處為界」，海域範圍採「以水深至某一高度為界」，故將新竹市海岸地區的範圍界定為北起頭前溪口，南至竹苗縣界，東至六十一號省道（西濱公路）及一號省道（台一線），西至海域三十公尺等深線，依此以利於研究的操作與進行（如圖一所示）。研究範圍面積約 1,534 公頃，其中涵蓋「新竹漁港特定區主要計畫」及「新竹市（朝山地區）都市計畫」兩都市計畫部分地區，都市土地面積共計約 300 公頃，佔研究範圍總面積的 19.58%；而非都市土地面積約有 1,234 公頃，佔研究範圍面積的 80.42%，其

中大部分為香山濕地（參見表二）。

根據本研究對新竹市海岸土地利用現況的調查結果，以及參考國內外海岸土地利用型態分類的標準，本研究將新竹市海岸土地使用型態概分為住宅用地、工業用地、遊憩用地、農業用地、保護區、交通用地 6 種類別，面積及使用內容參見表三，其中尚有 512.6 公頃的空地、荒地及未列入保護區之濕地，統一將其劃分為未使用地。



圖一 新竹市海岸土地使用現況圖

表二　研究範圍海岸土地面積分配表

項目	土地屬性分類	面積(公頃)	百分比%
都市土地	新竹漁港特定區主要計畫	210.5	13.72
	新竹市（朝山地區）都市計畫	89.9	5.86
	小計	300.4	19.58
非都市土地	香山溼地	912.0	59.44
	濕地以外	321.8	20.98
	小計	1,233.8	80.42
總計		1,534.2	100.00

資料來源：新竹市政府，2004

表三 研究範圍海岸土地使用分類表

類別	內容	面積(公頃)
住宅用地	住宅、商店、市場、餐廳、廟宇、教堂、機關	78.6
工業用地	工廠、污廢水處理、垃圾掩埋場、垃圾焚化場	28.9
遊憩用地	風景區、公園、遊憩區	2.9
農業用地	水稻田、旱作地、果園、漁塭、釣魚場、養牧場	331.6
保護區	動植物保育區	510.7
交通用地	公路、鐵路、車站	68.9
未使用地	空地、荒地、未列入保護區之濕地	512.6
總　計		1534.2

（二）目標式之建立

針對新竹市海岸地區之現況特性，將各目標式的係數加以導出，並構建出最大生態保育功能、最小水質污染程度、最大景觀知覺偏好，以及最大經濟功能價值四項目標式（其中 x_1 代表住宅用地面積、x_2 代表工業用地面積、x_3 代表遊憩用地面積、x_4 代表農業用地面積、x_5 代表保護區面積、x_6 代表交通用地面積）。

1.最大生態保育功能

平均嵌塊體愈大，對於環境衝擊愈小，保育能力相對的也愈強，也愈不容易造成物種的滅絕。本研究由土地使用現況調查及航照圖（行政院農業委員會農林航測所，2003-2004），將具有明顯界線（如：道路、開發體邊界、水域）圍成之區域當作一個嵌塊體（參見圖二）。

依嵌塊體數求得海岸開發體（具高活動量的開發用地，包括住宅、工業、遊憩、交通用地）及非開發體（低度使用之用地，如農業及保護區用地）的平均嵌塊體面積，其總和即為平均嵌塊體面積大小。目標式如下所示：

$$\max Z_1 = \frac{x_1 + x_2 + x_3 + x_6}{309} + \frac{x_4 + x_5}{181} \quad (9)$$

2.最小水質污染程度

參考相關研究之調查與檢測結果（參見表四）(李志賢，1996; Lee and Wen, 1996)，將各開發項目單位面積之 BOD 污染輸出量，作為最小水質污染程度目標式中各土地使用項目面積之係數，其中建地乃涵蓋住宅用地、工業用地及交通用地，故將建地之單位面積污染輸出量分別套用至三種用地之係數上。而保護區 x_5 為未開發地區，沒有人為污染情形，因此其 BOD 污染量以零計之。其目標函數如下：

$$\min Z_2 = 253.9x_1 + 253.9x_2 + 109.8x_3 + 152.0x_4 + 253.9x_6 \quad (10)$$

圖二 新竹市海岸開發體與非開發體示意圖

表四 各開發項目單位面積生化需氧量非點源污染輸出係數

土地使用型態	單位面積 BOD 輸出係數 (kg/year‧ha)
建地	253.9
農地	152.0
遊憩	109.8

資料來源：李志賢，1996

3.最大景觀知覺偏好

在人文價值方面，本研究將採用景觀美質評估法進行景觀美質偏好調查，亦即以海岸地區開發後之情境模擬圖，調查一般民眾對各種土地使用開發後的景觀感受度。調查方式是以同一地點之海岸現況照片為底圖，組合成六種土地使用情境，並分成四種不同程度的開發規模，以大幅照片展示方式，讓受測者進行美質偏好選擇。而後將得到的結果以「SBE 景觀美質評估方法」求出受測者對於情境模擬之偏好值 Z。

其中測量方法乃用分類量表(category scales)法，直接從受試者的判斷，建立心理屬性的等距量表，即要求受試者依所測試的景觀圖片感受，按照問卷所設計的類別等級加以分類或評分。本研究操作之 SBE 法設計 11 個等級（-5 到 5）對觀測者進行測試，共計有效問卷數為 325 份，現以其中某一景觀知覺調查結果為例，將各類別等級的受試者人數分析如表五所示。分析方式乃先計算各等級佔所有人數的比率，再累計其比率，依此累計比率可查「相對次數與標準分數互換表」而將其轉換為標準分數值 Z。此標準分數的平均值即為受測者對於情境模擬之知覺偏好值，其值愈大，表示景觀知覺偏好愈大；反之，其值愈小，則表示該項評測之景觀知覺偏好愈小。

之後再根據 Z 平均值以內插法的方式推算出各土地使用項目在不同面積比例下之感受度得點分數（如表六所示），最後將此一分數作為因變數與面積比例進行迴歸分析，即可求出關於各土地使用面積之景觀知覺偏好函數（如表七所示），以其作為目標式中各土地使用面積之係數。

求得之目標式如下所示：

$$\max Z_3 = [-2.1688x_1 - 1.0981] + [-0.4633Ln(x_2) - 3.6549] + [-5.795x_3^2 + 6.7532x_3 - 0.1626] + [1.8315x_4 - 0.0554] + [2.1652x_5 + 0.1629] + [-0.6038Ln(x_6) - 3.4157] \quad (11)$$

表五　SBE 法分析範例表

類別等級	人數	累積人數	累積比率	標準分數值（Z）
-5	0	0	0.000	---
-4	0	0	0.000	---
-3	0	0	0.000	---
-2	10	10	0.031	-1.866
-1	20	30	0.092	-1.329
0	67	97	0.298	-0.530
1	124	221	0.680	0.468
2	36	257	0.791	0.810
3	45	302	0.929	1.468
4	11	313	0.963	1.787
5	12	325	1.000	---

註：$\sum Z = 0.808$　$\bar{Z} = 0.808 / 7 = 0.115$

表六 各土地使用在不同規模下之感受度分數表

項目＼面積比	10%	20%	50%	100%
住宅用地 x_1	-1.267	-1.431	-2.430	-3.168
工業用地 x_2	-2.498	-3.007	-3.406	-3.575
遊憩用地 x_3	0.611	0.722	1.859	0.780
農業用地 x_4	0.110	0.211	1.052	1.702
保護區 x_5	0.236	0.562	1.558	2.193
交通用地 x_6	-1.812	-2.762	-2.967	-3.341

表七 景觀知覺偏好函數迴歸分析表

自變數 x_j(土地使用面積)	因變數 y(景觀知覺偏好函數)	R^2
住宅用地 x_1	$-2.1688x_1 - 1.0981$	0.9650
工業用地 x_2	$-0.4633Ln(x_2) - 3.6549$	0.9575
遊憩用地 x_3	$-5.795x_3^2 + 6.7532x - 0.1626$	0.9130
農業用地 x_4	$1.8315x_4 - 0.0554$	0.9690
保護區 x_5	$2.1652x_5 + 0.1629$	0.9435
交通用地 x_6	$-0.6038Ln(x_6) - 3.4157$	0.8796

4.最大經濟功能價值

海岸地區各土地使用之外部功能價值，即為各土地使用之目標成本價值，因此可藉由海岸土地開發總成本按各土地使用的功能目標重要程度來分攤求得。本研究先應用模糊 AHP 法進行功能目標重要程度的評比，邀請 24 位專家學者（海岸工程、生態景觀、環境管理）對於海岸各土地使用外部功能之重要程度進行評分，再由幾何平均法求出的平均功能目標權值將其乘上土地開發總成本，分攤後的目標成本，即為各土地使用之外部功能評價值。最後求其與海岸土地開發現實成本的比值，即能得到各土地使用之單位面積功能價值係數。

24 份問卷結果在經過一致性檢定之後，依照模糊 AHP 權重之計算方式，先求出專家 k 對於海岸土地使用 j 之功能目標權值 $\tilde{W}_{jk}$（j 為海岸土地使用類別，$j=1,...,n$；k 為專家學者數，$k=1,...,m$），再利用幾何平均法求出各土地使用之平均功能目標權值 $\tilde{W}_j = \left[\prod_{k=1}^{m} \tilde{W}_{jk}\right]^{1/m}$，並把所得到的權值以 α =0.5 計算出 α -cut 值 ${}^{\alpha}\tilde{W}_j = [{}^{\alpha}w_{jl}, {}^{\alpha}w_{jr}]$（$j=1,...,n$），而 ${}^{\alpha}\tilde{W}_j$ 即為各土地使用類別之功能目標重要程度。得到之結果如表八所示。

表八 海岸土地使用平均功能目標權值 $\tilde{W}_j$ 及功能目標重要程度 ${}^{\alpha}\tilde{W}_j$ 表

使用分區	$\tilde{W}_j$	${}^{\alpha}\tilde{W}_j = [{}^{\alpha}w_{jl}, {}^{\alpha}w_{jr}]$
住宅用地 x_1	(0.0519 , 0.0638 , 0.1025)	(0.0578 , 0.0831)
工業用地 x_2	(0.0322 , 0.0477 , 0.0732)	(0.0399 , 0.0604)
遊憩用地 x_3	(0.1074 , 0.1754 , 0.3514)	(0.1414 , 0.2634)
農業用地 x_4	(0.1112 , 0.1453 , 0.2307)	(0.1282 , 0.1880)
保護區 x_5	(0.1765 , 0.2648 , 0.4015)	(0.2206 , 0.3310)
交通用地 x_6	(0.0492 , 0.0775 , 0.1354)	(0.0633 , 0.1064)

由相關政府機關及單位提供之資料，本研究統計公部門對各土地使用項目開發及維護成本中屬於經常門之常態性資料，而推算出海岸地區各類土地使用開發時之平均基本單價，以作為各土地使用之土地開發現實成本 C_j。其結果及資料來源參見表九所示。

由於經濟功能價值之望大特性，因此選擇 ${}^{\alpha}\tilde{W}_j$ 中之樂觀估計值 ${}^{\alpha}w_{jr}$ 作為計算各土地使用外部功能評價值 F_j 的目標權重。各土地使用外部功能評價值 $F_j = {}^{\alpha}w_{jr} \times G$，其中 G 為土地開發總（平均）成本（＝79,428,266）。再計算 F_j 與土地開發現實成本 C_j 的比值，即為各土地使用之單位面積功能價值係數。其計算結果如表十所示。

表九　各土地使用之土地開發現實成本表

項目	土地開發現實成本 C_j（元/公頃）	資料來源
住宅用地 x_1	43,857,000	內政部營建署國宅組光復國宅開發工程提供
工業用地 x_2	8,962,194	和平工業用地開發工程開發計畫
遊憩用地 x_3	11,289,769	新竹市政府交通局旅遊觀光課提供
農業用地 x_4	19,303	台灣省新竹農田水利會 93 年度業務檢查報告
保護區 x_5	3,500,000	新竹市政府環保局提供
交通用地 x_6	11,800,000	道路工程造價概估系統
總平均成本	79,428,266	

表十　各土地使用外部功能評價值及係數計算表

使用分區	${}^{\alpha}w_{jr}$	F_j	F_j/C_j
住宅用地 x_1	0.0831	6,600,489	0.1505
工業用地 x_2	0.0604	4,797,467	0.5353
遊憩用地 x_3	0.2634	20,921,405	1.8531
農業用地 x_4	0.1880	14,932,514	773.5851
保護區 x_5	0.3310	26,290,756	7.5116
交通用地 x_6	0.1064	8,451,168	0.7162

將各土地使用之單位面積功能價值係數乘上各土地使用面積變數 x_j，即可得目標式如下所示：

$$\max Z_4 = 0.1505x_1 + 0.5353x_2 + 1.8531x_3 + 773.5851x_4 + 7.5116x_5 + 0.7162x_6 \quad (12)$$

（三）限制式之建立

本研究列有四種限制條件，依各限制條件的內容，建構限制式如下：

1.海岸地區總面積

本研究範圍總面積為 1534.2 公頃，因此海岸地區總面積限制式如下：

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 = 1534.2 \quad （13）$$

2.總允許開發面積

依據「新竹市綜合發展計畫」(國立中興大學都市計劃研究所，1997）所劃定之限制發展區面積（環境敏感地區）為 367.3 公頃，因此將總面積減去限制發展區面積即得總允許開發面積為 1166.9 公頃。此一限制式由住宅用地、工業用地、遊憩用地、農業用地、交通用地等五種類別構成，如下所示：

$$x_1 + x_2 + x_3 + x_4 + x_6 \le 1166.9 \quad （14）$$

3.各土地使用分區面積上限

依據「新竹市綜合發展計畫」土地使用部門，對於新竹市的土地使用適宜性分析，推算研究範圍內各類土地使用的最適開發面積分別為遊憩用地 100 公頃、住宅用地 603 公頃，以及工業用地 288 公頃，以此作為此三個土地使用類別之面積使用上限。

