出國報告（出國類別：出席國際會議）

赴巴基斯坦參加
第59屆國際灌溉排水協會國際執行委員會議暨第20屆國際灌溉排水研討大會報告

服務機關：行政院農業委員會等
姓名職稱：莊光明（國際灌溉排水協會中華民國國家委員會主席）
蔡明華（行政院農業委員會農田水利處處長）
楊豐榮（經濟部水利署總工程司）
派赴國家：巴基斯坦
出國期間：中華民國97年10月11日至10月18日
報告日期：中華民國97年12月25日

出國人員名錄

序號	姓名	職稱	服務單位
1	莊光明	主席	國際灌溉排水協會中華民國國家委員會
2	蔡明華	處長	行政院農業委員會農田水利處
3	楊豐榮	總工程司	經濟部水利署
4	吳瑞賢	副院長	中央大學工學院
5	鄭昌奇	副教授	清雲科技大學工業工程與管理系
6	高瑞祺	副所長	成功大學水工試驗所
7	詹明勇	副教授	義守大學土木與生態工程學系
8	李方中	兼任助理教授	成功大學水利系
9	鄭　遠	會長	台灣省屏東農田水利會
10	魏賢堉	工務組長	台灣省新竹農田水利會
11	王三連	股長	台灣省高雄農田水利會
12	鄭居倉	組員	台灣省南投農田水利會
13	劉茂梓	工程員	台灣省雲林農田水利會
14	王法三	助理工程師	台灣省桃園農田水利會
15	蕭武臺	組長	財團法人水利研究發展中心
16	葉世旭	秘書長	曹公農田水利研究發展基金會
17	倪佩君	研究專員	淡大水資源管理與政策研究中心

摘 要

國際灌溉排水協會第59屆國際執行會議暨第20屆灌溉排水研討大會自10月13日起至10月17日在巴基斯坦拉合爾舉行。此次由國際灌溉排水協會中華民國國家委員會莊光明主席爲團長及行政院農委會農田水利處蔡明華處長爲副團長，率領國內各單位派遣有關專家，組成17人之代表團，赴巴基斯坦參加此次大會。本次由國際灌溉排水協會巴基斯坦國家委員會主辦之研討會議主題爲「參與式之整體水資源管理—將理念付諸行動」，台灣代表參與論文發表共4篇，另分別參與 9 場技術委員會工作小組會議。大會並於閉幕式中發表「拉合爾宣言」，強調應加強灌溉排水系統現代化，以確保糧食生產符合所需；維護灌溉系統之永續運作及建立參與式水管理方案，以改善治理情形、回收成本及用水效率；重視水庫淤積問題之嚴重性，應結合各組織力量，集思廣議共商解決方案。該宣言所提出之議題，可供我國推動農田水利方向之參考。

此次國際會議在巴基斯坦召開，巴國位於乾燥及半乾燥地區，年平均降雨量東南部地區爲125㎜，西北部地區爲750㎜，全國平均爲250 ㎜，因此灌溉發展對農業是重要之基礎，巴國之灌溉地面積達1,912萬公頃，耕地之灌溉普及率達83%，爲世界排名第4的灌溉大國。其灌溉水源主要引用印度河流域之水，年平均取用水量達1,300億㎥，有20%之灌溉地全依賴地下水，地下水與地表水聯合運用之灌溉區域約占40%。灌溉方法除傳統之地表灌溉(如盆灌、溝灌、埂灌)外，加壓微噴、噴灑之灌溉系統亦正積極由政府協助推展。本次技術考察，對巴國之灌溉技術及經驗，有進一步之瞭解，在本報告中特別介紹該國之水資源及灌溉發展概況供參考。

參與國際技術交流提昇我國灌溉排水技術水準，持續參與國際灌

溉排水協會之研討會議活動有其必要。建議我國國家委員會每年參加前作參與規劃，鼓勵專家學者發表論文，並將國內農田水利成果譯成英文簡介，在會議地點提供各國水利專家分享，拓展國際能見度，會議後，將收集之國際農田水利資料及值得參考論文摘譯，供國內農田水利單位及人員參考。

目 錄

壹、目的

國際灌溉排水協會(International Commission on Irrigation and Drainage, ICID)成立於 1950 年 6 月 24 日，迄今計有 106 個會員國。ICID 爲一科學、技術和非營利爲目的之非政府國際組織(NGO)，致力於灌溉排水、防洪及環境管理等技術研討以提高世界糧食之需求；其主旨以工程、農糧、經濟、生態及社會等不同專業領域應用於水土資源管理，以達到永續灌溉農業環境的維護。目前 ICID 於水管理技術和處理相關問題已累積 50 年以上豐富經驗。ICID 每一年定期舉行國際執行委員會議及學術研討會議。

我國於 1969 年由農復會申請加入國際灌溉排水協會，至 1995 年由有關機關及團體組成國家委員會，並自 1996 年起以國際灌溉排水中華民國國家委員會(Chinese Taipei Committee-CTCID)之身分積極加入國際灌溉排水協會相關委員會與工作小組之委員，每年參與年度大會及各項研討會議。爲展現我國在灌溉排水領域之優勢實力及水利科技實務之成果，我國代表團積極投入參與大會國際執行會議及技術委員會之工作小組會議，期與各國代表相互交流經驗與研究成果，俾推展國際事務連繫及技術交流，以擴展我國在國際組織之活動空間，同時，增加我國對於世界各國在水資源管理、農業發展、環境與生態保護等方面發展之瞭解。

本次組團出國之目的，爲參加第 59 屆國際灌排協會執行委員會之技術委員會工作小組會議暨第 20 屆灌溉排水研討大會，除由專家學者作論文發表外，亦另外安排技術考察巴國之水利工程及灌溉農業情形。

貳、過程

一、考察團員

序號	姓名	代表單位	職稱
1	莊光明	國際灌溉排水協會中華民國國家委員會	主席
2	蔡明華	行政院農業委員會農田水利處	處長
3	楊豐榮	經濟部水利署	總工程司
4	吳瑞賢	中央大學工學院	副院長
5	鄭昌奇	清雲科技大學工業工程與管理系	副教授
6	高瑞祺	成功大學水工試驗所	副所長
7	詹明勇	義守大學土木與生態工程學系	副教授
8	李方中	成功大學水利系	兼任助理教授
9	鄭　遠	台灣省屏東農田水利會	會長
10	魏賢堉	台灣省新竹農田水利會	工務組長
11	王三連	台灣省高雄農田水利會	股長
12	鄭居倉	台灣省南投農田水利會	組員
13	劉茂梓	台灣省雲林農田水利會	工程員
14	王法三	台灣省桃園農田水利會	助理工程師
15	蕭武臺	財團法人水利研究發展中心	組長
16	葉世旭	曹公農田水利研究發展基金會	秘書長
17	倪佩君	淡大水資源管理與政策研究中心	研究專員

二、會議行程表

(一) 出國時間自 97 年 10 月 11 日至 10 月 18 日，10 月 11 日由台北搭機至泰國曼谷，10 月 12 日由泰國曼谷轉機至巴基斯坦拉合爾。10 月 13 日至 17 日參加會議及技術考察，10 月 18 日返國。

(二) 會議時間自 97 年 10 月 13 日至 10 月 17 日，行程如下：

日期（星期）	行程內容	地點
10 月 13 日 (一)	● 大會開幕式 ● 研討會－特別議題 「全球變遷對灌溉與排水系統發展與管理之影響」 ● 工作小組會議： 「ASRWG」、「WG-HIST」 「WG-ENV」、「WG-DRG」	拉合爾
10 月 14 日 (二)	● 研討會－專題研究 「從大流域水管理及乾旱歷史經驗中學習之課題」 ● 工作小組會議： 「WG-ON-FARM」、「WG-MIS」 「WG-CLIMATE」	拉合爾
10 月 15 日 （三）	● 工作小組會議： 「WG-DROUGHT」、「WG-WATS」	拉合爾
	● 技術考察：水庫、河川渠首工	伊斯蘭馬巴德
10 月 16 日 （四）	● 研討會－問題集： 「跨國界河流之水資源開發、管理及利用」 ● 專題討論會議：水庫淤積 ● 第 59 屆國際執行委員會議 (I)	拉合爾
	● 技術考察：灌溉農業、 田間灌溉方式	伊斯蘭馬巴德
10 月 17 日 （五）	● 第 59 屆國際執行委員會議 (II) ● 大會閉幕式	拉合爾

三、參加會議議程

日期 (星期)	時 間	會 議 項 目	開會出席人員 2008 年
10/13 (一) 拉合爾	08:00 － 17:00	註冊	
		開幕典禮	全體團員
	13:30 － 17:00	研討會－特別議題： 「全球變遷對灌溉與排水系統發展與管理之影響」	論文發表：吳瑞賢教授
		工作小組會議－【WG-HIST】 「灌溉、排水及防洪史」	李方中博士
		工作小組會議－【WG-ENV】 「灌溉排水與防洪對環境衝擊」	詹明勇副教授
		工作小組會議－【WG-DRG】 「排水」	鄭昌奇副教授
		工作小組會議－【ASRWG】 「亞洲區域」	莊光明主席、蔡明華處長 楊豐榮總工程司、高瑞棋副所長
10/14 (二) 拉合爾	09:00-12:30	研討會－專題研究： 「從大流域水管理及乾旱歷史經驗中學習之課題」	論文發表：鄭昌奇副教授
		工作小組會議－【WG-ON-FARM】 「田間灌溉系統」	葉世旭秘書長、王三連股長 鄭 遠會長、詹明勇教授
	13:30-17:00	工作小組會議－【WG-MIS】 「現代化灌溉服務」	李方中博士
		工作小組會議－【WG-CLIMATE】 「全球變遷與灌溉」	吳瑞賢教授