台灣海岸地區之農業用地及交通用地面積為因應未來之發展，依照現今發展的特性及趨勢，將比現況面積小。尤其西濱快速公路開闢後之使用率並不高，對環境之傷害尤其更大，因此本研究乃將這兩種土地使用之現況面積作為其土地面積的開發上

限；而保護區部分，依照現有對海岸地區開發限制的發展趨勢來看，其面積應要涵蓋鄰近環境敏感區，因此將目前已劃作保護區之面積 510.7 公頃與環境敏感區面積 367.3 公頃加總之值 878 公頃，作為保護區面積之上限。

各限制式表示如下所示：

$x_1 \leq 603$ （15）

$x_2 \leq 288$ （16）

$x_3 \leq 100$ （17）

$x_4 \leq 331.6$ （18）

$x_5 \leq 878$ （19）

$x_6 \leq 68.9$ （20）

4.各土地使用分區面積下限

住宅用地（x_1）、工業用地（x_2）、遊憩用地（x_3）及保護區（x_5）未來發展面積，如以海岸地區發展的特性及趨勢來看，應都大於現況面積，因此本研究將這四區的現況面積當作是它們的土地面積使用下限。

農業用地（x_4）部分，本研究以新竹市海岸地區農民的糧食需求（自給自足）之耕作面積來當作面積下限。由「新竹市統計要覽」（新竹市政府，2004）得知，平均每人消耗白米量為 87.9（公斤/年），而平均每公頃稻米產量為 3768.5 公斤，又海岸地區之農民人口數約為 3,751 人，因此最小農業面積需求為 3,751×87.9/3,768.5=87.49 公頃。

交通用地（x_6）則以新竹市平均的公路用地密度來當作面積的使用下限。由「都市及區域發展統計彙編」（行政院經濟建設委員會都市及住宅發展處，2004）可得知，新竹市平均的公路用地密度為 18,057.7(平方公尺/平方公里)，而新竹市海岸總面積為 1534.2 公頃，因此最小交通用地面積需求為 1,534.2×0.018057.7＝27.7 公頃。

各限制式表示如下所示：

$x_1 \geq 78.6$ （21）

$x_2 \geq 28.9$ （22）

$x_3 \geq 2.9$ （23）

$x_4 \geq 87.49$ （24）

$x_5 \geq 510.7$ （25）

$x_6 \geq 27.7$ （26）

（四）空間規劃整合分析

本研究所建立的海岸生態環境與土地使用整合模式中，共含有 4 列目標函數（其中 3 列線性函數、1 列非線性函數）、8 列條件限制式及 6 個變數。應用上述的多目標模式，利用「LINGO」電腦軟體，以個人電腦進行求解與分析，獲得滿足目標和限制條件之妥協解。

決定目標值與效率極端解之距離衡量方式，本研究採用目標值與目標理想解之最小距離衡量方式（Zeleny, 1973; Yu and Zeleny, 1975; 曾國雄等，1998a)，其表示如下：

$$\min_{x \in S} \left[L_p\left(Z(x), Z^*\right) \overset{\Delta}{=} \left\{ \sum_{j=1}^{n} w_j \left[Z_j(x) - Z_j^* \right]^p \right\}^{1/p} \right], for \quad 1 \leq p < \infty \qquad (27)$$

其中：

L_p 為目標值 $Z\ (x)$ 與目標理想解 Z^* 之距離

$Z_j(x)$ 為第 j 個目標函數

S 為可行解區域

w_j 為第 j 個目標之權重

p 為參數

對個別的目標函數求解，可獲得各目標的最佳解為 Z_k^*（均為 MAX 的型態下），並在假設 p 以及權重 w_j 均為 1 的情況之下求取最短距離（L_P）之最適解（如式(28)）（曾國雄等，1998a），此解即為滿足最大生態保育功能、最小水質污染、最大景觀知覺偏好及最大經濟功能價值之四項目標和各限制條件之最適解，也就是海岸地區土地使用最適開發方案，求解結果如表十一所示。

$$\min_{x \in S} \left[L_p\left(Z(x), Z^*\right) \overset{\Delta}{=} \left\{ \sum_{j=1}^{n} \left[Z_j(x) - Z_j^* \right] \right\} \right] \tag{28}$$

在滿足各個目標式之情形下，目前的農業用地與交通用地皆已達最適規模，不應再有擴張的需要。而高活動量的住宅用地與工業用地，雖然還有成長空間，但能容許範圍都已有限，也應該在適當規模內加以限制。只有遊憩用地與保護區具有較大的發展彈性，未來在相關政策及發展計畫的推動上，應該朝向非長住型及低活動量的生態旅遊觀光活動為主，才適合滿足各項目標達成的條件。

表十一　各目標函數結果求解表　　　　　　　　　　　　　　　單位：公頃

項目	住宅用地 x_1	工業用地 x_2	遊憩用地 x_3	農業用地 x_4	保護區 x_5	交通用地 x_6	最佳解 Z_k^*
Z_1	223.9	28.9	2.9	331.6	878.0	68.9	7.732
Z_2	78.6	77.1	100.0	331.6	878.0	68.9	118409.100
Z_3	168	28.9	100.0	331.6	878.0	27.7	2296.000
Z_4	78.6	77.1	100.0	331.6	878.0	68.9	143587.800
L_P	97.6	58.1	100.0	331.6	878.0	68.9	13444.140
現況	78.6	28.9	2.9	331.6	510.7	68.9	--------

一般海岸開發只考慮到經濟效益及水質污染程度，本研究特別加入了生態保育及景觀價值之目標來加以考量，以求得最佳方案。而由上述的結果發現，較注重生態保育的情形下，各分區土地使用面積變化的幅度很大，顯示生態保育目標對於各分區土地使用面積有較大的影響力，因此應為決策者所須注重且考量的。而景觀價值方面，雖變化幅度較小，但近年來新竹市政府大力推動海岸觀光遊憩的情形下，勢必會吸引大批觀光客前來，因此在景觀價值方面遊客對於新竹市海岸的感受度將成為海岸觀光遊憩品質的一項重要指標。綜合上述分析，本研究認為對於新竹市海岸最好的土地使用狀況，為本研究所提之四項目標互相平衡之情況下所得到的最佳解。其結果與現況比較變化如下：住宅用地由現況 78.6 公頃最佳可增至 97.6 公頃，工業用地由現況 28.9 公頃最佳可增至 58.1 公頃，遊憩用地由現況 2.9 公頃最佳可增至 100 公頃，農業用地維持現況不變，保護區由現況 510.7 公頃最佳可增至 878 公頃，交通用地則維持現況不變。

規劃結果住宅用地與工業用地雖然有增加的空間，但是多半可由目前未被開發使用的都市土地來吸收，對環境敏感地區的質與量，並不會造成影響，反而有利於土地的充分利用，減少閒置土地的浪費。不過，在開發時仍應特別注意其土地使用類別的管制。對於海岸地區而言，工業使用應該以低污染性及非鄰避性之工業使用項目為主，而且必須集中管理及經過環境影響評估方能進行，例如輕工業專區及倉儲物流中心等使用型態，來減少土地與環境的負荷。

五、結論與建議

海岸地區之土地使用開發類別複雜，在以往的海岸規劃開發研究中經常忽略到全盤的考量，尤其是在海岸生態環境及景觀價值兩方面。因此，本研究將這兩項目標作為研究的重點，並利用多目標規劃法，結合海岸地區土地使用規劃時所需考慮之水質污染及經濟功能目標，構建出海岸生態環境與土地使用整合多目標模式，來探討海岸地區各土地使用之最適開發量。

（一）結論

1.新竹市海岸資源豐富，且維護不易，再加上新竹市政府近年來對於海岸觀光的大力推動，因此本研究認為除了水質污染及經濟功能之目標外，生態保育及景觀價值目標亦是新竹市海岸未來開發應重視的要素。為此本研究選擇此四項目標函數，經由模式的操作，以妥協規劃法得到與理想解距離最近的妥協解，以相互平衡的土地使用最佳結果，作為新竹市海岸各項土地使用的最適開發面積。其計算結果各項土地使用最適規模分別為：住宅用地 97.6 公頃（6%）、工業用地 58.1 公頃（4%）、遊憩用地 100 公頃（7%）、農業用地 331.6 公頃（22%）、保護區 878 公頃（57%），以及交通用地 68.9 公頃（4%）。

2.由本研究最大經濟功能價值之目標式可得知，專家學者所認為保護區及農業用地對於海岸地區之重要功能程度頗高，但市政府在其維護費用上卻明顯的偏低，這使得其功能價值係數明顯的偏高。換句話說，農業用地及保護區所帶來的效益多屬於外部效果，無法真實反應在成本上，因此如果政府再不重視其重要性，將會因此損失無法彌補的珍貴資源。

3.從本研究可得知平均嵌塊體面積越大，保育能力越強，因此雖然新竹市政府近年來在沿岸規劃許多遊憩設施，吸引了大批的觀光人潮，但設施大多設置或緊鄰保護區之土地上，且過於分散，造成生物棲息地之不連續性，對於海岸自然環境有著不小的衝擊。因此本研究建議應劃設特定之遊憩區域，使其遊憩面積集中且完整，並配合針對民眾之遊憩區景觀知覺偏好調查結果一併規劃，如此才能降低對於生物棲息地之破壞，以提升生態保育之能力。

4.本研究之景觀知覺偏好調查結果顯示，雖然民眾對於遊憩用地的擴大發展有明顯偏好，但其偏好程度並非呈現直線成長，因此在進行海岸遊憩開發前仍應考量使用者的感受度，才不致於造成遊憩區過度開發的情況產生。

5.一般海岸開發只考慮到經濟效益及水質污染程度，本研究特別加入了生態保育及景觀價值之目標來加以考量，以求得最佳方案。而研究結果發現，較注重生態保育的情形下，各分區土地使用面積變化的幅度很大，顯示生態保育目標對於各分區土地使用面積有較大的影響力，因此應為決策者所須注重且考量的。而景觀價值方面，雖變化幅度較小，但近年來新竹市政府大力推動海岸觀光遊憩的情形下，勢必會吸引大批觀光客前來，因此在景觀價值方面遊客對於新竹市海岸的感受度將成為海岸觀光遊憩品質的一項重要指標，

（二）建議

1.本研究之目標函數屬於靜態整合模式，但現實環境狀況卻會隨者時間而有所改變，因此，若在模式中能夠考量到時間向度的因素，構建出一動態的整合模式（例如：各分區生態性指標的變動、未來土地地價及年度預算的變動，或是設施折舊的影響等），從中尋求土地之最適開發量，將可排除因外在環境的變化所引起的不確定性問題，進而提高整合模式的實用性及準確性。

2.水質污染程度目標函數當中之污染輸出量，因限於資料來源缺乏之故，本研究係參考國內對於各開發項目單位面積之生化需氧量污染輸出係數之調查數據來做分析，但對於建地之污染輸出量國內採取平均值的方式來呈現，使得水質污染目標函數中，住宅用地、工業用地及交通用地的污染輸出係數相同，造成不小的誤差，建議未來的研究

對於建地之污染輸出量應再加以細分，以建立完整且正確的分析模式。

3.本研究主要針對各類土地使用面積之使用量來進行計算，對於空間區位上之配置並未繼續探討，因此建議未來相關研究可利用地理資訊系統（GIS），根據本研究建立之土地利用發展潛能評估體系，進行土地使用適宜性分析，並且考量生態環境與土地使用整合模式中各土地使用分區承載量上限之建議，分析出各土地使用分區之最適建議區位。

4.未來可依照各地區特性的不同，對本研究中之多目標模式中的各個參數，進行適當的修正後，可應用在具有類似開發目標的海岸地區，以進行更有效的海岸資源管理。

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計畫成果自評

海岸環境敏感多變，對台灣生態體系的完整性又是不可或缺的一部分。但台灣土地資源有限，面對各項發展的需求，海岸開發勢必無法避免，然而過度開發對海岸將會造成不可逆之衝擊，其間接影響更是生態體系及地理環境上莫大的災難。因此，如何在自然生態環境與社會經濟效益上求得海岸土地使用的最佳平衡點，將是決策上的重要議題。台灣海岸的土地使用規劃若只考慮到單一目標，亦即決策者只依分析者評估結果即決定接受或放棄，將極易產生許多不適當的土地使用規劃政策。而在多目標規劃中，多個目標是可以在決策過程中被考慮的，且又能兼顧多個衝突性目標間的最佳平衡，分析者提供決策者更多資訊及可行性方案，最後依決策者的評定做出決策。再者同時兼顧到生態與經濟的土地使用政策，即是一種多目標規劃的手段。基於此，本研究延續先前之研究計畫，以新竹市海岸為例，發展一海岸環境資源管理模式，在環境資源平衡利用的前提下，尋求生態保育、水域污染、景觀價值及經濟功能四項目標函數的最佳解，再藉由敏感度分析推論不同環境變數對各種土地利用的影響程度。針對本計畫之計畫成果提出下列說明：

1.本計畫依照原定目標完成，在資料的分析與評估上都有成果產生，與原訂計畫目的相符。計畫中藉由多目標數學規劃(MOMP)方法，建構新竹市海岸生態環境土地使用規劃數學模式，利用多目標規劃方法中的妥協規劃法進行模式求解，於反應不同目標的權衡與考量下，獲致生態保育、經濟效益、社會心理以及環境保護各個規劃目標上的最佳平衡，藉以求得各類土地之最適開發量，作為未來台灣海岸地區土地使用規劃的一項參考依據。

2.本計畫界定出海岸所具備的功能價值，並以此為依據綜合出生態、水質、景觀與經濟四項目標函數，最後利用多目標規劃法求得各類土地使用面積的最佳解。以此分析結果為基礎，可依據決策者對目標的偏好程度來決定各類土地使用項目在最適承載量限制下的最佳使用面積，作為海岸環境資源管理的依據。將其應用在以新竹市海岸地區作為案例的研究之後，對照三分之一自然保護理論結果可發現：住宅、工業、遊憩、交通等人為開發用地可視為海岸地區的適度利用區，其與以農業使用為主的環境緩衝區及保護生態環境取向的自然保存區，恰可形成各約三分之一的環境保護態勢，以此來進行海岸土地的總量管制，將更具有彈性且符合生態保護的基本精神。