<table>
<tr><th>日期
(星期)</th><th>時 間</th><th>會 議 項 目</th><th>開會出席人員
2008 年</th></tr>
<tr><td rowspan="2">10/15
(三)
拉合爾</td><td rowspan="2">09:00-12:30</td><td>工作小組會議－【WG-DROUGHT】
「水源緊張區域之水管理」</td><td>鄭昌奇副教授</td></tr>
<tr><td>工作小組會議－【WG-WATS】
「農業節水」</td><td>李方中博士</td></tr>
<tr><td rowspan="2">10/16
(四)
拉合爾</td><td>09:00-12:30</td><td>研討會－問題集 55
「公私部門在水資源開發與管理所扮演之角色」</td><td>論文發表：李方中博士</td></tr>
<tr><td>13:30-17:00</td><td>第 59 屆國際執行委員會會議
(第一場)</td><td>莊光明主席、蔡明華處長
鄭昌奇教授</td></tr>
<tr><td rowspan="2">10/17
(五)
拉合爾</td><td>09:00-12:30</td><td>第 59 屆國際執行委員會會議
(第二場)</td><td>莊光明主席、蔡明華處長
鄭昌奇教授</td></tr>
<tr><td>13:30-17:00</td><td>閉幕典禮

發表「拉合爾聲明」</td><td>全體團員</td></tr>
</table>

四、技術考察

(一)參加團員：莊光明、蔡明華、楊豐榮、鄭遠、魏賢堉、王三連、鄭居倉、劉茂梓、王法三、蕭武臺、葉世旭

(二)考察內容：伊斯蘭馬巴德與拉合爾地區農田水利建設及灌溉農業情形

(三)時間：97 年 10 月 15 日及 16 日

參、心得

一、參加會議

(一)第 59 屆國際執行委員會會議

本次進行 16 項議程討論，CTCID 由莊光明主席代表出席參加本次會議，與會各國國家委員會主席表決各項議案，並投票改選總會 1 位主席及 3 位副主席。茲將本次議程決議重點整理如下，以了解 ICID 知會務運作，並供我國代表未來參與 ICID 相關活動及會議之參考。

1.新加入 ICID 之會員國

國際灌溉排水協會成立於 1950 年 6 月 24 日，迄今計有 106 個會員國。今(2008)年通過牙買加國際灌溉協會之申請入會案。

牙買加位於南美洲地處古巴的南邊，爲大安地列斯群島的一部分。1997 年的耕種面積約爲 274,000 公頃，其中 174,000 公頃爲可耕地，100,000 公頃爲永久作物耕地。1993 年度用水量估計 9.28 億立方公尺，用水量最大的產業爲農業，佔了 75%，其中約有 92%的用水擷取自地下水源，其餘部分則來自地面水。39,000 公頃的可利用水域中，僅有 11%的地面水與 25%的地下水，而運用排水系統與防洪工程保護的面積爲 15,000 公頃。

2.未來會議地點

- 2008 年

  (1) 11 月 6 日－英國・倫敦

  ICID/UEA 國際研討會–Towards a political ecology of irrigation & water use efficiency and productivity

- 2009 年

  (2) 5 月 18-24 日- 烏克蘭・Lviv

  第 23 屆歐洲區域研討會

  (3) 10 月-待定

  第 60 屆國際執行委員會

  (4) 10 月 11-17 日-奈及利亞・阿布札

  第 3 屆非洲區域研討會

(5) 12 月 8-11 日- 印度・新德里

第 5 屆亞洲區域研討會

- 2010 年

(6) 10 月 10-16 日- 印尼・Yogyakarta

第 61 屆國際執行委員會

第 6 屆亞洲區域研討會

3.爲 2009 年土耳其伊斯坦堡舉行第五屆世界水論壇之準備事項

2009 年 3 月 15-22 日將在土耳其伊斯坦堡舉行第五屆世界水論壇，本屆主題爲「跨越水資源的鴻溝」。這項中心主題可分爲兩項議題，預定處理六項主題與二十二項題目。第五屆世界水論壇的計畫架構，可以從該論壇的網站上獲知： http://www.worldwaterforum5.org/index.php?id=1897。

國際灌排協會計畫依循前次對論壇所做之實際方式，爲第五屆世界水論壇貢獻一臂之力。爲了將國際灌排協會之意見納入第五屆世界水論壇，於是成立了一個專案小組(TF)，並由主席 Aly Shady 領導。專案小組去年於美國沙加緬度(Sacramento)舉行第一次會議，根據會中的討論結果，決定了下列事項：

(1) 國際灌排協會將領導找出關鍵問題所在，主要著重於水、農業與二十一世紀新挑戰相關之現階段議題。

(2) 國際灌排協會應尋求與利益關係者及專業知識豐富的機構合作，籌劃第五屆世界水論壇的背景文件、設計研討會及簡報。

(3) 國際灌排協會應動員工作小組(WG)成員、區域工作小組和國家委員會，共同致力於主題、區域和政策方面之推動。

(4) 國際灌排協會主管(Office-Bearers)應參與第五屆世界水論壇的籌備過程。

(5) 國際灌排協會總會辦公室(CO)應肩負這些活動的主要協調工作。

4.國際灌溉排水協會出版品

2007 年間印刷的免費出版品，已經寄發給全體會員國的國家委員會/國際灌排協會委員會、現任主管、管理委員會(MB)成員及其他人士。下列出版品在拉合爾(Lahore)發行：

(1) 國際灌排協會專案小組於亞洲低度開發國家的工作報告(TF-LDCsAS)。其後續出版品亦預定於巴基斯坦拉合爾市召開第 59 屆國際執行委員會議時

出版。

(2) 2008 年於巴基斯坦拉合爾市舉行的第二十屆灌溉排水大會會議資料，主題爲「參與式之整體水資源管理—將理念付諸行動」(論文摘要書籍與光碟片)。

(3) 農業節水創新技術與管理(農業節水工作小組/WG-WATS)。

(4) 噴灑與滴水灌溉系統性能評估手冊(田間灌溉系統工作小組/WG-ON-FARM)。

5.節水（WatSave）獎

擔任評審團召集人的榮譽主席 Keizrul bin Abdullah，於會中宣布得獎名單，獎項及得獎人員如下：

(1) 節水技術獎—

Dr. Yella Reddy, Mr. Satyanarayana and Mrs.G Andal (印度)

(2) 節水創新水資源管理獎—

Dr. Yousri Ibrahim Atta (埃及)

(3) 青年工程師獎—

Dr. Amgad Elmahdi (澳大利亞)

6.聯合國糧農組織非洲農業與能源用水高層會議，2008 年 12 月 15-17 日

聯合國糧農組織(FAO)總幹事已經通知國際灌排協會，該組織現與非洲聯盟、非洲開發銀行、聯合國非洲經濟委員會及利比亞政府合作，共同規劃在 2008 年 12 月 15-17 日，在利比亞西迪市(Sirte)籌辦高層會議，議題爲「氣候變遷挑戰下之非洲農業與能源用水」。這場會議旨在解決非洲水源的議題，並考量在不斷變遷的氣候環境下，農業與能源部門的漸增需求。由於非洲人口多半住在農村地區且仰賴農業爲生，迫切需要新的策略與政策，確保非洲大陸的水資源能獲得有效管理及永續性。爲求向各國政府領導者提議有效管理水資源的政策、策略和計畫，會中將分析現況及農業與能源部門的需求，成本及融資來源等。

7.主席及三位副主席之改選

(1) 主席選舉

根據國際灌排協會組織章程第 6.2.3 條的規定，主席 Peter S. Lee 的三年任期(2005-2008 年)於拉合爾舉辦的大會及研習之旅期間結束。

新任主席：

- Prof. Dr. Chandra Madramootoo

  現任：CANCID(加拿大)主席。

  簡歷：具有 20 年參與 ICID 之資歷。

  2000-2003 曾任 ICID 副主席。

(2) 副主席選舉

根據國際灌排協會憲章第 6.2.4 條文規定，下列三位副主席（2005-2008）將於拉合爾舉行的國際執行委員會議結束後任職期滿。

新任 ICID 副主席：

- Mrs. Samia El-Guindy (埃及)
- Mr. Shinsuke Ota (日本)
- Prof. Lucio Ubertini (義大利)

(埃及)

(日本)

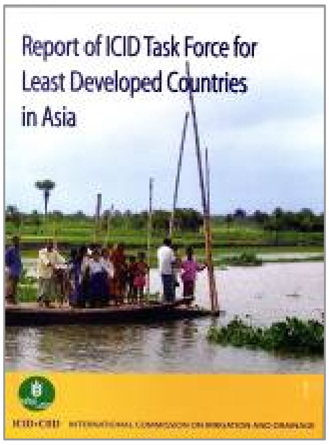
(義大利)

(二)技術活動委員會工作小組會議

目前 ICID 技術委員會各類別工作小組中台灣 CTCID 所屬之正式委員計有 12 位，然各委員並無法全數出席本年度會議，故由代表團分派代表分別參加 9 場工作小組會議，茲將各工作小組會議內容重點摘要如下：

<u>區域性工作小組</u>

1.亞洲區域工作小組會議【ASRWG】



本次亞洲區域工作小組會議共討論 16 項議程，主要討論各屆亞洲區域會議辦理情形、聯合區域性及跨國性機構之合作之議題。CTCID 莊光明主席於去(2007)年允諾與伊朗、澳洲及日本等國共同分攤該工作小組發表「亞洲低開發國家工作推動報告-Report of ICID Task Force for Least Developed Contries in Asia」之印刷經費，該書於本次會議出版發行。

ICID 亞洲區域工作小組(ASRWG)與水田與水環境國際學會(PAWEES)互動密切，尤其，韓國、日本與台灣均是此二個組織之會員國家，前次(2007年沙加緬度)工作會議後，隨即於會後召開附會商議未來合作之可能性。今年 CTCID 由莊光明主席、行政院農委會農田水利處蔡明華處長與經濟部水利署楊豐榮總工程司出席參加會議，並分享台灣致力於有關全球氣候變遷下之水資源因應策略之相關議題。

亞洲區域工作小組(ASRWG)及氣候變遷工作小組(WG-CLIMTE)，參與第五屆世界水論壇(WWF5)-議題 1「全球變遷及風險管理」之子議題 1.1「適應氣候變遷」。ICID 成立「亞洲區域氣候變遷與灌溉專案小組(ARTF-CC)」，由 Shinsuke Ota 博士(日本)擔任主任委員，延攬亞太地區國家的成員，本工作小組委員配合提供「適應亞洲氣候變遷的灌溉排水措施」問卷調查。

知識類組

2.灌溉、排水及防洪史工作小組會議【WG-HIST】

本工作小組編纂各區域性灌溉史，包括：東亞灌溉史、南歐及地中海地區之灌溉、排水與防洪歷史等。同時，配合本年度第 20 屆灌溉排水研討大會議召開一場專題研究研討會「從大流域水管理及乾旱歷史經驗中學習之課題」，探討議題如下：

(1) 技術面：系統之計畫、設計，乾旱應變。
(2) 制度及法律面：農民組織、聯合用水人協會、水資源委員會、法律制定。
(3) 環境面：環境影響評估及抑制。
(4) 社會經濟面：遷移/遷居及補償、社會衝突、成本回收。

本次會議亦通過將延長工作小組之任期至 2014 年。

流域類組

3.水源緊張區域之水管理工作小組會議【WG-DROUGHT】

本年度新成立之工作小組，未來將針對「乾旱管理對策」、「面對水源稀少性」及「永續農業之降雨管理」等議題，訂定新的工作任務及計畫。

4.全球變遷與灌溉工作小組會議【WG-CLIMATE】

將配合國際灌溉排水協會參與 2009 年土耳其伊斯坦堡舉行之第五屆水論壇，並針對「水與糧食」協助籌辦相關研討會議如下：

議題二「促進人類發展與千禧年發展目標(MDG)」

- 子題 2.3「消弭貧窮與飢餓之水與糧食」

另，將參與其他議題之內容探討

議題一「全球變遷與風險管理」

- 子題 1.1「適應氣候變遷：理解氣候變遷之影響、脆弱性評估及調適策略」
- 子題 1.3「減緩災害」

5.灌溉排水與防洪對環境衝擊工作小組會議【WG-ENV】

本次會議通過調整新的工作任務如下：

「對於現在及未來的灌溉、排水與防洪計畫，提供系統及計畫設計者、經理人及操作人員有關環境影響分析之準則，其所謂之環境面向綜括物理、化學、生態、經濟、氣候、人類健康等範疇。惟透過良好管理所進行之環境評估將可維護環境之永續性，並且減低現在及未來灌溉、排水及防洪工作及計畫所引致之負面效應」

本工作小組將參與 2009 年第五屆世界水論壇(WWF5)議題 3「水資源及供水系統之管理與保護，以符合人類及環境需求」之子議題 3.3「流域及海岸區域自然生態系統之維護」。

系統類組

6.排水工作小組會議【WG-DRG】

為慶祝本小組慶祝 25 周年，ICID期刊特於 2007 年 12 月第 56 卷(增刊)出版「排水，整合水管理之要素」專刊。本書收錄 20 篇有關世界各國相關農業排水之經驗與成果，並回顧本工作小組 25 年來之重要貢獻，瀏覽網站如下：http://www.interscience.wiley.com/journal/ird.。

7.現代化灌溉服務工作小組會議【WG-MIS】

本次會議通過工作小組工作方針：

任務：「透過漸進式基礎建設、管理方法以及機構現代化等方法，於國際灌排內提供持續的灌溉系統服務。」

目標：「本工作小組的目標在協助增進灌溉服務，採用創新方法於管理方法、基礎建設、機構及操作等方法，初期將專注於服務提供者的管理改變上，而後續配和需求改變而改善建設與操作。」

8.農業節水工作小組會議【WG-WATS】

本次會議通過工作小組委任事務之要點：「確認業已證明具節水成效之方案，並確定及推廣成功之水資源保育工作」。

出版「農業節水之創新技術與管理」，其中收錄十位歷屆獲頒節水創新獎

「Water Save award」得獎人之訪查資料，以瞭解這些年來可能發生的變化，同時也對這些創新發明的永續性進行評估。

農田類組

9.田間灌溉系統工作小組會議【WG-ON-FARM】

本工作小組目前致力彙編出版相關手冊與論文如下：

- 「噴灌與滴灌灌溉系統成效評估」手冊
- 「改善田間灌溉使用簡易配水、量水及應用系統」論文
- 「小型農作與溫室微灌系統」論文

有關訂定「地表灌溉設施標準」事宜：

雖然全世界灌溉區域約有 79%係使用地表灌溉，但有關地表灌溉設施標準的建立，卻不甚受到關注。此由 ISO 的 SC18 標準截至目前爲止僅有一項與地表灌溉有關即可得知，該相關標準爲 ISO 16149 - 灌溉設施；PVC 地面上供水低壓灌溉用管 - 標準與檢測方法。ISO 地表灌溉設施標準化專門小組召集人 Allen R. Dedrick 博士(美國)，請求 ICID 徵詢各國家委員會對於其國內所使用地表灌溉相關設備的看法/建議，俾建立相關國際標準。

(三)第 20 屆國際灌溉排水研討大會-台灣論文發表

研討會議主題：「參與式之整體水資源管理—將理念付諸行動」

作者	論文題目	內文
特別議題 (Special Session)： 「全球變遷對灌溉與排水系統發展與管理之影響」		
吳瑞賢 Ray-Shyan Wu	Analysis for Field Effective Rainfall Under Climate Change 全球氣候變遷下田間有效降雨之分析	附錄一
專題研究（Seminar）： 「從大流域水管理及乾旱歷史經驗中學習之課題」		
鄭昌奇 Chang-Chi Cheng	The Evaluation of Compensation Price for Agricultural Water Transfer during Drought in Taiwan 臺灣乾旱時期之農業用水移用補償價格評估	附錄二
問題集（Congress Question）： 54.3－「多目標之水庫聯合營運」		
張斐章 Fi-John Chang 賴伯勳	Intelligent control for modeling multiple-purpose reservoir operation in Taiwan 臺灣智慧型多目標水庫操作系統	附錄三 （書面發表）
問題集（Congress Question）： 55.3－「跨國界河流之水資源開發、管理及利用」		
李方中 Fang-Chung Lee	Viewing GMS Program from International Water Law Systems 就國際水法之觀點評估「大湄公河流域開發計畫 (GMS) 」	附錄四

(四)拉合爾宣言

聯合國千禧年發展目標(MDG1)的第一項，希冀於 2015 年以前將飢餓人口減半。此項目標雖然已有些進展，但是距離實現目標仍落後一大截。令人沮喪的是，世界糧儲確有逐漸耗竭之虞，而此情形已導致糧食短缺，並使得 2008 年間的糧食價格驟升。此情況讓我們關注農業用水及改善農業用水管理的全球議題，而這也是國際灌溉排水協會(ICID)的首要使命。

第二十屆國際灌排大會於拉合爾舉行，大會主題與當務之急的糧食安全議題相關。參與式水資源整體管理的主題「將理念付諸行動」涵蓋了數項子議題。此次共有逾一百五十國的與會代表以及四百名當地代表齊聚巴基斯坦，巴基斯坦擁有全球最爲龐大的鄰接式灌溉系統，而此項系統有助於公允地評估「永續農業生產的水管理」施行的契機與瓶頸，並同時確認重要的議題。