3.海岸地區各種土地使用類別的區位，除了必須符合地區發展潛力與環境限制等因素的條件外，還應維持在一個總承載量的限制下進行分配，才能真正避免過度開發的情形發生。因此，在經過環境資源的承載量規劃之後，可以根據相關評估指標進行開發區位的評估與選擇，將適度的活動量分配到適當的區位上，才能確保生態與土地的永續發展。在區位選擇的後續研究方面，可應用地裡資訊系統 GIS，將評估標準、條件及承載量限制等因素投入，經由計算分析後建議出各類土地使用的最適區位。

4.海岸環境資源利用空間承載量模擬及整合分析，可預測各類開發行為對環境可能造成之影響，並作為未來整合土地開發利用、沿海相關規劃建設及海岸環境資源保育之參考。本計畫中環境資源決策敏感度分析，亦可彌補海岸環境資源管理成效不彰之缺點。

5.本計畫為一具獨創性的研究，相關研究成果已經分別發表在 15th Annual International Sustainable Development Research Conference(ISIP)(Utrecht, Netherlands)及 2009 Business &Economics Society International (B&ESI) Conference(Hawaii, USA)國際研討會，以及國內期刊(「都市與計劃」(TSSCI)，新竹市海岸生態環境與土地使用整合模式之建立與應用，已接受刊登)，未來將進一步投稿國內外的學術期刊。

可供推廣之研發成果資料表

□ 可申請專利　　☑ 可技術移轉　　日期：98 年 8 月 31 日

國科會補助計畫	計畫名稱：新竹海岸環境資源管理最適化模式建立之研究 計畫主持人：閻克勤 計畫編號：NSC 97-2410-H-216-006　學門領域：環境與資源管理
技術/創作名稱	新竹海岸生態環境資訊調查系統
發明人/創作人	閻克勤
技術說明	中文：海岸環境敏感多變，面對各項發展的需求，海岸開發勢必無法避免，然而過度開發卻會對海岸造成不可逆之衝擊，並間接影響生態體系平衡及破壞地理環境資源。新竹市西臨台灣海峽，近年推動「新竹市沿海 17 公里觀光帶」促進民眾體驗生態旅遊及對海岸資源的認知，臨海的濕地面積為全台灣最大，益加突顯此濕地生態系平衡的重要性，如何在自然生態環境與社會經濟效益上求得海岸土地使用的最佳平衡點與空間分配模式，將是未來香山海岸規劃決策上的重要議題。本研究建構新竹香山濕地海岸生態 GIS 分析系統，設計一套生態環境及土地使用分類標準與調查模式，在滿足生態需求、社會經濟與民眾心理多目標前提下，利用 GIS 軟體、土地使用適宜性分析與生物多樣性分析資訊系統，進行海岸環境的空間分析與資源利用整合，使海岸開發對生態環境、人文經濟之衝擊減至最低，並可作為生態學空間化之環境管理技術的研究基礎。
	英文：Coastal environment is susceptible to changes of all kinds. With the demands for development, the coast exploitation is inevitable, but excessive development, however, brings irreversible impacts, tilting the balance of ecological system while ruining the resource in the geographic environment. The wetland in Hsiang Shan of Hsin Chu is the largest in Taiwan, the importance of keeping a balanced ecological system on this wetland becomes even more significant, and the question on how to achieve a balanced point in coastal land use between the natural environment and the economic benefits of the society, along with the approach for its spatial allocation, will be an important issue for the decision-making on the coastal developments in Hsiang Shan area. This study introduces a framework for a GIS information reporting system on the coastal environment in Hsiang Shan Wetland of Hsin Chu, featuring a system that examines the types of land use or the utilization of ecological environment by a set of categories. By giving consideration to the demands of the ecology, the economy, the expectation of the general public, the system is aided by GIS application software and information systems that analyze the worthiness of land use and biodiversity. The spatial ecology of the coastal environment is analyzed and the utilization of the resource is integrated, so that the impacts of the coastal developments on the ecological environment and social economy can be minimized. This study can also serve as a foundation for spatial ecology studies that feature tactics on environmental management.

可利用之產業 及 可開發之產品	相關應用產業部門：新竹市政府相關單位、建設公司土地開發部門 可開發之產品：手持式環境資源調查行動裝置
技術特點	建立之生態環境及土地使用分類標準與調查模式可應用在濕地保育與開發評估上，應用的工具分為內業與外業兩部分，外業調查使用 SuperPad Suite 中的 SuperPad 為主要運用軟體，輔以 SuperPad Builder 修改調查使用介面，而內業資料整合則使用 SuperGIS 2.0 進行運算、重疊、分析與疊圖之功能。
推廣及運用的價值	SuperPad 是由台灣本土自行研發的行動地理資訊系統軟體（Mobile GIS），透過手持式行動裝置（如 Pocket PC、Tablet PC 等）即可在野外進行現地調查、量測、圖資修正等工作，再配合全球衛星定位系統（GPS）裝置，可取得即時的座標資訊。對於外業資料的蒐集，SuperPad 提供一個簡易、快速，而且是即時、有效的方式。

※ 1. 每項研發成果請填寫一式二份，一份隨成果報告送繳本會，一份送 貴單位研發成果推廣單位（如技術移轉中心）。

※ **2. 本項研發成果若尚未申請專利，請勿揭露可申請專利之主要內容。**

※ 3. 本表若不敷使用，請自行影印使用。

附錄：著作發表情形

1. Yen, Ke-Chin* (2009), "An Integrated Approach for the Spatial Studies on Coastal Land Use in Taiwan", 2009 Business &Economics Society International (B&ESI) Conference, Hawaii, USA. (NSC 97-2410-H-216-006 and CHU-NSC 97-2410-H-216-006)
2. Yen, Ke-Chin*; Lin, Po-Yi (2009), "Establishment of Optimal Resource Management Models for Coastal Environment in Hsinchu", 15th Annual International Sustainable Development Research Conference (ISIP), Utrecht, Netherlands. (NSC 97-2410-H-216-006 and CHU-NSC 97-2410-H-216-006)
3. 閻克勤*、林伯頤，新竹市海岸生態環境與土地使用整合模式之建立與應用，「都市與計劃」(TSSCI)，2009.04.08 已接受刊登。(NSC 97-2410-H-216-006 and CHU-NSC 97-2410-H-216-006)

----- Original Message -----
From: city and planning
To: 'dama'
Cc: 林楨家教授
Sent: Wednesday, April 08, 2009 1:20 PM
Subject: 「都市與計劃」 審查結果通知 08(聯)10 二修

您好：

台端所賜稿件「新竹市海岸生態環境與土地使用整合模式之建立與應用（稿編 08(聯)10 二修）」審查作業已完成，本刊編輯委員決定此論文爲『刊登』。隨信附上審查結果通知書、格式說明與範例，請您參考修改後於 3 月 14 日前傳回本刊編輯委員會。(本次格式修改主要以作者資訊及參考文獻格式爲主，字型與行距等部份可於出刊前交由出版社一併排版)

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附上審查結果通知書。並再次謝謝您對「都市與計劃」的支持！

敬祝　研安

「都市與計劃」編輯委員會
主編　林楨家
助理　陳志豪　敬上

聯絡電話：02-25009715
聯絡地址：台北市 104 建國北路 2 段 69 號 台北大學都市計劃研究所

出席國際學術會議心得報告

計畫編號	NSC 97-2410-H-216-006
計畫名稱	新竹海岸環境資源管理最適化模式建立之研究
出國人員姓名 服務機關及職稱	閻克勤 中華大學建築與都市計畫學系　副教授
會議時間地點	98 年 7 月 5 日至 7 月 8 日 Utrecht, Netherlands
會議名稱	15th Annual International Sustainable Development Research Conference
發表論文題目	1. Establishment of Optimal Resource Management Models for Coastal Environment in Hsinchu 2. Building Criteria Standards for Performing Sustainable Management of Coastal Wetlands Preservation

一、參加會議經過

7/3 搭機前往荷蘭，當地時間 7/4 早上抵達 Schiphol 機場，後轉搭火車前往 Utrecht 之旅館住宿。7/5 上午九點前往會場 Utrecht University 教育院館報到，並參加開幕儀式及分享荷蘭與各國代表在當前氣候變遷下的因應之道。下午開始進行論文發表的專題報告，此次共計有 300 篇論文在十三個會議室分成兩天半以 92 個場次進行發表，另有 102 篇的論文張貼，參與國家達到 50 國，規模可謂非常盛大。每日在論文發表告一段落之後，傍晚還安排有相關的討論會，提供參與人員進行交流。

7/5 共進行 72 篇的論文發表，相關主題涵括永續科學之需求轉變與趨勢評估、氣候變遷與能源、永續性生產與消費的創新、永續發展管理等範疇。7/6 上午開始有永續性土地使用與區域研究方法之議題的論文發表，亦即與本人研究方向有關之議題。本人發表之論文排在 7/6 下午三點及 7/7 上午九點 114 會場的兩個場次，研究子題為藉由土地使用規劃達成水與生態資源的永續管理，Sesion Chair 是荷蘭 Utrechty 大學的 Wassen 教授和波蘭 Warsaw Agricultural 大學的 Okruszko 教授，報告之後 Wassen 教授提問有關台灣海岸管理與使用上的相關問題。當天發表的論文尚有關於永續及健康都市、永續性的交通運輸、永續性之建築與建成環境，以及永續性農業發展等多篇論文共同進行討論。

7/8 則進行相關議題的參訪，包括市中心貨物運銷、物質再利用、教育與發展之永續性支援工具、廢棄物與能源、生產者的責任、水位上升的自然發展，以及不自然國家中的自然發展，與會者可以任選一議題自由參加行程。

研討會會議在 7/8 傍晚圓滿閉幕，7/9 搭機回國。

二、與會心得

第十五屆國際永續發展年會(ISDRS) 於 2009 年 7 月 5-8 日在荷蘭烏德勒斯 Utrecht 舉行，今年會議主題為「面對全球挑戰：分析永續發展之創新與管理的實現」。面對全球環境變遷所造成的氣候異常，愈來愈多的都市及環境發展的議題逐漸被重視，並且期待透過研究創新與改革來提供有效的因應之道。本次研討會即聚焦在透過各國在永續性發展創新和管理的實

施案例，來解釋科學分析上的成功或失敗的主要因素，以作為未來相關政策之借鏡。

本次研討會共計超過 300 篇的論文被發表，參與的國家多達 50 個國家，研究主題涵蓋科學研究方法、氣候變遷與能源、產業發展、都市與區域發展、管理政策等方面，各國專家藉由在各自領域和地區的永續發展策略和成功案例，來討論有關於研究方法學的應用及相關政策上的發展經驗，討論的結果將會促使相關關鍵問題的明朗化，並且使得這樣的發展足以因應在下一個十年中所將面對的快速發展和環境變遷的結果。

此次會議為第三次參加國際研討會，會議中與世界各國大學教授面對面接觸，除能拓展視野、增加見聞之外，對於專業領域中的新思潮、新觀念並有耳濡目染之效。尤其議程中針對都市土地及生態環境資源永續發展方面的專題報告及論文發表，對於日後進行相關研究，具有啟發式的正面意義，在接受新知、激發創意上，達到加分的效果。此外，認識了相當多此一領域的朋友，對於國外的做事方法與態度具有深刻印象。亦接觸了相關領域的期刊，包括永續發展、經營策略和環境、環境生態學等，在環境管理方面的發展有著相當大的助益。

三、考察參觀活動

此次研討會安排的參訪議題分成七大方向，包括市中心貨物運銷、物質再利用、教育與發展之永續性支援工具、廢棄物與能源、生產者的責任、水位上升的自然發展，以及不自然國家中的自然發展，本人選擇的是與個人研究方向有關的「水位上升的自然發展」之參訪活動。

荷蘭建國史即是一篇與水抗爭的歷史，「與水爭地」向來是荷蘭低地國給人的第一印象。然而面對全球氣候變遷的議題，海平面不斷上升的威脅下，荷蘭與水的關係，遂由抗爭逐漸轉為妥協與合作。荷蘭坐落在一個水平面總是在變動著的河口三角洲上，洪水的威脅隨著暴雨量的頻繁，以及益發密集的都會發展型態而使問題愈發嚴重，因此坐落於河口地區的已發展地，除了必須被適當防護之外，荷蘭還採取了特別且前衛的措施來處理雨和河的水的問題。

這次參觀的兩個地區即是已經實施這種特別措施的場所。其中 Blauwe Kamer 是一個鄰近河岸的自然保護地區，在 1992 年的夏天拆除了所有的河岸堤防設施，並且允許鄰近的河流定期氾濫淹沒此一地區。此一措施不僅使得自然環境受到適當保護，而且還降低了七月至八月雨季氾濫的機率。第二個參訪地區是鄰近 Utrecht 的一個新興城鎮 Leidsche Rijn，這裡事先有系統地規劃配置了一些特別的設施。平常乾淨的雨水由屋頂、花園和街道被導引到下水道，並且輸送到一座污水處理廠淨化。在 Leidsche Rijn 尚有一種可以暫時儲存雨水和幫助輸送雨水至鄰近小溪、池塘的設施。目前乾淨的雨水可以在長期的乾季裡，被導引注入指定的自然水域，也可以將儲存的雨水直接送達地下水層並藉以提升地下水水位。

四、建議

由研討會會議及參訪過程中可以深深了解到荷蘭在海岸防護的決策上已經漸漸放棄結構式防災策略，取而代之的是「還地於河」的非結構式減災措施，實施的成果不僅對自然生態環境的復育有所幫助，而且還能有效的預防災害，這對於台灣在河川治理與海岸規劃上，不失為一個良好的參考範例。另一個相關議題是雨水的回收再利用，荷蘭的作法不僅是將其利用在生活用水上，還可以將其導引至自然水域，復育日漸枯竭的淡水資源與生態，並且還能恢復地下水位的水準，這些都值得台灣借鏡。

五、攜回資料名稱及內容

1.會議資料：包括議程、作者個人基本資料

2.研討會論文摘要集一本

3.Summary The Netherlands in a Sustainable World 一本

4.Utrechty 大學 Faculty of Geosciences 簡介一份

六、其他

荷蘭國土面積與地理環境與台灣類似，有關於環境規劃與管理方面的政策及研究，有相當多值得台灣在制訂相關法規時加以參考，尤其是海岸防護的相關議題，是未來台灣因應全球氣候變遷時應該要及早考量與防範的，未來有機會還可以再參加類似的國際研討會。

Establishment of Optimal Resource Management Models for Coastal Environment in Hsinchu

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Taiwan is comprised of a number of islands. Most developments in Taiwan are related to the coastline. Given the guidelines for economic development and environmental protection, conflict between coastal resource preservation and coastal land development is inevitable. The development of coastal environments, in addition to considering techniques for hydraulic engineering and economic benefits, should also effectively evaluate the impacts of development on the environment, landscape, and regional development, thereby providing a reference for policy decisions. Moreover, given the unstable characteristics of coastal environments, the concepts of ecological planning can be adopted when evaluating land development and management policy, enhancing the ease with which one can identify reasonable and effective strategies for sustainable development. This study applies analytical methodology based on ecological planning theories to generate a comprehensive system for planning and evaluating coastal environments. Given the premise of striking a balance between ecological conservation and economic development, the four goals, ecological conservation, water pollution prevention, landscape and economic benefits, are adopted as four functions, whereas the solution, thereby achieving a balanced utilization of environmental resources. The impacts of land use are assessed using different environmental factors in sensitivity analysis, and this data then serves as reference for spatialization of coastal environment categorization with Geographic Information System (GIS) and to establish a tool for monitoring coastal planning. The coastal area in Hsinchu, is adopted as an example for the empirical study, with the aim of providing a reference for policy decision makers when planning coastal development. Finally, this dissertation illustrates the applicability of the comprehensive system in the dominance of land use and the optimization of land use development, allow the data to serve as an appropriate reference for management and utilization of environmental resources along coastal Taiwan.