審慎考量會中提出的報告、國際灌排協會專任工作小組的討論內容、以及許多不同利害關係者給予的建議後，歸納出下列幾項重要意見：

1.爲使糧食產量增加以因應日漸增加之需求，應迫切進行灌排系統之現代化與擴增，並力求大幅改善系統運作與維護，此爲最重要之方法。

2.全球人口日益增加，且世界各地對於生活標準的要求提高，因此需要更多的糧食產量，才能因應漸增的需求。逐漸形成的氣候變遷及其可能對農業用水管理造成的衝擊，更需要跨越國界攜手合作，特別是喜馬拉雅河系。

- 分享知識與資訊、強化資料蒐集網路、從事研究與技術研發，藉此適應在氣候變遷的衝擊下逐漸增加的需求；
- 從氣候變遷的動態角度，檢視蓄水系統的運作：有必要加強以水庫系統爲基礎的蓄水壩、加強土壤蓄水與集水結構、勘驗水壩、地下水復育、農地用蓄水池與強化糧庫 － 虛擬蓄水；

- 對於使用已處理或部分已處理用水之灌溉系統，進行設計與運作，包括廢水回收再利用；
- 處理耐礦植物、鹽地作物與耐濕作物。

對於喜馬拉雅河流經之國家，首要之務在於進一步提高覆雪區域的相關過程知識。

3.會中所討論的經驗反映出與用水者積極致力於系統的永續運作與管理有關之水管理參與方案。在新興國家中，一般由政府擔負起系統運作與維護之責。在此種情況下，值得關切的問題在於：全部或部分之系統責任及所有權逐漸轉移至農民以及/或水利灌排機構。處於過渡經濟的國家，其關切問題各有不同，例如檢視系統鋪設計畫之必要，此部分至今多以大規模的農業生產爲基礎。灌溉系統的管理職責，從傳統政府機關，轉移至水利管理局和用水者協會，系統現代化所需資金及後續運作和維護，缺乏良好治理，無法承擔抽水系統成本及環境劣化等等，都是逐漸浮現的議題。

4.從事(大規模)表面灌溉計畫的現代化投資，將能提供更好的服務。將此類計畫部分轉移以利參與灌溉管理，將有助於改善治理情形、分階段回收成本及用水效率。

5.過去幾年來，因提高水的效用而產生的資產，尤其是仰賴水庫的蓄水壩，正面臨到有效儲水以日漸嚴重的速度逐漸流失的挑戰，喜馬拉雅河域水庫及中國、伊朗和土耳其等地的其他河系的沈積速度甚快，引發全球開始研究此一領域；除了國際灌排協會以外，國際大型水壩委員會(ICOLD)、國際水力發電協會(IHA)、國際水利協會(IAHR)等國際組織，以及在此方面進行的研究學會充分合作，不僅能集思廣益，更能彼此交流，進而解決在處理此議題上的問題。

6.各國代表團在塔貝爾水庫沈積作用的專題研討會之中，與會代表非常重視因儲水流失而即將發生之問題嚴重性；與會代表檢視了現有的解決方案，卻不得不承認塔貝爾的情況特別需要進一步的研究，應用嶄新知識的創新方案，並彼此交換意見。國際灌排協會根據組織章程，成立專案小組以著手研究這方面的水庫沈積作用，不僅會員國的專家參與，更與其他國際組織合作，如國際大型水壩委員會和國際水力發電協會等。

7.各國與會代表對主辦國全體參與人員的努力，讓他們在現有條件下，仍能

於逗留期間獲得最好的款待，紛紛表達無上的謝意。

8.2009 年的會議主旨：

(1) 水資源逐漸稀有下的灌溉工作，以及農地轉換和農地破碎化的議題。

(2) 小地主從事的灌溉農業，於往後數十年所面臨的挑戰：

a.確保糧食用的灌溉用水

b.支持人類生活的灌溉用水

c.支持環境用的灌溉用水

(3) 在小地主普及的情況下，如何透過參與灌溉系統發展和管理，改善灌溉與排水效率。

(4) 灌溉用水所具的多功能角色，以及在小地主普及之下，維持生態系統永續平衡的作用。

(5) 透過城鄉基礎建設的迅速發展，促進大小地主合作以利灌溉。

(五)參加會議心得

1.因應氣候變遷之灌溉排水、防洪、水資源灌理之調適策略及措施，是今後各國重要研究課題，台灣今後亦應加強重視此課題。在不斷變遷的氣候環境下，農業與能源方面的需求漸增，非洲人口多半住在農村地區且依賴農業爲生，迫切需要新的策略與政策，確保非洲大陸的水資源能獲得有效管理及永續性，因此，聯合會糧農組織於 97 年 12 越舉辦「氣候變遷挑戰下之非洲農業與能源用水」高層會議，要求各國政府領導者提議有效管理水資源的政策、策略及計畫，並分析現況、農業與能源部門的需求、成本及融資來源。在亞洲地區工作小組會議，爲因應全球氣候變遷及風險管理，亦成立「亞洲區域氣候變遷與灌溉專案小組」，要求各國提供「適應亞洲氣候變遷的灌溉排水措施」問卷調查，爲適應氣候變遷，要理解氣候變遷之影響、脆弱性評估及調適策略，以期減少災害。氣候變遷之研究，有需要跨國界之合作，分享知識與資訊，強化資料蒐集網路，從事技術研發。

2.糧食短缺，使得糧食價格上昇，爲確保糧食安全，必須關注農業用水問題。農業用水改進措施包括：改善農業用水管理，提昇用水效率；大幅改善灌溉系統運作及維護，拓增灌溉地面積，增加生產量；對既有水庫改善淤積情形；重視灌溉用水所具有之多功能角色，維持生態系統永續平衡的作

用；在小地主普及下，透過參與灌溉管理，改善灌溉排水效率，並配合其農業經營，增加農業收益。透過農田水利基礎建設發展，促進小地主合作以利灌溉。台灣在此方面已有相當的經驗與技術，可供其他國家之參考分享。

3.全球農地共計 15.25 億公頃，灌溉農地面積 2.75 億公頃，占總農地之 18%，無法灌溉之看天田面積共 12.5 億公頃，占總農地之 82%。灌溉農地生產之糧食占全球之 40%，看天田生產糧食占全球之 60%。單位面積之糧食生產量比較，灌溉農地爲看天田之 3 倍，灌溉發展爲增加糧食生產之主要手段。但全世界之灌溉事業成長率趨緩，1970-1980 年爲 2.3%，1980-1990 年爲 1.3%，1990-2000 年爲 1.0%，2000-2005 年爲 06%。台灣農地之灌溉普及率約 50%，較全世界之平均值 18%爲高，約其 3 倍，顯示台灣之灌溉發展在全世界上之排名屬較先進之國家。

4.全球水資源利用概況，依 2000 年之統計，全球水資源量有 71%用於農業，20%用於工業，9%用於民生。臺灣水資源利用結構，農業用水占 70%，民生用水占 20%，工業用水占 10%，臺灣與世界之農業用水比率值相近。

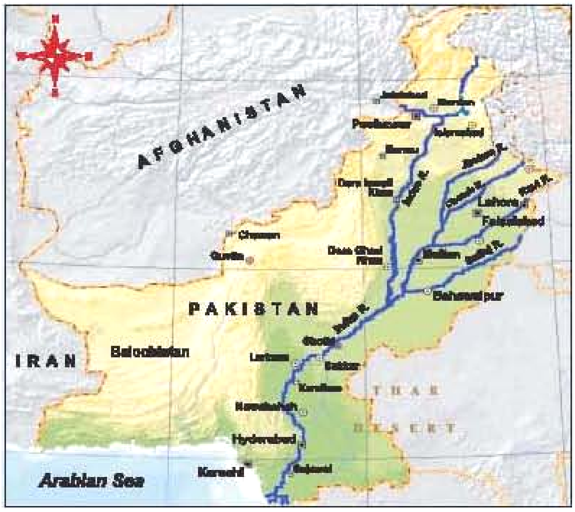
二、技術考察

(一)巴基斯坦之水資源及灌溉發展

農業爲巴基斯坦主要經濟來源，其佔國內生產毛額(GDP)24%，並吸納 40%人口就業率。印度河流域具有全球最大規模之連續型灌溉系統，亦是農業用水主要來源。儘管有豐富的水源及沃饒的土地，巴國仍面臨水源短缺及糧食不足的危機，以下說明巴基斯坦之水資源及灌溉發展概況。

1.水資源概況

Indus Basin in Pakistan



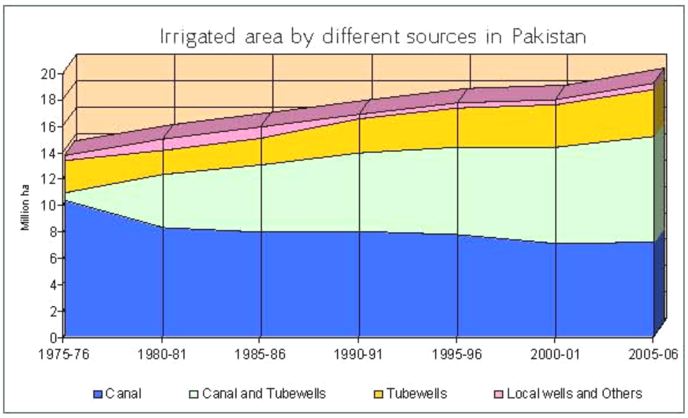
巴基斯坦地理面積達 7,961 萬公頃，其中耕作面積佔 2,310 萬公頃，平均年降雨量為東南部地區 125 mm，西北部地區 750mm。印度河流域系統提供巴國主要的地表水源，印度河總長 2,900 公里，有五大常年支流，傑赫勒姆河(Jhelum)、傑納布河(Chenab)、拉維河(Ravi)、比亞斯河(Beas)及薩特萊傑河(Sutlej)，另有三條小支流，索安河(Soan)、哈羅河(Harow)及錫蘭河(Siran)。印度與巴基斯坦於 1960 年訂定「Indus Waters Treaty」中規範，東部三大支流(Beas, Sutlej and Ravi)為無限制供給印度用水，而西部三條河流(Indus, Jhelum and Chenab)則提供巴基斯坦水源。

印度河系統包括 3 個主要的水庫(Mangla, Chashma, and Tarbela)，總蓄水量達 187 億 m^3。19 個大型水閘門、45 個渠道系統共長 64,000 公里，以及 160 萬公里長的水道，形成全球最大規模連續型灌溉系統之一。

巴基斯坦可再生水資源總量估計有 2,400 億 m^3，包括印度河流域年平均流量 1,720 億 m^3，以及地下水量 680 億 m^3。巴國在聯邦政府層級上，由水電部負責水資源管理(MWP)，在省層級上，由灌溉及排水局(PIDAs)(原灌溉處併入省政府)負責。

2.灌溉發展概況

巴基斯坦位於乾燥及半乾燥地區，年蒸發率達 1,500 至 2,000 mm。因此須依賴灌溉以維持作物生長所需水量。巴國境內 83% 的耕作區採用灌溉系統設



巴基斯坦之灌溉地(依水源別區分)

施，爲全球第 4 大灌溉國(灌溉面積達 1,912 萬公頃)。自河川引水之灌溉水量平均達 1,300 億 m³。在印度河流域(Indus Basin)中，約 20%灌溉區域全然依賴地下水，約 40%區域則與地面水聯合運用，在此流域中將近有 1 百萬口水井，地下水抽取量達 70 億 m³。儘管渠道灌溉範圍逐漸減小，在灌溉渠道所經區域範圍內部與外部，水井數量仍持續增加(如圖)。根據官方調查，渠道灌溉之整體用水效率達 35%至 40%，而巴國現在所需要關注的是排水不良及鹽化的問題。目前，約有 45 萬公頃的灌溉區域排水不良，同時 213 萬公頃農地受到鹽化影響，有 600 萬公頃的農地正採用各種排水方法。

稻米、小麥、棉花、豆類及甘蔗是主要的農作物，除此之外，還有水果與蔬菜，穀類平均產量爲 2.16 噸/公頃。巴國所運用的是傳統的地表灌溉方式，如盆灌、溝灌與埂灌等，而加壓灌溉系統正開始發展。由政府提供支持的計畫項目包括：(1)果樹、蔬菜及棉花之微灌系統，以及(2)噴灌系統，包括運用中心支軸式施灌豆類、玉蜀黍及甘蔗。此項計畫自 2007 年開始實施，耗資 2 億 9 千萬美元，試驗範圍達 117,868 公頃。

3.議題與挑戰

巴基斯坦計有 1 億 6 千萬人口，其中 66%居住於農村地區並直接或間接依賴農業維生。2030 年預估全國將達 2 億 2 千 5 百萬人口，儘管已大規模投資於灌溉事業與農業，巴國仍將面臨糧食短缺之危機。2007 年糧食生產量總計有 3,130 萬噸，相對於實際需求量，仍不足 200 萬噸。

爲能達到充足的糧食供應，同時兼顧永續性與生態系統，必須將土地與水資源作最佳化利用。水資源與灌溉永續發展之主要課題在於公平的水分配，較佳的操作、管理與成本回收，灌溉與農業部門之間的合作，提升整體灌溉效率及農作物產量，改善因排水不良與鹽分造成之土質惡化、水與風之侵蝕以及洪水。其他課題，如原始耕種、不當使用肥料及農業物質、收成後的損失、不完善的市場機制、複雜的農業信用制度、專業人力缺乏、研究不足及推廣服務等仍需關注。

(二)伊斯蘭馬巴德與拉合爾地區農田水利建設考察

1.灌溉農業

灌溉農地現況

巴基斯坦旁遮普省面積比台灣大，農業灌溉的成功是旁遮普省富庶的原因。從拉合爾至伊斯蘭馬巴德之間，貫穿巴基斯坦全國唯一長達 300 公里的高速公路兩旁，盡是無邊際的農田與作物，並見灌溉運河及其周圍水利系統，巴國有二億的人口，極少的年雨量，卻有自給自足的農業，全靠這條綿延數百公里的運河，所以農業與農田水利灌溉是巴基斯坦人的驕傲。他們最要感謝印度河，而印度河的源頭源自喜馬拉雅山，所以這座世界最高大的山脈，孕育出印度河，也養育著二億的巴基斯坦人口。

巴國年供灌溉水量 1300 億立方公尺，灌溉地區有 20%之灌溉地區全靠地下水，有 40%之灌溉地係靠地表與地下水聯合運用，其餘 40%均靠地表水灌溉。地下水井有 100 萬口以上，年抽地下水量達 700 億立方公尺，地表水供灌渠道系統之整體灌溉效率為 35%~40%。

巴國主要農作物為水稻、小麥、棉花、豆類、甘蔗、水果、蔬菜。水的重要不言可喻，有水源灌溉的農業區作物收成量，比沒有水源灌溉的農業區作物收成量多出至少 2 倍。巴基斯坦以極少的雨量，卻能成為世界最重要的糧食生產地之一，水資源的充分利用功不可沒。

蔡明華處長與田間操作灌溉之農民合影

2.Rawal 水壩

巴基斯坦 Rawal 水庫為一座人工湖，湖面積為 8.8 平方公里，集水區面積達 275 平方公里，最大湖深 31 公尺，Rawal 水壩坐落在國家公園 Margalla 山麓，此座水庫主要供給遮普北部洛瓦平第與伊斯蘭馬巴德等二大城市之用水。

Rawal 水壩 (雲林農田水利會 劉茂梓攝)

3.灌溉運河

一條取用傑赫勒姆河(Jhelum)上游河水的人工運河，灌溉著全巴基斯坦最富裕的省分-旁遮普(PUNJAB)省，運河主幹線長數百公里，綿延整個旁遮普省灌區。我們在 Jhelum 附近看到的運河均約有 80 公尺寬，你可以想見該運河工程之浩大。運河中段有一個重要的水利工程－JAGGU 攔河堰，該攔河堰截取結隆(Jhelum)河支流，設計可以承受 60,000 CMS 之河川流量，工程告示牌記載了歷史最大洪水量爲西元 1933 年之 51,084CMS，西元 1992 年亦發生了 25,073 CMS 之洪水，至今該攔水堰依然屹立不搖的站在世人的面前，扮演著調節運河水量之重責大任，讓人不禁讚嘆巴基斯坦的水利工程之進步。

JAGGU 攔河堰（雲林農田水利會 劉茂梓攝）

(三)考察心得

巴國全國年降雨僅約 250 ㎜，屬乾燥氣候及半乾燥氣候地區，不能與台灣 2,000~3,000 ㎜之年降雨量相比，惟該國憑藉淵遠流長之印度河水，發展出可觀之農業產值，其水資源有效利用之技術及經驗值得我國借鏡。

巴國耕地面積 2,310 萬公頃，灌溉地占 1,912 萬公頃，灌溉普及率達 83%，印度河源自喜馬拉雅山系，由北向南貫穿巴國，河川長度 2,800 公里，有 5 大支流，爲主要水資源來源，建有 3 大水庫，總蓄水容量 187 億 m^3，19 個大型河川取水工，45 條灌溉系統，灌溉水路總長 6.4 萬公里，爲世界第 4 大灌溉國。主要農作物爲水稻、小麥、棉花、豆類、甘蔗、水果、蔬菜。

巴國的水資源管理策略，爲達到充分糧食供應，同時兼顧永續性與生態系統，必須將土地與水資源作最佳化利用。水資源與灌溉永續發展之主要課題，考慮公平的水分配，較佳的操作管理與成本回收，灌溉與農業部門之間的合作，提昇整體灌溉效率及農作產量，與我國之灌溉管理策略相似。至於巴國約有 45 萬公頃灌溉區域之排水不良及有 21 萬公頃農地受到鹽分影響，在台灣尚無此方面之困擾問題。

由於巴國外交較爲封閉，但其與中國卻爲緊密之友好盟邦，我國代表團此次參訪明顯感受當地居民對其他亞洲人之友善，且此次大會中，我國代表團爲與會各國人數較多者之一，對我國代表團之接待頗爲親切友善。未來台灣似可藉由此次所建立之機緣及友誼，由 ICID 之名義進行水利專家之互訪，進而推廣至學術教育之交流，以增進兩國之間之交流，也爲台灣農田水利界國際交流開啓另一國度。