Key Words: Coastal Environment, Resource Management, Land Use, Multiple Criteria Decision Making

I. Introduction

The country or area lain on the island, such as Japan, Taiwan etc., has comparatively different water environment and development condition with respect to other continental area because of its special geographical condition. Based on the premise that the economic development and ecological conservation must be taken care together, that how to consider the characteristics of geography, hydrology, ecology, humanity of water area or water bank, plan suitable use area, environmental symbiosis area, natural recovery or conservation area, and create the protection regulation for the development work, has become an urgent topic. Taiwan belongs to the island type of country; the area of its coastal wetland is about 11,846 hectares, which contributes to a very big range. This makes most developing behaviors relate to the coast directly or indirectly, and often causes the dilemma between resource conservation and economic development. The essence of coastal area is composed of many different fields. The disappearance and sinking of coastal land is not only a regional problem; it often may be one of the economic and social changes (Dearden, 1990). In order to solve the coastal development problem, it is necessary to identify the basic characteristics of coastal environment at first, particularly its integrated characteristics.

The coast is the natural buffer area bred by the nature, an important key to maintaining ecological environment. Its significance has already been acknowledged by every country. So, in the management of coastal environment, the developed countries such as America, Canada, Japan etc. adopt the system of “sustainable management” (Yamashita, 1994; Broll et al., 2002) to carry on the management in various degrees by classifying and grading the functional condition of coastal area. The European countries such as England, Holland, Sweden etc. apply the ecological principle to the undeveloped land, employing the city design principle of semi-wild landscape to develop a investigation method and classification criterion that are suitable for the coexistence of human and nature through the existing growth condition of land. They attempt to incorporate the naturally ecological information in city planning process in order to classify the undeveloped coastal land and help determine the way of usage in the future (Soderbaum, 2000). However, for many years, the use and development of coastal land in Taiwan is restricted to the external use only; the resources management of its potential characteristics is seldom discussed, so the environmental protection is often overlooked, causing many further ecological problems in the environment.

In the “Agenda 21”, the topics such as the ecological utilization of resources and environmental planning management are being greatly emphasized. The sustainable development concept is used to resolve the conflict between the land use and its resources, and to develop the effective management policy. The main objective is to make it comply with the resources distribution principle for the coexistence of ecology and economic efficiency (Chiau, 1999). The traditional land-use zoning control method is still being executed for the management system of domestic coastal environmental resources at present. The method, which maintains environmental quality by monitoring the type and intensity, cannot precisely control the land use to achieve the purpose of environmental conservation (Kuo, 2000). Particularly, it is not suitable for the management and conservation for the resources of sensitive area, such as the coast and wetland.

Moreover, the application of previous procedural planning theory and traditional ideal planning method on the management planning of water environment does not comply with the trend of sustainable development concept and the requirement of ecological conservation in nature. As a result, it is an inevitable drift to define the development of coastal space, respond the concept of ecological conservation properly, maintain the regional stability, balance the continuous development, consider the planning method of ecological environmental, and propose relevant plan objectively and fairly.

The single-objective issue was usually considered for land-use planning in Taiwan in the past; the policymaker could determine whether to accept or abandon it in accordance with the calculated result only after the objective was established (Lai, 1994). Even if the land-use planning and the multiple strategic theory are combined to function as a whole, the economic topic still overrules, making decision which lacks strategic analysis and research that involves environmental and ecological objective (Lai, 1994; Tzeng et al., 1998). However, since the planning or research with single economic objective does not take into the account of environmental resources management, it will be easier to trigger the subjective bias of environmental development, causing the conflict between ecological and economic development factors. The coastal area belongs to a highly sensitive area, and it will be the development center of human activity in the future. In the past, it obviously lacked the consideration and balance of multiple objectives by using the single development objective as a developing guild for economic. So, it should move towards the common development objective, such as economy, society, humanity and ecology etc. in order to carry on a combining coastal land use and planning for the development decision of coastal area in the future. In the planning of multiple objectives, a lot of objectives are being measured at the same time in the decision-making process, which helps balance the issue among many conflicting objectives. The analyst offers a lot of information and feasible alternatives to the policymaker. Finally, the optimal conclusion is made in accordance with the evaluation of policymaker (Tzeng et al., 1991).

This research wants to set up a decision way for the mutual integration of coastal ecological environment and rational land-use alternative. In order for the operators to take the development scale of coastal land as a reference for their investment, the objective of satisfying the ecological conservation, social psychology, economic efficacy, and environmental protection is achieved through the multiple-objective mathematical planning method. After the rational solution is created by taking into account the ecological environment and social psychological objective, the impact of coastal development on the ecological environment and social psychology will be minimized, and the requirement for development efficacy of coastal development can be met and satisfied at the same time.

This research will analyze the function value of coast by screening the functional index first, and then use it to summarize four objective functions including ecology, water quality, landscape, and economic. Finally, it utilizes the multiple-objective planning method to get the optimal solutions of every land use area. Based on this analysis result, the best possible use area for each type of land under the optimal load constrain can be determined according to the objective preference degree of policymaker, so it can be used as the basis for managing coastal environmental resources. After applying it to the case study for the coastal area in Hsinchu, the optimal solution of every land use area under every preference can be obtained. After the result is reflected on the ecological planning theory, it can be found that the developed land for households, industry, recreation, and transport etc. can be regarded as the appropriate use area along the coast. This area, the environmental buffer area of agriculture, and natural conservation area that are ecologically protected will each dedicate about one third of the environmental protection situation. Employing this method to control the total amount of coastal land will be more flexible and meet the fundamental spirit of ecological protection.

II. Establishment of Model Structure

This research will establish the objective of coastal environment in accordance with the characteristics of coastal resources. It will be integrated into the development model of coastal land use. The corresponding development amount of land use in the coastal environment will be measured under the mutual conflict of various objectives. The basic concept of four objective functions and five constrains will be described in detail as follows.

1. Objective function

As for the development of private sector, most motive and objective for the coastal development is to pursue the greatest economic benefit. The impact on the ecological environment in the surrounding area is seldom concerned. But as the degree of demanding higher environmental standard by the people rises day by day, the public department should respond to the developing behavior of private sector in the policy with consideration.

As for the development of coastal area, the main region should be the one with natural resources or development potential. In order to achieve the protection and sustainability of resources, the principle which states that the conservation is more important than development for the use of coastal resources should be applied. In order to reduce the negative influence on coastal resources resulted by coastal development, the environmental supply aspect will be used as the constraint condition.

This research is conducted in accordance with the recommendations specified in "The Planning on National Technological Project of Ecological Engineering" by relevant experts and scholars in environmental planning, coast engineering, ecosystem, and wetland conservation etc. (National Science Council, 2004), as well as past study results on the environmental function index of coast and wetland (Yen et al., 2005; Yen et al., 2007). The coast has the functions of hydrology and chemical circulation such as purification of water, prevention of flood, protection of coastline, makeup of groundwater to water-containing stratum etc. The coast is called the "biological supermarket" (Mitsch and Gosselink, 1993), which is where the vast food chain and abundant biological diversity exist, so it also has the function of ecology. In recent years, due to a large amount of coastal land being exploited and the implementation of two days off per week, the coast is not only an activity center for general people, but also the best place of leisure for outside visitors, so its function value of recreation is increasingly important (the functions of coast are summarized in **Table 1**). From the description mentioned above, single economic objective should not be used as the trend for the development of coastal area; the ecological conservation and hydrological purification should be fulfilled, and the security of peripheral people in the coast and the satisfaction of visitor should be improved. Thus, this research summarizes four major objective functions for the establishment of coastal ecological environment and the integrated model of land use consist of those four functions: ecological conservation ability, water pollution degree, preference for landscape perception, and economic function value. Their contents are described as follows:

(1) Maximum ecological conservation function

As for the habitat of species, when a bigger patch is divided into smaller patches, the inside habitat will be changed, causing the size and the number of different inner groups to be reduced. The patch size is the main parameter for studying the characteristics of landscape, because it directly affects the amount of living beings per unit area, the productivity and storing amount of nutrient, and the species composition and species diversity (Forman and Godron, 1986; Marsh, 1991; Forman, 1995; Bourgeron et al., 2001). As for a specific species, a larger patch will have a larger community compared to a smaller patch, so the regional extinction is not easy to occur in the larger patch. On the contrary, if the patch is too small, the probability for regional extinction of species will be increased. This happens mainly because that the larger patch consists of more habitats, allowing more different species to coexist compared to a smaller patch, and the regional extinction is not easy to occur (Forman and Godron, 1986; Forman, 1995; Dramstad et al., 1996). From the above-mentioned description, it is known that if the patch size is larger, the conservation ability will also be higher. On the contrary, if the patch size is smaller, the conservation ability will be lower. So, this research takes the study, The Ecological Index of Landscape, conducted by Forman (1995) as a reference, and selects the mean patch size (MPS) related to land-use area as the index for evaluating the ecological conservation function of coastal area.

The MPS is employed as the evaluation standard of ecological conservation ability in the objective function of maximum ecological conservation function. If the MPS is larger, then the scope of ecological influence will be more concentrated, and the conservation ability will be better. So it is defined as the characteristics of looking for maximum.

(2) Minimum water pollution degree

The pollution degree of coastal water is an importance index of assessing the environmental quality in the coastal area. There are many methods to measure water pollution degree. For example, the dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus, ammonia nitrogen, suspended solid and coliform etc. (Canter, 1977). The amount of oxygen dissolved in water is called the dissolved oxygen. The fish and shellfish can only breathe in the oxygen dissolved in water. The microorganism will also use part of oxygen dissolved in water to decompose the organic substance into simple substances. The amount of oxygen consumed by the microorganism for decomposing the organic substance is called the biochemical oxygen demand (BOD). If there are more water pollutants, the BOD will be higher. A good water area must have high DO and low BOD.

When the function is established, it is necessary to consider if the information is easy to be extracted, and whether the water quality model is reliable or not. After various water quality parameters are assessed, this research select more reliable and common BOD-DO model as the water quality model (Canter, 1977). But considering that the velocity of water flow is fast for the rivers on the western coast in Taiwan, the DO can be kept above the standard of water, so this research uses the BOD as water pollution index, and it is defined as the characteristics of looking for minimum.

(3) Maximum landscape perception preference

Often, the issue of social and psychological aspect is not considered for the coastal development. This research will use the investigation method of “scenario feeling degree" to study the landscape perception preference of outside visitor on the coastal environment. In the estimation methods of landscape preference, the most familiar and popular one is the Scenic Beauty Estimation (SBE). The SBE was proposed by Daniel and Boster in 1976. It is considered that the landscape perception of mankind depends on the beauty experience of landscape and the beauty judgment standard (Schroeder, 1984). Among them, the beauty experience is influenced by the landscape beauty, and the judgment standard is different due to the influence of past personal experience and environmental background. In order to eliminate the error due to the use of different judgment standards, the SBE is proposed.

This research adopts the environmental perception scales established by Schroeder in 1984 as the standard of SBE. According to the category scales, the equal distance scales of psychological attribute is established from the judgment of subjects directly. The subjects are asked to classify or grade the landscape pictures according to the category or rank of how the questionnaire is designed. Finally, the constructed scales is used to calculate the landscape perception preference function of land-use item, and larger preference value represents higher landscape value, so it is defined as the characteristics of looking for maximum.

(4) Maximum economic function value

The coastal land development will create external effects because of the environmental resources, making it difficult to directly estimate its economic efficacy from the cost. The value (V) is the ratio of the external function (F) to the internal cost (C) ($V = F/C$), and the external function value is the objective cost value (Li, 1995). So, if the external function of land development can be quantified by the estimation of objective cost, the unit value of every land development can be estimated by dividing it into the unit cost. This value can be regarded as the economic efficacy of land development, which is the unit development efficacy obtained from the investment per unit cost. Because it is a unit ratio, when it is multiplied by the land use area, the economic efficacy of land development can be obtained, and the sum of objective equations will be the total "economic function value" of land development. This research will use the sum of function value of every land use category as the objective function for the assessment of economic efficacy of land development, and it is defined as the characteristics of looking for maximum.

2. Constrains

Through the objective function, the development efficacy of coastal land searched by the planner can be achieved while maintaining the balance between each objective. But in reality, the development scale of coastal land often depends on the upper limit of regulation allowance and other constrains. Therefore, this research considers the influence of objective environment based on the setup of planning objectives. After both the land use zone and permit category are determined, according to the use area of coastal land, land use category and specification, ecological conservation, and recreation plan, the most suitable development scale can be sought in order to obtain the balance of every objective.

This research regards the coastal area as the main research subject. As for the constrains of development area and the objective conditions of developer, total area of coastal region, the upper limit of total allowable development area, the upper limit of every land use area, and the lower limit of every land use area are being considered respectively. They are described as follows:

(1) Total area of coastal region

In the research field, the sum of every land area should be equal to total area of coastal region. So, total area of coastal region is considered as a restraint condition.

(2) The upper limit of total allowable development area

In order to prevent over-development, total allowable development area should be restrained (such as residential land, industrial land, recreational land, agricultural land, transport land etc.). The upper limit of total allowable development area is obtained by subtracting the restrained development area (the environmental sensitive area) from total area of coastal area.

(3) The upper limit, lower limit of every land use area

Total area of every land use zone in coastal area should has the constrain of upper limit and lower limit according to its current development situation, regional characteristics and future policy requirement and direction. This restraint condition not only can comply with the actual development requirement, but also can avoid the infinite large or small objective function.

III. An Empirical Example for Integrating the Coastal Area in Hsinchu City

According to the four objective functions mentioned before (maximum ecological conservation function, minimum water pollution degree, maximum landscape perception preference, and maximum economic function value), and four restraint functions (total area of coastal region, the upper limit of total allowable development area, the upper limit of every land use area, and the lower limit of every land use area), the coastal area of Hsinchu with vast wetland is selected to conduct the case verification. After relevant factors are derived, the complete objective functions and restriction functions are established.

1. Description for the background of case

The west border of Hsinchu City is Taiwan Straits. The coastline starts from Nanliao in the north to Nankang in the south, which is about 17 km in length. It belongs to the type of emergence coast. The muddy beach land in intertidal zone is the largest coastal wetland in northern Taiwan. A large number of shrimps, crabs and shellfishes attract large quantities of aquatic birds in more than a thousand hectares of intertidal zone. According to the statistics, there are 274 kinds of birds and 43 kinds of crabs (Hung and Ho, 1999), especially in the Hsiang-Shan intertidal zone that lies between Koya River and Nankang Creek. It is a rather crucial location for the aquatic birds while they migrate from eastern Asia (Wetlands International, 1996), showing its importance to the balance of ecosystem of this wetland.

In recent years, Hsinchu City government promotes the project titled “17 Kilometers Sightseeing Belt along the Coast” in order to encourage people to experience the eco-tour and cognition of coastal resources. Provided the observation of the city development at its present stage, it can be seen that the economic growth has been significantly increasing yet restricted to a scarcity of available hinterlands, so Hsinchu, the city that pays great attention to both technology and humanity, has proposed a sightseeing development project that will impel the exploitation of coastal land and release the pressure from endless city expansion and high population. In addition, the pollutants from city area are increased suddenly and violently, which eventually diffuse to the coastal area. The problems such as the declination of feeding sector, environmental pollution, resources competition, and incompatible land use continue to occur, showing the defect and careless omission in environmental resources management of coastal area in Hsinchu City. How to get the best balance point and space distribution model of coastal land use under natural ecological environment and social economic efficacy will be an important issue when making the decision for the future coastal planning in Hsinchu City.

This research will take the coastal area of Hsinchu City as an example, which will conduct the study on the integrated model of coastal ecological environment and land use. Both ocean and land-based region overlap with the coastal area, so the geographical range seems quite ambiguous and complicated, and its width can even change over time; in other words, it is comparatively difficult to get the boundary of the scope. This research refers to the definition of relevant coastal scope, and the environment with significant changes is used as the boundary line. The land scope is drawn by "the highway or obvious places like administrative boundary line and booked property line", while for the sea scope, "a certain depth of water" is used as the boundary line. So, the scope for coastal area of Hsinchu City is determined from the estuary of Toechin River in the north, the border of Hsinchu County and Miaoli County in the south, No. 61 Provincial Highway (Siebin Highway) and No. 1 Provincial Highway in the east, to the isobaths line of 30 meters of sea area in the west (as shown in **Fig. 1**). The area of research scope is about 1,534 hectares, which covers part of the city plan area of "Special District Planning of Hsinchu Port" and "Master Plan of Hsinchu City". The area of urban land is about 300 hectares, which accounts for 19.58% of the total area. That of non-urban land is about 1,234 hectares, which accounts for 80.42% of the total area, wherein most land remains as Hsiang-Shan wetland.

According to the investigation result for present situation of coastal land use in Hsinchu City by this research, and the reference of domestic and foreign standards for the classification of coastal land, this research divides the coastal land use type of Hsinchu City into six categories, including residential land, industrial land, recreational land, agricultural land, conservation area, and transport land. The area and the content of use are shown in **Table 2**. There are 512.6 hectares of vacant land and wasteland, which have not been listed in the wetland of conservation area, so it is divided into the unused land.

2. Setting-up of the objective functions

As for current situation and characteristics of coastal area in Hisn-Chu City, the coefficients of every objective function are derived, and the objective functions of maximum ecological conservation function, minimum water pollution degree, maximum landscape perception preference, and maximum economic function value are established (where x_1 represents the area of residential land, x_2 represents the area of industrial land, x_3 represents the area of recreational land, x_4 represents the area of agricultural land, x_5 represents the area of conservation area, and x_6 represents the area of transport land)

(1) Maximum ecological conservation function

If the mean patch size is larger, the environmental impact will be smaller, the conservation ability will be higher, and the regional extinction is not easy to occur. This research considers a patch (see **Fig. 2**) as an area enclosed by obvious boundary lines (such as road, developing zone border, water area) in accordance with current investigation of land use and aerial photo (Aerial Survey Office, Forestry Bureau, Council of Agriculture, Taiwan, 2003-2004).

According to the number of patches, the mean patch sizes of coastal developing patch (development area with high activity, including the land used for house, industry, recreation, and transport) and non-developing patch (the land with low degree of use, such as land used for agriculture and conservation area) are obtained. The sum is the area of mean patch sizes. The objective function is shown in **Table 3** (Eq. (1)).

(2) Minimum water pollution degree

The BOD per unit area of every development item is used as the coefficient for every land use item in the objective function of minimum water pollution degree, according to the investigation and inspection results. Among them, the building land covers the residential land, industrial land, and transport land, so the output of pollution amount per unit area of building land includes all three coefficients. The conservation area x_5 is a non-developing area, where no pollution is detected, so the BOD is taken as zero. Its objective function is shown in **Table 3** (Eq. (2)).

(3) Maximum landscape perception preference

As for the humanity value, this research adopts the SBE to assess the landscape perception preference. The scenario simulation diagram of developed coastal area is used to investigate the landscape perception of general people. As for the investigation method, the photos of present coastal situation at the same place are used as base diagrams, and they are firstly combined to form six kinds of land use scenarios, and then divided into four kinds of development degrees. It is shown in widespread photo in order to let the people select scenic beauty preference. After the result is obtained, the SBE is used to get the value Z of scenario simulation.

According to the mean value of Z, the interpolation method is used to estimate the perception score under different proportion of area for every land use item. Finally, the regression analysis is conducted for the parameter of this partiality and area ratio in order to obtain the landscape perception preference function for every land use area. It can be used as the coefficient of every land use area in the objective function. The objective function is shown in **Table 3** (Eq. (3)).

(4) Maximum economic function value

The value of external function for every land use in coastal area is the value of objective cost for every land use. So, it can be obtained by sharing the total development cost of coastal land according to the importance degree of the objective function. This research employs the fuzzy AHP method to evaluate the importance degree of objective functions. 24 experts and scholars (coastal engineering, ecological landscape, and environmental management) are invited to score the importance degree of external functions. The geometric method is used to get the mean value, Wj. Multiply it by the total cost of land development to get the evaluation value of the external function for every land use. Finally, the coefficient of function value per unit area of every land use can be obtained from the ratio of real cost of the coastal land development.

The information provided by relevant government authorities and units helps summarize the statistical data for the development and maintenance cost of every land use. The average unit price for the development of various lands in coastal area is then extracted from the data, and used as the real cost C_j for the development of every land.

Due to the maximum characteristics of economic function value, the optimistic evaluation value wj is selected from Wj to calculate the objective weight of external function assessment value Fj. As for every land use, the external function assessment value is determined by Fj=wj*G, where *G* is total (mean) cost of land development (＝79,428,266). The ratio of Fj and real cost of land development Cj is the coefficient for the function value per unit area of every land use.

The following objective function can be obtained by multiplying the coefficient of function value per unit area of every land use and the area parameter of every land use xj in **Table 3** (Eq. (4)).

3. Establishment of constraints

There are four kinds of constraints in this research. The following constraint functions are established in accordance with the contents of constraints:

(1) Total area of coastal region

The total area of this research scope is 1534.2 hectares, so the constraint function for total area in the coastal region is shown in **Table 3** (Eq. (5)).

(2) The upper limit of total allowable development area

According to the "Comprehensive Development Plan of Hsinchu City" (National Chung Hsing University, 1997), the area of development constrained area (the environmental sensitive area) is 367.3 hectares. The development constrained area is subtracted from the total area to get the total allowable development area of 1166.9 hectares. This constraint function is formed by five different categories; residential land, industrial land, recreational land, agricultural land, and transport land, which are shown in **Table 3** (Eq. (6)).

(3) The upper limit of every land use area

According to the "Comprehensive Development Plan of Hsinchu City", the optimal development area for land use in Hsinchu City shall be dissected into 100 hectares of recreational land, 603 hectares of residential land, and 288 hectares of industrial land. These three land use classifications will be used as the upper limit of every land use area.

In order to react to future development, the agricultural land and transport land in the coastal area of Taiwan will be less in area than the current situation according to present characteristics and trend of development. Especially after the Siebin Highway is finished, it does not contribute to a high use rate but a great hazard to the environment. So, this research regards the current situation of these two kinds of land use as the upper limit of development. As for the conservation area, along with the trend of development constrains on the coastal area, it should embrace the adjacent environmental sensitive area. As a result, 510.7 hectares of present conservation area are added to 367.3 hectares of the environmental sensitive area to get 878 hectares of total area, which will be used as the upper limit for the area of conservation area.

Every constraint function is shown in **Table 3** (Eqs. (7)-(12)).

(4) The lower limit of every land use area

According to the characteristics and trend of development, the future development area of residential land (x_1), industrial land (x_2), recreational land (x_3), and conservation area (x_5) will be larger than the existing area. So, this research regards current situation of these four kinds of land use as the lower limit of development.

As for the agricultural land (x_4), this research regards the food demand (self satisfaction) of farmers in the coastal area of Hsinchu City as the lower limit of development. According to the "Outline of Statistics in Hsinchu City" (Hsinchu City Government, 2004), the average consumption of rice per person is 87.9 (kg/year), the average output of rice per hectare is 3768.5 kg, and the population of farmers in the coastal area is about 3,751, so the minimum agricultural area demand is 3,751*87.9/3,768.5 =87.49 hectares.

As for the transport land (x_5), the average density of road land is used as lower limit in Hsinchu City. According to the "Urban and Regional Development Statistics" (Economic Construction Committee, Taiwan, 2004), the average density of road land in Hsinchu City is 18,057.7 (m^2/km^2), and the total area of coastal region in Hsinchu City is 1534.2 hectares, so the minimum demand of transport land is 1,534.2*0.0180577=27.7 hectares.

Every constraint function is shown in **Table 3** (Eqs. (13)-(18)).

4. Integrated analysis of space planning

The integrated model for ecological environment and land use on coastal planning established by this research contains 4 objective functions (where 3 linear functions, 1 nonlinear function), 8 constraint functions and 6 parameters. The "LINGO" software and personal computer are use to solve the above-mentioned multi-objective model to get the compromise solution that satisfies the objective and constraints.

As for determining the objective value and the distance measurement method for efficiency extreme solution, this research adopts a minimum distance measurement way that measures the difference between the objective value and ideal solution (Zeleny, 1973; Yu and Zeleny, 1975). It is expressed in **Table 4** (Eq. (19))

By solving every objective function, the optimal solution Zk* (under MAX condition) can be found. Under the assumption that both *p* and wj are 1, the optimal solution of shortest distance (Lp) can be calculated (as Eq. (20) in **Table 4**) (Tseng et al., 1998). This solution will be the optimal solution which satisfies the objectives of maximum ecological conservation function, minimum water pollution degree, maximum landscape perception preference, and maximum economic function value as well as every constraint condition. It will be the optimal development alternative for land use of coastal area. The solutions are tabulated in **Table 5**.

Present agricultural land and transport land have already reached the optimal scale under the condition that every objective function is satisfied; there is no need for any further expansion of the two lands. Also, though the residential land and industrial land that are highly active are still expandable, they should be restrained to proper scale since the allowable scope is limited. Only the recreational land and conservation area have larger development flexibility. The promotion of relevant policy and development plan in the future should lean towards ecological tour and sightseeing activity that are mainly non-long residence type and low active in order to satisfy the conditions of various objectives.

General coastal development only considers the economic efficacy and the degree of water pollution, which is why this research concerns more about the objectives of ecological conservation and landscape value, in order to get the optimal solution. From the aforementioned results, it is found that when the ecological conservation is paid more attention, the variation for the area of land use will be larger. It shows that the influence on land use area is greater for the ecological conservation objective, so the policymaker must notice and account for it. As for the landscape value, although the change is relatively small, in recent years Hsinchu City Government has been greatly promoting the coastal sightseeing and recreation that are going to attract a lot of tourists. So, the perception of tourists on the coast in Hsinchu City will become an important index for the coastal sightseeing and recreation quality in the landscape view aspect. Summarized from the above-mentioned analysis, this research considers the optimal solution for the coastal land use in Hsinchu City as the balance among four objectives proposed by this research. Its result and change of present situation are described as follows: The residential land can be increased from 78.6 hectares to 97.6 hectares for the best situation; 28.9 hectares to 58.1 hectares for the industrial land; 2.9 hectares to 100 hectares for the recreational land; no change for the agricultural land; and 510.7 hectares to 878 hectares for the conservation area, while the transport land can remain the same situation.