肆、建議事項

以下建議提供我國灌溉排水協會國家委員會及其團體會員參考，共同努力推動：

一、持續參與國際灌溉排水協會(ICID)活動，維繫良好國際關係，增進農田水利專業資訊交流

我國自 1995 年起以國家委員會名義加入 ICID 總會，並積極參與技術委員會工作小組，至今(2008)年爲止，共有 12 位國內專家學者代表成爲 ICID 總會工作小組正式委員。各工作小組委員必須接受該小組委任之任務，並就各小組所關心之議題，爲 ICID 提供台灣訊息之主要橋樑。2008 年亞洲區域工作小組會議向各會員國要求填寫「適應亞洲氣候變遷的灌溉排水措施」問卷資料，我國由吳瑞賢教授及郭勝豐教授負責彙整。建議各團體會員編列預算持續儘量派員參加 ICID 每年之會議活動。

二、加強報導國內相關組織推動農田水利工作之成果，擴展國際能見度

台灣農田水利事業之發展年代已久，基層水利會組織亦已相當健全，有關台灣灌溉排水之運作及實務推廣，應以農田水利會爲發展主體。惟水利會人員出身基層，雖有豐富灌溉及排水之實務及操作經驗，礙於外語能力，常無法以論文發表方式與他國水利人員即時交換心得，建議爾後，各水利會與會人員可提供該會最具代表性之水利構造物或灌溉操作之簡介小冊，由我國 ICID 國家委員會聘請專精外語之專家學者翻譯成英文簡介小冊，屆時帶往與會地點供各國水利專家分享參考。

三、收集國際農田水利資料，增加農田水利專業書籍典藏供研參

本次代表團人員參加大會開幕儀式，聆聽國際農田水利情勢專題簡報，並分別參予 9 個工作委員會議，除關心各項工作會議議題之時事消息外，並蒐集有關灌溉排水書籍出版訊息(如下)，建議將各冊專書典藏於我國灌排協會(CTCID)文件資料室或網站，俾利國內各工作小組代表及農田水利界研究相關議題之參考。

1. ICID 年度專題報告－「當今全球糧食危機下之灌溉」－irrigation in the context of today’s global food crisis
2. 「亞洲低開發國家工作推動報告」－Report of ICID Task Force for Least Developed Countries in Asia.

3.「噴滴灌溉系統績效評估手冊」－Manual for Performance Evaluation of Sprinkler and Drip Irrigation System

4.「巴基斯坦水資源及能源的發展」－Water and Power Development in Pakistan.

5.「世界環境日」 - World Environment Day.

6.「世界水資源日」－World Water Day.

7.「農業節水」Water Saving in Agriculture.

四、翻譯國際灌溉排水協會研討會議論文資料，提供國內農田水利單位參考應用

本年度 ICID 舉辦第 20 屆國際灌溉排水研討大會，研討會議主題「參與式之整體水資源管理—將理念付諸行動」，相關議題包括「永續性整體水資源管理」、「公私部門在水資源開發與管理所扮演之角色」、「流域之整體水資源管理」、「從大流域水管理及乾旱歷史經驗中學習之課題」、「全球變遷對灌溉與排水系統發展與管理之影響」，論文資料共計 89 篇，建議我國灌排協會國家委員會(CTCID)翻譯本論文輯各篇論文摘要，主動提供國內相關農田水利單位參考應用。

五、邀集各專家學者代表發表論文並參予各議題工作小組委員，作為參與國際議題溝通之橋樑

ICID 每年度討論議題皆為現階段全球各國家關心之灌溉排水時事問題，其內容囊括基本資料蒐集、技術創新、教育訓練、經營管理與政策規劃等，藉由參加工作小組會議與研討會議的方式，可見證各國家實行灌溉排水之經驗以增廣見識。建議我國灌排協會國家委員會(CTCID)每年針對研討會議題主動邀請各農田水利專家與學者參與論文投稿與發表，並積極安排各專家代表參與 ICID 技術委員會工作小組會議討論。

附　錄　一

第 **20** 屆國際灌溉排水研討大會論文發表

Analysis for Field Effective Rainfall Under Climate Change

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and Chia-Chi Ma[3]

ANALYSIS FOR FIELD EFFECTIVE RAINFALL UNDER CLIMATE CHANGE

ANALYSE DES PRECIPITATIONS EFFICACES AU NIVEAU DE LA PARCELLE, AVEC LE CHANGEMENT CLIMATIQUE

ABSTRACT

The Taoyuan pond irrigation system in northern Taiwan was intended to provide a major agricultural water resource system to the region in the early twentieth century. The concept of the pond irrigation system was to store excess runoff in ponds as if in small reservoirs and then to supply water to farmland during droughts. Rainfall is a vital irrigation resource in Taiwan. However, in recent years, rainfall has been hit by global climate change. The purpose of this study is to assess how changes in climate and rainfall affect agricultural irrigation.

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This study used the Markov chain to construct a daily rainfall model. Differences between effective rainfall were then compared in the study area. Although total rain strength in Taiwan has increased during the last 10 years, rainfall has decreased during the months of March to June. The simulation of high effective rainfall condition revealed that an extra 25cm effective rainfall can support about 885000 m^3 water in the middle and downstream irrigation region of the second feeder.

RESUME

Le système d'irrigation par flaquage d'eau de Taoyuan au nord de Taiwan était conçu au début du 20ème siècle en tant qu'important système de ressource en eau agricole. Le concept du système de flaquage d'eau consiste à stocker dans les bassins, l'excédent d'écoulements comme dans le cas des petits réservoirs, et ensuite à distribuer l'eau aux exploitations agricoles lors de la période de sécheresse. Les précipitations constituent une ressource vitale de l'irrigation. Cependant, lors des dernières années, le changement climatique au niveau global a exercé un impact sur les précipitations. Cette étude a pour but d'évaluer comment les changements climatiques et les précipitations exercent un impact sur l'irrigation agricole.

Cette étude utilise le procédé de « Markov chain » pour établir un modèle de précipitation journalière. Les différences de précipitations efficaces ont été comparées au chantier d'étude. Quoique l'intensité des précipitations au Taiwan ait augmenté lors des dix dernières années, la pluviosité a diminué au cours de la période de mars à juin. Une étude de haute précipitation efficace montre qu'un excédent de précipitation de 25cm peut contribuer un apport d'eau d'environ 885000 m^3 dans le tronçon moyen et de l'aval du second distributeur.

1. INTRODUCTION AND BACKGROUND

Increased urbanization, higher living standards, and new industrial areas and high technology science parks in Taiwan have dramatically increased domestic and industrial water usage. Developing new water resources is difficult, and continually rising water costs result in diversion of agricultural water supplies to domestic and industrial use.

The implications of effective rainfall are profound because irrigational constructions can only compensate for the lack of natural rainfall. Very often, non-irrigational facilities rely on weather conditions to maintain crop growth; therefore, effective rainfall plays a significant role in irrigation. In the Shihmen Reservoir irrigational regions, 48 per cent of the water supply is from the Shihmen Reservoir and approximately 52 per cent is groundwater and return flow (Hsieh, 2004), which is arrested by effective rainfall and river dams. However, the Taoyuan area, which differs from other irrigational areas in Taiwan, belongs to a region in the 'farm pond system'. Owing to its geographical and hydrological features, the Taoyuan Plateau region achieves its irrigational upstream flow and downstream collection by using a farm pond (Chen et al., 2004) for water storage and runoff in order to enhance the usage of rain water. Surplus irrigation water or return flow (Chien, 2003) can be received by the downstream farm pond for reuse in irrigation.

According to a previous regional study of the second feeder of the Taoyuan main canal, the irrigation system should be supplied by three water sources: a second feeder reservoir, a river dam and farm ponds. Considering effective rainfall and limited irrigation water from rainfall, the use of irrigation water was simulated by using data from 2005. The simulation results revealed an insufficient supply of water in the downstream second feeders of five irrigation areas without farm ponds. According to the deep-water irrigation theory (Kan, 1978), the retention of rain water in irrigation areas is effective when rainfall increases; by increasing effective rainfall value by 210 mm, water shortages in irrigation areas can be effectively decreased, and days of water shortages can be minimized.

In recent years, rainfall characteristics have changed because of weather changes. Most rainfall is heavier and clustered, despite a consistent overall rainfall volume. This phenomenon severely affects the availability of effective rainfall, which is most likely to affect future irrigation. As water resource become scarce, the farm pond system presents the dilemma of whether to expand to preserve water resources. Since Taiwanese agriculture is vital for the domestic population, early research is needed to determine the effects of weather changes on rainfall, which influences agricultural irrigation.

2. CONCEPTS OF CLIMATE CHANGE AND EFFECTIVE RAINFALL

The United Nations established the UN Intergovernmental Panel on Climate Change (IPCC) in 1988. Its research on climate and environmental change are well recognized. Since 1991, the IPCC has published an assessment report of global climate change every five years, and the fourth assessment report was published in 2007. The 2007 report reviewed the effects of abnormal climate changes since 1990 and expanded the content discussed and studied in the third assessment report by additional research and analysis of global data. Regardless of whether climate change is due to human behaviour or whether it is a natural mechanism, its existence has finally been confirmed by global climate changes, especially its direct effect on temperature and rainfall variations. Climate change is also due to the impact and challenges of the surrounding environmental climate, and hydrological conditions related to agricultural irrigation work must be carefully considered. This study assessed the effects of agricultural irrigation and water management on climate change and rainfall type.