As for the planning result, though there is an increasing space for the residential land and industrial land, most of their land can be absorbed by undeveloped urban land at present. It will not influence the quality and quantity of the environmental sensitive area. On the contrary, it will be favorable for the land to be used sufficiently, avoiding the waste of unused land. However, one must pay special attention to the category control of land use upon developing. As for the coastal area, the industry land should be mainly used by low polluting industry without influencing the neighbors; examples like the specialized light industrial district and logistics center must be managed centrally and be conducted through the environmental impact assessment in order to reduce the load of the land and environment.

IV. Conclusions

The development category for land use of the coast area is very complicated. The overall consideration, especially in the aspect of ecological environment and landscape value, was often neglected in coastal preplanning or development research. Therefore, in order to study the optimal developing amount of land use for each coastal area, this research marks these two objectives as the focal point, and utilizes the multiple planning method to construct an integrated objective model which will incorporate both the costal ecological environment and land use, provided that the water pollution and economic function objective are taken into consideration.

1. The coastal resources in Hsinchu City are abundant, and Hsinchu City Government highly encourage the coastal sightseeing in recent years, so this research concludes that apart from the objectives of water pollution and economic function, the objectives of ecological conservation and landscape value are also the key factors for future coastal development of Hsinchu City. Thus, this research selects these four objective functions as the operation model. The compromise planning method is employed to get the compromise solution which is closest to the ideal solution. The best result of balanced land use is taken as the optimal development area for the use of coastal land in Hsinchu City. Its calculated results for the optimal land use are: 97.6 hectares of residential land (6%), 58.1 hectares of industrial land (4%), 100 hectares of recreational land (7%), 331.6 hectares of agricultural land (22%), 878 hectares of conservation area (57%), and 68.9 hectares of transport land (4%).

2. In the objective function of maximum economic function value in this research, the

experts and scholars consider that the conservation area and agricultural land are very important for the coastal area, but the maintenance fee paid by city government is fairly low, which makes the coefficient of the function value noticeably higher. In other words, the benefit of agricultural land and conservation area is mostly external effect, which is unable to reflect the real cost. Therefore, if the government does not pay attention to its importance, the precious resources might be lost and cannot be remedied.

3. From this research, it is known that if the patch size is larger, the conservation ability will be higher. Although Hsinchu City Government sets up many recreational facilities around the coastal area in recent years, which has attracted a lot of tourists, but most facilities are close to the conservation area dispersedly, causing the discontinuity of biological habitat and a large impact on the natural environment of the coast. Thus, this research recommends setting up the specific recreational area that is centralized and staying intact in the area, while the landscape perception preference is planned according to the result of investigation on people who live in the recreational area. Therefore, the destruction of biological habitat can be reduced in order to improve the ability of ecological conservation.

4. The investigation result of landscape perception preference in this research shows that even though the people obviously prefer the enlargement development of recreational land, the preference degree does not grow linearly. As a result, the perception of user must be considered before developing the recreational land at the coast site, so that the recreational area will not be overdeveloped.

5. General coastal development only considers the economic efficacy and water pollution degree. This research has especially to consider the objectives of ecological conservation and landscape value in order to get the optimal solution. From the research results, it is found that when the ecological conservation is paid more attention, the variation for the area of land use will be larger. It shows that the influence on land use area is greater for the ecological conservation objective, so the policymaker must be aware of it and take it into account. As for the landscape value, even though the change is relatively small, the government of Hsinchu City has been greatly promoting the coastal sightseeing and recreation over these years, so it certainly will attract a lot of tourists. Consequently, the perception of tourists on the coast in Hsinchu City will act as an important index for the coastal sightseeing and recreation quality in the aspect of landscape view.

V. ACKNOWLEDGMENTS

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Table 1 Summary for the functions of coast

Function	Items	Content
Ecological function	Production function	The coastal area is the area with high productivity, and it is the bearing stage of a lot of economic marine organisms. In addition, the coastal area often becomes the migration route of migratory birds, and it is also the important habitat of birds.
	Capacity function	It can hold the human activity, and it can store, dilute, and filter the organic and inorganic pollutants.
Hydrological function	Balance function	Keep the dynamic equilibrium at the interface of fresh water and sea water in underground layer of coastal area, prevent the penetration of salty water, and avoid the sudden change or deterioration of the coastal ecological environment.
	Purification function	The chemical purification function of waste and the metabolism function of organism or ecosystem. Purify water quality, and maintain the normal circulation of hydrology.
Economic function	Economic function	Possess the marine biological resources, mineral resources, energy, shallow sea cultivation resources and land resources etc. Because its natural characteristics, the coastal area can be used for industry, energy facility, inhabitation and building development, industrial development and operation, port and transportation, sightseeing and recreation, military equipment etc.
Recreational function	Recreational function	Offer the recreation place for public hydrophilic space and help release the stress of body and mind.
	Educational function	The lively natural classroom that offers research resources to observe and collect samples.

Figure 1 Current distribution of the coastal land use in Hsinchiu City

Table 2 Coastal land use classification of Hsinchu City

Items	Area（Hectares）	Content
Residential land	78.6	house, shop market, restaurant, temple, church, institution
Industrial land	28.9	factory, sewerage, landfill, waste incinerator
Recreational land	2.9	scenic area, park, coastal recreation
Agricultural land	331.6	Paddy, upland, orchard, fish farm, pastureland
Conservation area	510.7	animal conservation area, plant conservation area, restoration park
Transport land	68.9	roadway, railway, stations
Unused	512.6	vacant land, wasted land, unclaimed wetland
Total	1534.2	

Figure 2 Current distribution of the developing zone in Hsinchiu City

Table 3 Objective functions and constraints

Items	Equation	Equation numbers
Ecological conservation function	$\max Z_1 = \dfrac{x_1 + x_2 + x_3 + x_6}{309} + \dfrac{x_4 + x_5}{181}$	(1)
Water pollution degree	$\min Z_2 = 253.9x_1 + 253.9x_2 + 109.8x_3 + 152.0x_4 + 253.9x_6$	(2)
Landscape perception preference	$\max Z_3 =$ 〔-2.1688 x_1-1.0981〕+〔-0.4633$Ln(x_2)$-3.6549〕+〔-5.795 x_3^2 + 6.7532 x_3-0.1626〕+〔1.8315 x_4 -0.0554〕+〔2.1652 x_5+0.1629〕+〔-0.6038$Ln(x_6)$-3.4157〕	(3)
Eeconomic function value	$\max Z_4 = 0.1505x_1 + 0.5353x_2 + 1.8531x_3 + 773.5851x_4 + 7.5116x_5 + 0.7162x_6$	(4)
Total area	$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 = 1534.2$	(5)
Total allowable development area	$x_1 + x_2 + x_3 + x_4 + x_6 \le 1166.9$	(6)
The upper limit of every land use area	$x_1 \le 603$ $x_2 \le 288$ $x_3 \le 100$ $x_4 \le 331.6$ $x_5 \le 878$ $x_6 \le 68.9$	(7) (8) (9) (10) (11) (12)
The lower limit of every land use area	$x_1 \ge 78.6$ $x_2 \ge 28.9$ $x_3 \ge 2.9$ $x_4 \ge 87.49$ $x_5 \ge 510.7$ $x_6 \ge 27.7$	(13) (14) (15) (16) (17) (18)

Table 4 The objective value and the distance measurement method

Items	Equation	Equation numbers
Distance measurement way	$\min_{x \in S} \left[L_p(Z(x), Z^*) \overset{\Delta}{=} \left\{ \sum_{j=1}^{n} w_j \left[Z_j(x) - Z_j^* \right]^p \right\}^{1/p} \right], for \quad 1 \le p < \infty$ where： L_p is the distance between the objective value $Z(x)$ and the optimal solutions Z^* $Z_j(x)$ is the j^{th} objective function S is the sets of feasible solution w_j is the of weight of the j^{th} objective function p is parameter	(19)
The optimal solution of shortest distance (L_P)	$\min_{x \in S} \left[L_p(Z(x), Z^*) \overset{\Delta}{=} \left\{ \sum_{j=1}^{n} \left[Z_j(x) - Z_j^* \right] \right\} \right]$	(20)

Table 5 Solutions to each objective function. Unit: hectares

Items	Residential land x_1	Industry land x_2	Recreation land x_3	Agriculture land x_4	Conservation area x_5	Transport land x_6	Optimal solutions Z_k^*
Z_1	223.9	28.9	2.9	331.6	878.0	68.9	7.73
Z_2	78.6	77.1	100.0	331.6	878.0	68.9	118409.10
Z_3	168.0	28.9	100.0	331.6	878.0	27.7	2296.00
Z_4	78.6	77.1	100.0	331.6	878.0	68.9	143587.80
L_P	97.6	58.1	100.0	331.6	878.0	68.9	13444.14
Current Status	78.6	28.9	2.9	331.6	510.7	68.9	--------

Building Criteria Standards for Performing Sustainable Management of Coastal Wetlands Preservation

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Abstract

Wetlands are natural buffer areas crucial to the protection of coastal environments, especially for an island country like Taiwan, Japan, Ireland, Norway, etc. in which land resources depend on wetlands for protection. However, current land zoning is unable to effectively prevent the coastal wetlands from being damaged. As sensitive lands, the survival of wetlands relies heavily on environmental surveillance and sustainable management for protection from development. Therefore, a management system with building criteria standards for performance indicators based on sustainable managerial concepts would be an essential tool for achieving the goal of wetlands conservation. The purpose of this study, then, is to establish criteria standards for performing coastal wetlands preservation and, by means of Grey Relational Analysis Model (GRAM), to obtain the performance indicators of higher independence, representative and availability or ease of data collection that can serve as a guide for future study by a hierarchical management and quantitative evaluation. Among the 22 initial indicators for wetland environmental functionality, which are primarily based on the definition and functionality of wetlands preservation, then seven indicators are obtained of applicability for the coastal wetland performance management. Finally an empirical case is illustrated to test and show our proposed indicators which can be used in the feasibility and validity. In other words the extracted indicators by this study can be used to manage the coastal wetland environments where there is high extent of informational uncertainty, significant difficulty gathering data, ambiguous correlations among functionality indicators, and vulnerability to subjective definition.

Key Words: Coastal wetland, wetland preservation, sustainable management, criteria standards, grey relation, performance indicators

I. Introduction

Wetland preservation is typically in conflict with development. Wetlands are natural buffer areas and their importance has been well recognized by many countries. Advanced countries, such as the United States, Canada, Australia, Japan and the most European countries, have adopted sustainable management systems to protect their wetlands (Chiau, 1998a; Broll et al., 2002; Parish, 1997; Yamashita, 1994), implementing different levels of wetland in accordance with wetland functions. However, in many years of development of west coastal wetland, it is mostly for external use of land, but seldom for management on inherent characteristics of land in preservation. The results in some environmental issues and creates many land ecological problems being overlooked.

Agenda 21, was adopted by the United Nations Conference on Environment and Development, its contents emphasized ecological land use and environmental planning and management. Agenda 21 favored the use of sustainable development to resolve the conflict between land use and resource protection (Chiau, 1999). Current land management systems, such as Taiwan, etc., are still based on traditional land classifications and zoning and cannot exert precise control over land-use and fails to protect the environment. The conventionally adopted systems are particularly not applicable to resource management and preservation for sensitive areas such as waterfront and wetlands. Criteria standards for performing coastal wetlands preservation, which are substantial and flexible criteria for land resource utilization, accommodate public interests while prioritizing the carrying capacity of the land (Kendig et al., 1980). Criteria standards for performance apply quantitative measurements to identify the acceptable degree (civic minimum) and desired/aspiration level of change in the natural environment brought on by land-use activities (Tzeng et al., 1991; Huang, 1998). The features of criteria standards for performance indicators are that land use plans and resource management measures are combined. To respect carrying capacity of environment and resources, criteria standards for performance indicators are developed to control the negative effect of zoning and achieve the goal of coexistence of humans and their surrounding environment.

This study, which adopts the concept of sustainable management, attempts to establish the criteria standards for performing sustainable management of coastal wetlands. After examining issues related to wetland resources, indicators that can investigate performance management for different development activities were identified. Since wetland environments are complex and dynamic environmental systems, there are numerous obstacles to data collection. Thus, this study considers wetland performance management systems as a Grey System. Under the condition of small sample with uncertainty, Grey relation from Grey system theory is used to select criteria standards for managing the coastal wetlands preservation. The method will increase the feasibility of the proposed research and reduce subjectivity in manual operation of information. After the characteristics of the performance indicators are selected by independence, data accessibility and simple operation, these criteria standards for performance indicators are used as references to develop land use zoning for coast. These criteria standards for performance indicators also used to review policies and mechanisms for development and management on domestic wetlands, and help establish the method of research for wetland classification, assessment and quantification. Finally an empirical case is illustrated to test and show our proposed indicators which can be used in the feasibility and validity. In other words the extracted indicators by this study can be used to manage the coastal wetland environments where there is high extent of informational uncertainty, significant difficulty gathering data, ambiguous correlations among functionality indicators, and vulnerability to subjective definition.

The rest of this paper is organized as follow: In Section 2 the definition of wetlands and environmental indicators are introduced. In Section 3, a selection criteria model for performance management indicator is proposed. In Section 4, an empirical example for selecting the coastal wetland performance management indicators is conducted to illustrate to demonstrate our proposed methods. Finally, in Section 5, conclusions are presented with suggestions for further studies.

II. Definition of Wetlands and Environmental Indicators

The section examines the importance of wetland environments to ecology and regional development. A literature review is define and performed to elucidate the functional value of wetlands and develop the wetland environmental indicators.

2-1 Wetland Definition and Function

Wetlands do not currently clearly define nor are criteria standards for performance indicators agreed upon by even the public, governments or academic organizations throughout the world (La Peyre et al., 2000). Thus, prior to proposing wetland performance management criteria, this study begins by presenting the wetland definitions in international treaties and laws and summarizes these descriptions and related regulations and standards (**Table 1**).

Wetlands are transitional hybrid areas between a water and land. Wetlands are primarily composed of hydraulic soils, aquatic vegetation and water. Thus, wetlands can be defined in terms of hydrologic conditions, soil compositions and aquatic plants.

Wetlands are environmental buffers and ecological incubators. As an environmental system, wetlands typically possess non-use functions such as water purification, water regulation, boarder preservation and ecological preservation. Also, wetlands facilitate a significant amount of sustenance and use functions in a social economic system. (Carter et al., 1978; Novitzki, 1979). As wetland non-use functions are more valuable than use functions, this study favors non-use functions in establishing a wetland management system. Non-use wetland functions are as follows:

1. Water Purification

Wetlands filter water-borne contaminants. When river water carrying contaminants passes through wetlands, aquatic plants in the wetlands slow water flow, absorb heavy metals, causing contaminants to settle on wetland bottom and decompose eventually（Gosselink and Turner, 1978). Furthermore, wetland plants absorb nitrogen and phosphorus to prevent eutrophication and become nutrients for plant growth, and then plant photosynthesis converts organic substances into energy and produces oxygen (Kadlec and Brix, 1994).

2. Water Regulation

Water regulation has direct impact on contents of hydrology. Wetlands operate as sponges, through which permeation and compensation mechanisms provide stabilizing effects on water sources by regulating underground water levels (Mitch et al., 1988; Davies and Claridge, 1993). Wetland water regulation is also strongly related to wetland soil constituent parts and structure. Because of the unique structure of wetland soils, water can be preserved in voids and soils can retain sufficient space for respiration.

3. Waterfront Protection

According to previous research, maximum flood levels clearly increase with increased land development; that is, the amount of time required to reach flood levels is significantly shortened by development. When land development reaches 80%, maximum flood levels are two times that before development. Such a phenomenon occurs because buffer mechanism at water land boarder is lost and, as a result, the pervious layer disappears and runoff increases (Price and Probert, 1997). The wetland flood reservation function nourishes aquatic plants and promotes soil fixation. This mechanism protects the water-land interface from tidal erosion.

4. Ecological Incubation

Wetlands typically have muddy areas that are one to two meters deep, containing organic substances produced by wetland plants which are the primary sources for wetland ecological nutrients (Price and Probert, 1997). The abundant wildlife that live in wetlands engenders a complex food chain.

2-2 Wetland Environmental Function Indicators

According to the elements comprising wetlands and their non-use functions, this study uses hydroperiod, soil structure and aquatic plants as the three natural wetland components to develop the wetland environmental function indicators. **Table 2** presents a summary of these function indicators.

1. Hydroperiod

Hydroperiods is a result of a balance between water influent and water effluent in wetland. There is substantial variation in phenomenon over time. Hydroperiods has an essential role in wetland structure and function. Hydroperiods affects numerous biological factors and influences soil characteristics, that is to say, hydroperiods directly affects the development of wetland animals and plants (Gilman, 1994; Gosselink and Turner, 1978). The environmental function indicators for wetland hydrology primarily comprise supplementary underground water volume, surface water inflow, assimilative capacity, tidal effect, water level, water flow velocity, self-purification capability, influent and effluent quantity and flood frequency.

2. Soil Structure

Chemical conversion occurs in wetland soil. For the majority of wetland plants, soil is the primary source for nutrients (Mitch et al., 1988). Therefore, wetlands are very important ecological systems in terms of substance conversion and nutrient circulation. The principal functional factors of wetland soil are salinity, water quality, water saturation period, soil porosity, nutrient effectiveness, soil erosion, contaminant sediment and organic substance content.

3. Plant Ecology

Wetland plants are not necessarily passive. Dense plant growth can control wetland water flow and related chemical and biological activities (Price and Probert, 1997). The plant ecology indicators are vascular plant type, aquatic plant density, plant energy flow, plant colony quantity, and animal colony quantity.

2-3 Wetland Developments and Environmental Impact

Wetland change or destruction typically affects three main factors of a wetland system: water level, nutrition condition and natural disturbance (Chiau, 1998b). Change in any of these factors by human activities will affect wetland ecology. Different land uses or development activities impact wetland ecology differently. Based on a review of related research, this study summarizes the types of environmental impacts due to various developmental activities on wetlands. This study also provides a preliminary analysis of impact type due to the influence of hydrology, soils and plants to elucidate how land development or use activity impacts wetland environments. This analysis is used as a reference for screening performance indicators. **Table 3** presents a summary of the environmental impacts.

III. Selection Criteria Model for Performance Management Indicators— Grey Relational Analysis

Building criteria standards for performance indicators, indicator selection largely attempts to identify indicators that are representative, non-redundancy, minimal size, simplified to use and availability or ease of data collection; these criteria will ensure their feasibility and accuracy for further study. In typical study, two methods of indicator selection are adopted: a brainstorming method such as the Delphi method; and statistical analysis such as factor analysis, principal component analysis, etc. The most common technique for brainstorming is to employ a cluster consensus process to select indicators recognized as important. Although brainstorming is not restricted by whether an indicator is quantified, however, this method is overly subjective and fails to resolve the drawback imposed by data multicollinearity. Similarly, although statistical analysis can resolve the multicollinearity problem among indicators and identify representational and independent indicators, however, prior to any statistical analysis indicators should be quantified, the sample volume should be large and have a normal distribution. In addition, statistical analysis fails to analyze the indicator that has difficulty in obtaining sample data. Furthermore, tedious calculations or reconfirmation of the composition of factor increases the difficulty in selecting indicators.

The grey system is a real-world system that can accommodate incomplete or uncertain information. A small sample with uncertainty can be described in the grey system (Deng, 1989). Correlation grade is typically a relationship between two variables, functions, etc. Grey relational analysis assesses the relationship between factors (grey relational grade) to evaluate correlations among factors (Tzeng and Tsaur, 1994). Through such a correlation grade differentiation, the independence of factors can be identified.

The grey relational analysis model is an influence measurement model based on grey system theory which, in turn, is based on the following principles (Tzeng and Hu, 1996): (1) the established model is a non-functional sequence model; (2) the calculation method is simple and easy; (3) there is no strict requirement for sample quantity; (4) sequence data for section characteristics do not require normal distribution with probability compliance; and, (5) the correlation grade among sample data can be analyzed and conclusions made without any conflict with qualitative analysis.

This study, therefore, adopts the grey relational analysis model as its indicator selection method for building coastal wetland performance indicators and criteria standards. For wetlands with complex environments, uncertainty of information and difficulty in data collection, this methodology can identify simply representative wetland indicators. Then criteria standards for performance indicators apply quantitative measurements to identify the acceptable degree (civic minimum) and desired/aspiration level of change in the natural environment brought on by land-use activities. Therefore, the proposed methods will be presented as following. Basic assumptions and equations for grey relational analysis model will be introduced in **Fig. 1**(Eqs. (1) and (2)).

The grey relational analysis model in the previous section is used to construct the operational flow process for following coastal wetland performance indicator selection:

1. Assessment of Indicator Performance Level

Due to difficulties in collecting wetland data, the sample data in the grey relational factor set is obtained by wetland experts who have assessed the performance value a_{ik} of each wetland environmental functional indicator on wetland preservation (*i* is indicator item; *k* is wetland expert type). The performance range is set at 0-100.

2. Establishment of Normalization Matrix for Performance Indicator

The purpose of normalization is to unify a data unit and level within a particular range.

Because this study employs a small number of samples, the normalization methodology is selected. The raw data value, then, is between 0 and 1. If indicator performance assessment results in a performance value of a_{ik} for the *ith* indicator for the *kth* expert under a specific environmental impact condition, the matrix ***X*** after normalization is Eqs. (3) and (4) (**Table 4**).

3. Calculation of Grey Relational Grade r(x0,xi)

After normalization of the indicators, Eqs. (1) and (2) are applied to calculate the grey relational grade r(x0,xi) for each indicator in a comparative sequence xi and its corresponding value in the reference sequence x0.

4. Sequencing of Grey relational grade

First, a threshold value for grey relational grade is set as the standard. Then, the indicators of grey relational grade below the threshold value are removed for the comparative sequence indicators respecting to the same reference sequence. The remaining indicators, which are all over the threshold value, are ordered from high to low values according to the grey relational grade.

5. Clustering of Reference Sequence Indicator

The comparative sequence indicators with similar grey relational grade sequencing are clustered according to the reference sequence indicator type. High correlation indicators can then clustered together, as can the indicators with low correlations. Thus, the goal of obtaining highly independent indicators can be achieved.

6. Selection of Representative Indicators

The standards for selecting representative indicators are as follows: (1) non-redundancy among indicators; (2) minimal number of indicators; (3) typify of indicator; (4) economical data collection; (5) controllability of indicator content; and, (6) comparability of indicator (Tzeng and Hu, 1996). Based on these principles, one indicator out of clustered of proposed indicators can be identified as the representative indicator.

IV. An Empirical Example for Selecting the Coastal Wetland Performance Management Indicators

As an island, Taiwan has approximately 11,846 hectares of wetlands. Most coastal development therefore is directly or indirectly related to wetlands. The range and degree of impact on wetland environments differ for differ according to development type. This section presents the representative indicators identified for references and control in the coastal wetland management process. The established operational flow process is applied to the performance management indicator selection model and the proposed wetland environmental function indicators. These indicators are based on wetland definitions and functions under different environmental impacts.

4-1 Establishment of Normalized Matrix

The proposed 22 wetland environmental functional indicators were integrated into a survey, which was assessed by ten wetland environmental experts and ecological specialists for indicator selection. The assessment results are normalized by Eq. (3). The indicator is placed in a row in a normalized matrix established by the experts (**Table 4**).

4-2 Grey Relational Grade Calculation and Sequencing

Data (**Table 4**) are sequenced for each indicator as the reference sequence. Equations (1) and (2) are used to obtain the grey relational grade for the indicators under each reference sequence. The section is uses supplemental ground water (*W*1) as reference sequence example to describe the sequencing results of grey relational grade for comparative sequence indicators corresponding to the reference sequence indicator (*W*1).

1. Calculation of Grey Relational Grade r(W1,Wi)
2. Grey Relational Grade r(W1,Wi) Sequencing

The threshold value of grey relational grade is set at 0.78 according to selection criteria. Indicators over the threshold values are sequenced in decreasing order as follows: *W*8, *W*16, *W*3, *W*12, *W*15, *W*17, *W*10, *W*14, *W*5, *W*20, and *W*21.

3. Clustering of Performance Indicator

Repeating steps 1 and 2 for grey relational grade calculations and sequencing obtains the comparative sequence indicator result for each reference sequence. The comparative sequence indicators with similar sequencing are clustered as are those with high correlations. **Table 5** lists each reference sequence indicator in the same cluster as *W*1 and the comparative sequence indicator sequencing results. The Tables shows the similarities in comparative sequence indicator sequencing. The six corresponding values in the normalized matrix to the reference sequence are plotted as a broken line. From **Table 5**, the similarity among *W*1, *W*5, *W*8, *W*12, *W*16, and *W*20 is identified.

4-3 Selection of Performance Management Indicator

Following the calculation in Section 4-2 the 22 wetland environmental functional indicators are clustered into seven categories (**Table 6**). Then one indicator in each category is selected as the representative indicator by applying the six principles of selection for a representative indicator with consideration of data availability, indicator controllability, minimization of indicator and repeating relationships among indicators (**Table 6**).

V. Conclusions

Increasing urbanization is gradually destroying Taiwan’s western coastal wetlands. Most advanced countries recognize the importance of wetland preservation. If effective wetland management measures are not instituted, the roughly 20 remaining wetlands in Taiwan will likely disappear. This attempted to develop an effective wetland environmental management standard despite the lack of wetland environmental data and related research activities. Grey System Theory was applied to identify a coastal wetland performance management indicator. Such representative indicators should provide a reference for further management system planning.

5-1 Findings

1. Wetlands systems are composed of three indivisible elements: hydrology, soils and plants. Thus, when establishing wetland environmental management systems, the interaction among these elements must be understood. According to this study’s wetland definition and wetland functional conditions, this study proposes that environmental functional indicators for hydroperiod, soil structure and plant ecology.
2. The study applies the Grey System to resolve particular issues, such as difficulties in obtaining wetland environmental data and the uncertainty in management indicators, and to make the management indicators more available. The performance management indicator selection model established by applying grey relational analysis is more objective and fair than the common brainstorming or normal distribution methodologies.
3. Wetland environments are complex and their major components are inter-related. The selection of a wetland environmental management representative indicator must accommodate the difficulties in indicator data collection, controllability of indicator, minimization of the number of indicators, and the repeating relationships among indicators. Selection of a representative indicator is from a systematic perspective.

4. A total of 22 proposed wetland environmental indicators were clustered into seven clusters: water level; surface water inflow; water quality; water flow velocity; organic content; soil porosity; and, aquatic plant density. The indicators of the same cluster were directly or indirectly correlated. Among clusters with low correlation make representative indicators.

5-2 Research Recommendations

The study sets establishing wetland environmental development management factors as its research goal and identifies the principal directions for wetland performance management. Through performance management indicator selection, the study identifies and simplifies complex data to facilitate future analysis of coastal land use by decision makers in public department. However, these preliminary research results still have some deficiencies. The following suggestions for further research directions should improve the likelihood of the proposed measures being implemented.

1. This study is a preliminary work to establish performance standard management system. Further work should focus on the selected representative indicators for classification of wetlands. Continuous research should focus on the control range of performance standards to follow through on the implementation of a coastal wetland management system.
2. The calculation of grey relational grade can be performed with weighted averages according to each expert representative; this method would produce results that can promote objective and feasible.