The Taoyuan Irrigation Association planned its irrigation system in accordance with 'The twenty-year monthly fourth water level law', a method of estimating effective rainfall by considering monthly effective rainfall volume at the fourth water level during the past twenty years as the estimated value of monthly effective rainfall for irrigation the following year. Effective rainfall is determined by daily recordings.

The water requirement of a crop is defined as the amount of water needed for its growth and this includes water to meet both consumptive and special needs, such as land preparation, land submergence, leaching and so on. In view of this current concept, it follows that from the production point of view, the annual or seasonal effective rainfall, as far as the water requirement of crops is concerned, should be interpreted as that portion of total annual or seasonal rainfall which is useful directly and/or indirectly for crop production at the site where it falls but without pumping.

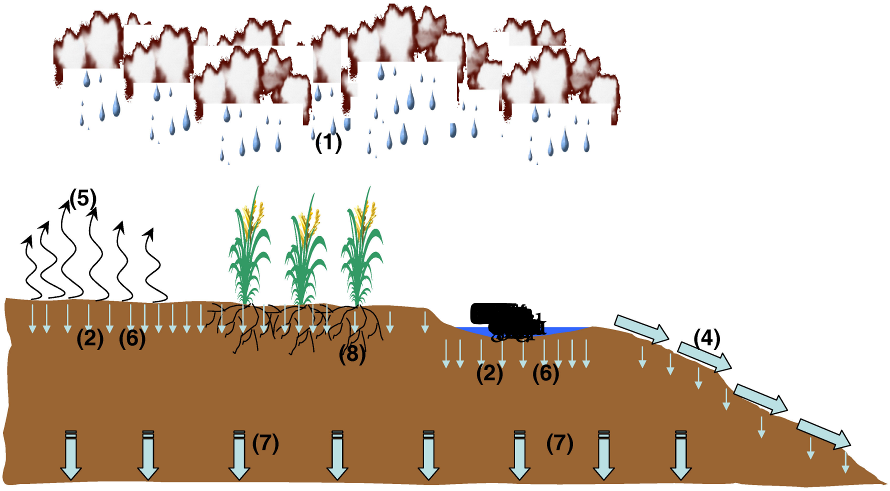
Effective rainfall, sometimes called excess rainfall, is the component of the storm hyetograph which is neither retained on the land surface nor which infiltrates into the soil. The effective rainfall produces overland flow that results in the direct runoff hydrograph from a sub-area of a catchment.

As showed in Figure 1, when rain water (1) falls on the soil surface, some of it infiltrates into the soil (2), some stagnates on the surface (3), while some flows over the surface as runoff (4). When the rainfall stops, some of the water stagnating on the surface (3) evaporates to the atmosphere (5), while the rest slowly infiltrates into the soil (6). From all the water that infiltrates into the soil ((2) and (6)), some percolates below the root zone (7), while the rest remains stored in the root zone (8).

The effective rainfall (8) is the total rainfall (1) minus runoff (4) minus evaporation (5) and minus deep percolation (7); only the water retained in the root zone (8) can be used by the plants, and represents what is called the effective part of the rainwater.

$$\text{Effective rainfall } (8) = (1) - (4) - (5) - (7) \tag{1}$$

The term effective rainfall is used to define this fraction of the total amount of rainwater useful for meeting the water need of the crops.



(2)

where I is the inflow, O is the outflow, S_f is the field storage, and t is time.

Analysis of the mechanisms of the paddy field water equilibration in this study, e.g., rainfall, evapotranspiration, irrigation routing water, etc., excluding the study of soil water content, used the paddy field as control volume (Figure 2). The formula for water equilibration for a specified period is shown:

$$S_i = S_{i-1} + IR_i + IO_i + P_i - (ET_i - F_i) - DR_i \tag{3}$$

where the S is field storage, IR is irrigation inflow, IO is return flow from upstream, P is rainfall water, ET is evapotranspiration, F is field depletion, DR is field outflow, and i is a specified period of time. The restriction conditions for studying fields using irrigation water volume and return flow output volume are:

$$N_i = ET_i + F_i$$

$$\text{if} \quad S_{i-1} + IO_i + P_i < N_i, \text{ then } IR_i > 0 \tag{4}$$

$$\text{if} \quad S_{i-1} + IO_i + P_i \geq N_i, \text{ then } IR_i = 0$$

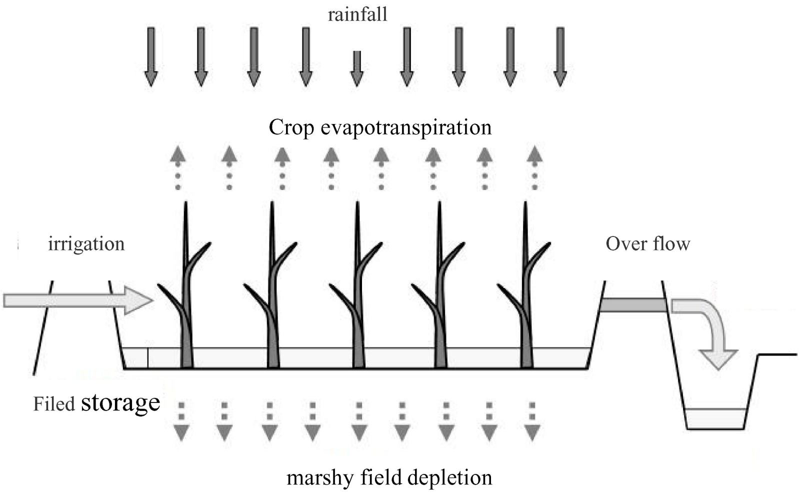


Figure 2 Paddy field water balance model.

When the field storage (S), rainfall volume (P) and upstream field return flow volume (IO) are unavailable for crop fields, irrigation is needed to supplement water ($IR > 0$). No irrigation ($IR = 0$) is necessary if the condition is reversed.

$$\text{if} \quad S_i \geq H_i, \text{ then } DR_i = S_i - H_i \tag{5}$$

if $S_i < H_i$, then $DR_i = 0$

When the field storage (S) water reserves exceed the water exiting field ridges (H), then a field return flow volume ($DR > 0$) is observed; no outflow ($DR = 0$)is observed in a vice versa scenario.

3.2 Estimation of Water Requirement in Fields

Crop water requirement is the sum of crop evapotranspiration and marshy field depletion, which is the daily decrease in water level. Crop evapotranspiration includes the evaporative water volume needed for growth during the crop maturation stage, also called crop water requirement. Further, the continuous evaporation of field water depletes the irrigation water supply; therefore, evaporation must include the field water surface evaporation volume. The marshy field depletion volume can be used for farming land return flow or for supplementing ground water; hence,

requirement in fields (N) = crop evapotranspiration (ET_{crop}) + marshy field depletion (F)

= crop water requirement + water surface evaporation + marshy field depletion (6)

The crop water requirement could be decided by direct measurement or through indirect calculation. Although direct measurement could yield an actual water requirement, it would cost more money and labour due to morphological constraints. Instead, the indirect calculation is usually used. The calculation equation is expressed as:

$$ET_{crop} = K_c \times ET_o \tag{7}$$

where ET_{crop} is the crop water requirement, K_c, varies with season, wind speed is the dimensionless crop coefficient—approximately 0.95 ~ 1.35 for paddy rice—and ET_o refers to the evapotranspiration of standard crop canopy, which is often estimated using the Penmen-Monteith method (Monteith, 1994; Kan et al., 1996). According to the growing seasons of all crops (paddy rice) (Masakazu, 1999; Chang et al., 2001), one can determine the total crop water requirement for any period.

3.3 Estimation of Effective Rainfall

Generally, the Cropland Irrigation Association (CIA) previously analysed water usage in a paddy irrigation test field. The analytical results showed that the effective range is within 60 per cent of average rainfall volume or 50 per cent of the field water requirement in that time period, assuming the smaller range is significant (Tsao, 1971). The two methods of achieving effective water use proposed in this study are (1) to provide water directly to field crops and (2) to reserve water retained by soil accumulation. According to the irrigation instruction method, the structured calculation mode for effective rainfall by using the crop, soil and rainfall data for the past several years can be modelled to calculate effective rainfall during a certain time period.

3.4 Estimation of Field Water Usage

The first step in water source management is estimating the water usage volume of the planned irrigation area; this volume should be based on the method of development, classification of the crop, cultivation soil type and environmental climate data. The water uptake from rice (also called field water uptake or water uptake) should be estimated as well as should be the varying water uptake required for growth and maturation of rice (also called water requirement volume or requirement volume, which is the sum of crop evapotranspiration and depletion) and the availability of effective rainfall. Hence,

$$\begin{aligned}\text{Total water usage} &= \text{field water uptake} + \text{water conveyance loss} \qquad (8)\\ &= (\text{requirement in fields} - \text{effective rainfall}) + \\ &\quad (1 - \text{rate of water conveyance loss})\end{aligned}$$

Conveyance loss, including evaporation, seepage, and operational loss, is the loss suffered during transportation from the water source to fields. The transportation path consists of a main canal (from the main intake to a lateral intake), a lateral canal (from the lateral intake to a farm intake), and ditches (from the farm intake to fields). According to conventional irrigation analysis, conveyance losses in canals and ditches are generally considered to be within a constant range, depending on soil texture and type. According to the 2005 irrigation plan of Taoyuan Irrigation Association, the conveyance loss in this study was assumedly 13 per cent.