VI.ACKNOWLEDGMENTS

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Table 1 Definitions and Criteria for Various Wetlands

Definers	Definitions	Criteria
Ramsar Convention (1971)	Whether natural or artificial, temporary or permanent, stagnant or mobile, freshwater or saline water, a wetland is the region composed of swamps, sloughs, peatlands or waters, including coastal areas that retain six meters of water at low tide. (Mitsch and Gosselink, 1993)	Swamps, sloughs, peatlands, coastal area that has water of six meter deep at low tide
US Environmental Protection Agency (1975)	Wetlands are areas covered by surface water or fed by underground water with a frequency sufficient to support growth of aquatic plants under normal conditions. Such areas include swamps, marshes, and bogs. (Salvesen, 1994)	Frequency of flooding Growth of aquatic plants
US Fish and Wildlife Service (1979)	Wetlands meet more than one of the following conditions: 1. have hydrophytic vegetation 2. water under soil surface is at a certain depth 3. Within a minimum period of time or frequency range, the area is flooded or the soil is saturated with water. (Cowardin et al., 1979)	Hydrophytic vegetation Hydric soils Soil water saturation period
US Wisconsin (1979)	Ground or near ground areas have sufficient water to sustain aquatic plants or wetland plants, and have wetland representative soil. (Novitzki, 1979)	Surface water quantity Aquatic plant growth Index soil type
US Connecticut (1982)	Areas composed of alluvial soil or flooded soil. The contents of soil are calibrated by US Agriculture Department. (Salvesen, 1994)	Area with poor drainage Flooded area Soil type
US California (1982)	Coastal areas, which are covered by shallow water seasonally or permanently, include saline marshes, marshes, open or closed saline swamps, and peatlands. (Salvesen, 1994)	Coastal area covered by shallow water
Canada National Wetlands Working Group (1987)	Areas in which soils are covered by water or saturated for a long periods of time, thus, improving wetland or habitat conditions, including hydric soils, hydrophytic vegetation and various kinds of biological activity which are adapted to the wet environments. (Mitsch and Gosselink, 1993)	Soil flooding periods Aquatic plant growth Biodiversity
Canada Ministry of Natural Resources, Ontario (1992)	Areas in which wetlands and soil is covered by water, the depth of which varies with seasonal snow melting, and sustains aquatic plant growth. (Mitsch and Gosselink, 1993)	Prevailing wetlands Soil covered by water Water level variation cycle Aquatic plant growth
China (1992)	Where land meets the sea; areas with temporarily or permanently shallow water layers with hydrophytic vegetation, including swamps, tidal areas, lakes, marshes and palustrine. (Chiau, 1998b)	Surface water accumulation cycle Hydrophytic vegetation
Taiwan Council of Agriculture (1987)	1. time of seasonal flooding matches the time for agricultural activities 2. transitional area between land and water with water level usually at or near surface, or are continually covered by shallow water; must possess one of the following conditions: (1) ground surface has periodicity and hydrophytic vegetation (2) base soils do not drain (3) base is not soil, but is saturated with water or has water accumulation at some time during the growth season. (Chiau, 1998b)	Seasonal flooding Soil water Accumulation depth Hydrophytic vegetation Soil water accumulation periodicity
Wild Bird Federation Taiwan (1994)	Transitional areas between land and water, excluding permanent water such as rivers, lakes or palustrine, estuarine. The three principal elements are hydric soils, water and hydrophytic vegetation. (Chiau, 1998b)	Hydric soils Water regime Hydrophytic vegetation

Table 2 Wetland Environmental Functional Indicators

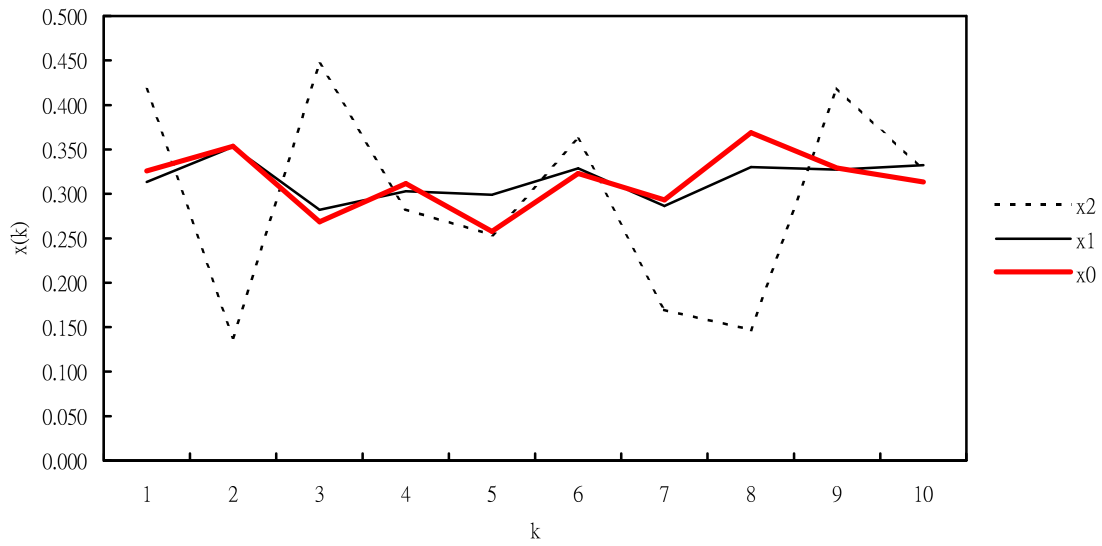
Indicators		Active influence	Passive influence
Hydrology	Groundwater recharge	Wetland water volume; wetland chemicals source	
	Surface water inflow	Wetland water volume; wetland nutrition source; chemicals source	
	Assimilative capacity	Water level and flood storage; water quality	Water regime area
	Tidal effect	Wetland water volume and flood frequency; wetland nutrition source; wetland chemicals source	
	Water level	Create different ecological system	Assimilative capacity; soil porosity
	Water flow velocity	Wetland preliminary productivity; biological decomposition; organics accumulation	Carbon formation; granule sediment; nutrient retention; water shed
	Self-purification	Water resource reutilization	Water flow; hydrophytic plants; soil reduction; granule sediment
	Influent and effluent	Ecological versatility	Supplemental ground water volume; surface water inflow; tide; precipitation; evaporation
	Flood frequency	Seasonal habitats; biological versatility; nutrient storage	
Soil structure	Salinity	Create different wetland types	
	Water quality	Benthos growth condition	
	Water saturation period	Aquatic plant growth	Flood frequency
	Soil porosity	Soil reduction degree; water level; water filtration	Sludge character
	Nutrient effectiveness	Preliminary productivity	Flood frequency; water flow
	Soil erosion	Bank shape; sludge quality	Species colony
	Contaminant sediment	Benthos colonization ability	
	Organic content	Create different ecological system	Vascular plant type; aquatic plant density
Plant ecology	Vascular plant type	Plankton; blockage of organics	Salinity; water level
	Aquatic plant density	Water blockage ability; coastal erosion	Nutrient effectiveness; organic content
	Plant energy flow	Benthos colonization ability	
	Plant community structure	Preliminary productivity; contaminant absorbing ability	Nutrient effectiveness
	Animal community structure	Biological versatility	

Data Source: the Present Research

Table 3 Environmental Development Impact

Impacts	Indicators	Functions	Descriptions
Land excavation	Development extent	Hydroperiod	Surface water load; Water flow
		Soil structure	Quality(porosity, viscosity); Organic layer
		Plant ecology	Preliminary productivity; Aquatic plant density
Dense population	Population density	Hydroperiod	Assimilative capacity; Self-purification
		Soil structure	Reduction ability
		Plant ecology	Preliminary productivity; Species
Traffic expansion	Traffic intensity	Hydroperiod	Water flow velocity; Flow direction change
		Soil structure	Nutrient accumulation
		Plant ecology	Ecological habitat division; Preliminary productivity reduction
Point or non-point contamination source	Point source contamination intensity	Hydroperiod	Assimilative capacity
		Soil structure	Reduction; Sediment increase
		Plant ecology	
Industrial activity	Industrial impact	Hydroperiod	Water level
		Soil structure	Land production value
		Plant ecology	Species
Water resource development	Water intake	Hydroperiod	Water level; assimilative capacity
		Soil structure	Soil water saturation period
		Plant ecology	Species

Data Source: the Present Research



If k samples are used to form an x axis and $x_i(k)$ is the y axis, and m+1 sequences for $x_0 \sim x_m$ are plotted to form a two-dimensional figure, then the level of correlation can be determined by checking the similarity in broken-line shapes between each comparative sequence x_i and reference sequence x_0 (Tzeng and Hu, 1996); that is, the more similar the broken-line shapes are, the larger $\gamma(x_0, x_i)$ is. Furthermore, when the two broken lines overlap, $\gamma(x_0, x_i)$=1 (Fig. 1).

From each of the above assumptions, the equation for grey relational grade $\gamma(x_0, x_i)$ can be derived as

$$\gamma(x_0, x_i) = \frac{1}{n}\sum_{k=1}^{n}\gamma(x_0(k), x_i(k)) \qquad (1)$$

$$\gamma(x_0(k), x_i(k)) = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \varsigma \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \varsigma \max_i \max_k |x_0(k) - x_i(k)|} \qquad (2)$$

where ς is discrimination coefficient (DC, $\varsigma \in [0,1]$); the larger its value, the stronger the grey relational grade. Typically, the value of ς is set at 0.5 (Tzeng and Hu, 1996).

Fig. 1 Illustration of Grey Relational Grade Analysis

Table 4 Normalized Matrix $\boldsymbol{X}$ for Wetland Environmental Indicator Performance Value a_{ik} (impact of land excavation on wetlands)

Expert(k) / Indicator(i)	1	2	3	4	5	6	7	8	9	10
Groundwater recharge W1	0.314	0.353	0.282	0.303	0.299	0.329	0.286	0.330	0.327	0.332
Surface water inflow W2	0.334	0.305	0.250	0.285	0.254	0.293	0.429	0.344	0.316	0.316
Assimilative capacity W3	0.313	0.289	0.281	0.298	0.285	0.330	0.365	0.323	0.375	0.288
Tidal effect W4	0.290	0.296	0.236	0.305	0.303	0.317	0.473	0.319	0.274	0.295
Water level W5	0.348	0.333	0.312	0.328	0.333	0.293	0.308	0.333	0.290	0.276
Water flow velocity W6	0.295	0.323	0.326	0.330	0.383	0.368	0.221	0.292	0.307	0.291
Self- purification W7	0.285	0.272	0.282	0.486	0.399	0.359	0.160	0.356	0.204	0.218
Influent and effluent W8	0.326	0.354	0.269	0.312	0.258	0.323	0.293	0.369	0.329	0.314
Flood frequency W9	0.295	0.299	0.293	0.315	0.350	0.389	0.259	0.301	0.368	0.269
Salinity W10	0.310	0.327	0.315	0.343	0.333	0.365	0.229	0.330	0.312	0.278
Water quality W11	0.236	0.220	0.297	0.452	0.450	0.265	0.161	0.398	0.273	0.267
Water saturation period W12	0.328	0.320	0.302	0.334	0.279	0.311	0.309	0.358	0.318	0.295
Soil porosity W13	0.318	0.294	0.237	0.290	0.287	0.367	0.357	0.335	0.375	0.274
Nutrient effectiveness W14	0.307	0.303	0.280	0.333	0.310	0.383	0.253	0.341	0.371	0.251
Soil erosion W15	0.322	0.304	0.262	0.278	0.296	0.298	0.419	0.309	0.315	0.336
Contaminant sediment W16	0.315	0.319	0.315	0.324	0.324	0.316	0.301	0.320	0.316	0.312
Organic content W17	0.309	0.302	0.282	0.325	0.303	0.384	0.266	0.339	0.372	0.255
Vascular plant type W18	0.300	0.321	0.369	0.358	0.336	0.325	0.220	0.317	0.308	0.285
Aquatic plant density W19	0.418	0.138	0.446	0.282	0.254	0.361	0.170	0.147	0.419	0.327
Plant energy flow W20	0.326	0.318	0.303	0.326	0.173	0.312	0.325	0.355	0.319	0.299
Plant community structure W21	0.288	0.311	0.281	0.351	0.327	0.340	0.361	0.330	0.278	0.281
Animal community structureW22	0.287	0.313	0.287	0.359	0.335	0.340	0.343	0.333	0.277	0.276

Data Source: the Present Research

$$x_{ik} = a_{ik} \Big/ \sqrt{\sum_{k} (a_{ik})^2} \quad (3)$$

$$\boldsymbol{X} = [x_{ik}], \quad \forall i, k \quad (4)$$

Table 5 Sequencing Table for Comparative Sequence Indicator in W1, W5, W8, W12, W16, and W20

		Sequencing of Grey Relational Grade in Each Comparative Sequence Indicator										
		1	2	3	4	5	6	7	8	9	10	11
Reference Sequence Indicator	W1	**W8**	**W16**	W3	**W12**	W15	W17	W10	W14	**W5**	**W20**	W21
	W5	**W16**	**W12**	**W20**	**W1**	**W8**	W22	W21	W17	W9	W3	
	W8	**W1**	**W12**	**W16**	**W20**	**W5**	W9	W22	W17	W14		
	W12	**W16**	**W20**	**W5**	**W8**	**W1**	W22	W21	W3	W13	W9	
	W16	**W12**	**W5**	**W1**	**W20**	**W8**	W22	W9	W17	W21		
	W20	**W12**	**W5**	**W16**	W22	**W8**	W21	W3	W13	**W1**		

Data Source: the Present Research

Table 6 Coastal Wetland Performance Management Indicator Selection Table (impact of land excavation on wetlands)

Cluster	Identical Indicator	Representative Indicator
First	Supplemental ground water W1	Water level
	Water level W5	
	Influent and effluent W8	
	Water saturation period W12	
	Contaminant sediment W16	
	Plant energy flow W20	
Second	Surface water inflow W2	Surface water inflow
	Tidal effect W4	
	Soil erosion W15	
Third	Self-purification W7	Water quality
	Water quality W11	

Cluster	Identical Indicator	Representative Indicator
Fourth	Water flow velocity W6	Water flow velocity
	Salinity W10	
	Vascular plant type W18	
Fifth	Flood frequency W9	Organic content
	Nutrient effect W14	
	Organic content W17	
Sixth	Assimilative capacity W3	Soil porosity
	Soil porosity W13	
	Plant community structure W21	
	Animal community structure W22	
Seventh	Aquatic plant density W19	Aquatic plant density