3.5 Rainfall Stochastic Theory

The Markov chain theory is often used to describe a constant phenomenon, such as rainfall change. Daily rainfall mode is used to predict daily rainfall for a period of time. For example, the mean volume of daily rainfall distribution index is used to express climate change, but the relation of constant rainfall must be considered to determine the probability of constant rainfall by the first degree of the Markov chain.

The Markov chain mode uses the probability concept for explanation, while the first degree estimates its mode.

$$T_t = \mu + \rho_1(T_{t-1} - \mu) + \sigma n_t(1 - \rho_1^2)^{1/2} \tag{9}$$

where T_t is hydrological division of time (t), ρ is first order serial correlation coefficient, μ is average, σ is standard deviation, and n_t is standardized random normal variable.

The probability of continuous rainfall must be considered by the rainfall mode. Using the first degree of the Markov chain to determine constant rainfall intensity, this mode can be used to estimate rainfall probability and rainfall intensity.

If no rain occurs on day (t–1) in month (n), the conditional probability of no rainfall occurring on day (t) would be $P_n d/d$, but if no rain occurs on day t–1, the conditional probability of rain on day (t) would be $P_n w/d$. If rain occurs on day (t–1), the conditional probability of rain on day (t) would be $P_n d/w$, but if rain occurs on day t–1, then the conditional probability of rain on day (t) is $P_n w/w$.

When rainfall probability is to be simulated by the first degree of the Markov chain for a period of time, one must first determine whether rain would occur on that day before determining rainfall intensity for the day via rainfall probability distribution function.

When $P_r(Y_t) > P_n d/d$, $Y_{t-1} = 0$, the rainfall occurs on day t and vice versa, rainfall intensity is as follows:

$$P_r(Y_t) = P_n d/d + P_n w/d F_n(y_t),\ Y_{t-1} = 0 \tag{10}$$

$$y_t = -\ln\left(1 - \frac{P_r(Y_t) - P_n d/d}{P_n w/d}\right) \times \lambda_n,\ Y_{t-1} = 0$$

When $P_r(Y_t) > P_n d/w$, $Y_{t-1} > 0$, the rainfall occurs on day t and vice versa, rainfall intensity is as follows:

$$P_r(Y_t) = P_n d/w + P_n w/w F_n(y_t),\ Y_{t-1} \geq 0 \tag{11}$$

$$y_t = -\ln\left(1 - \frac{P_r(Y_t) - P_n d/w}{P_n w/w}\right) \times \lambda_n,\ Y_{t-1} = 0$$

The rainfall probability distribution function is shown here:

$$F_n(y_t) = 1 - e^{(-y_t/\lambda_n)} \tag{12}$$

where $P_n d/d$ is in month n, the conditional probability of no rain on day t under the circumstances of no rainfall on day $t-1$ is $(Y_{t-1} = 0)$; $P_n w/d$ is in month n, the conditional probability of rain on day t under the circumstances of no rainfall on day $t-1$ is $(Y_{t-1} = 0)$ $P_n d/w$ is in month n, the conditional probability of no rain on day t under the circumstances of rainfall on day $t-1$ is $(Y_{t-1} \geq 0)$ $P_n w/w$ is in month n, the conditional probability of rain on day t under the circumstances of rainfall on day $t-1$ is $(Y_{t-1} \geq 0) F_n(y_t)$ is the probability distribution functions of rainfall on day t in month n and λ_n is average rainfall on rainy days in month n.

4. STUDY AREA SYSTEM

4.1 Study Area Description

The study area is the second of 15 feeders in the Taoyuan main canal, with a size of 2,765 ha, belongs to the Taoyuan Irrigation Association. There are 38 irrigation areas; water requirement is supplied from the main canal except in 29 areas with water ponds, which received a part of their water requirement from ponds. The effective capacity of all 29 water ponds is totally 4,707,912 m^3, the geographic positions of which, are shown in Figure 3. There are 16 river weirs in this irrigation pond system, and the water right for each weir is collected and collated in Table 1.

The study area lies in a subtropical climate. The wet season is from May to September, and the dry season is from October to April. Although the mean annual rainfall is 2658 mm in Taoyuan area, about 61.9 per cent is concentrated in the wet season. Thus, the distribution of rainfall is very uneven. The first-season paddy rice begins in late February and ends in mid-July, while the second-season paddy rice begins in early June and ends in early November. This paper applies the pond irrigation system model, and applies data that contains details of crop water requirement, Taoyuan main canal supply, evaporation, precipitation, water right of river weir and river flow in the first-season period. The analytic period is from 3 March

2005 to 30 June 2005, thus a total of 120 days. The simulation procedure calculates water balance day by day in each irrigation area from upstream to downstream.

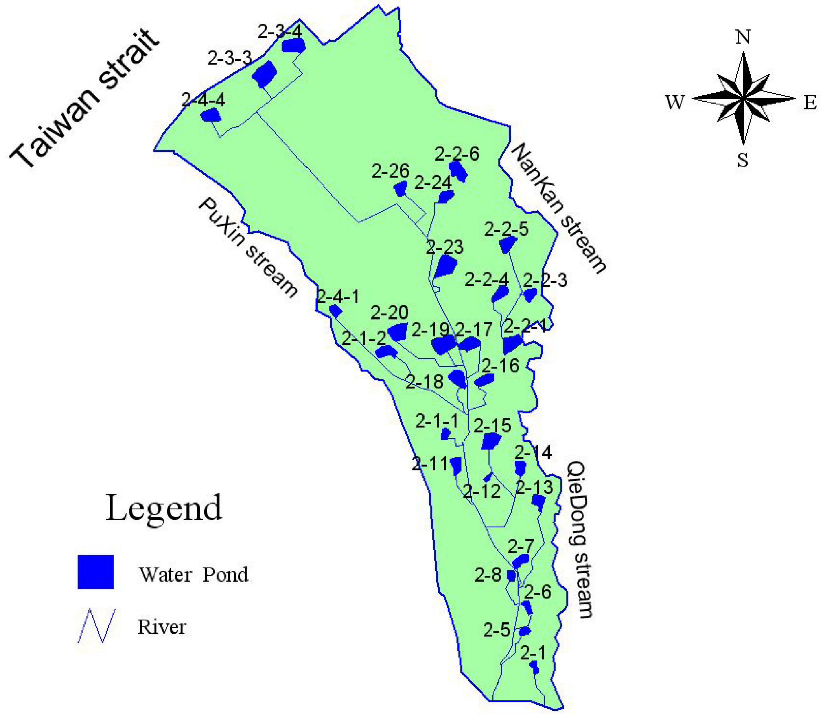


Figure 3 Distribution of water ponds Irrigation site of the second feeder in Arcview layer.

Table 1 The water right of river weir

River weir	Water right (CMD)	River weir	Water right (CMD)
#6	1555.2	#12	8553.6
#7	4060.8	#13	864.0
#7-1	2160.0	#24	691.2
#9	15120.0	#24-8	777.6
#10	1987.2	#24-9	1555.2
#10-2	1209.6	#25-7	21513.6
#10-3	864.0	#28-3	5702.4
#11	3456.0	#28-4	3024.0

4.2 Taoyuan Irrigation Area Irrigation System

The irrigation water is supplied from five sources, including precipitation, return flow from upstream paddy field, river weir, water pond and main canal. In this study, the water usage order is described as follows. Firstly, to calculate the effective rain and storage in paddy field and return flow from upstream field. If the crop water requirement is still not met, river weir and water pond are considered in the irrigation-pond system. Finally, the main canal would provide overall deficit.

4.3 System Establishment

The characteristic of the pond irrigation system model is that the upstream areas (near Taoyuan main canal) are prioritized to be provided with water. Areas where likely deficit occurs are the middle and downstream canal when the Taoyuan main canal cannot supply enough irrigation water. Therefore, the water ponds play an important role in supporting crop water requirements during this time. The capacity of the pond and the demand of responsible irrigation are essential to determine the presence of deficit.

4.4 Supply Style Classification

In this study area, the irrigation system is divided into four supply styles, which are associated with main canal, water pond and river weir. As showed in Figure 4, style A is the most complete supply style, consisting of the main canal, water pond and river weir; thus, three components of water resources simultaneously. The supply style of style B includes mainly the main canal and water pond; the irrigation water is diverted from the main canal into the water pond, then to the crop field in a regulated fashion. Style C immediately supplies irrigation water to farmland from main canal and river weir and Style D only has the main canal.

5. APPLICATION AND DISCUSSION

After collecting rainfall data from 1955 to 2006 within the research areas in this study, rainfall volume change and its distribution trends were analysed. The analytical results showed that the mean rainfall volume collected at the second feeder rainfall station in that time period (1955–2006) was 1761.2 mm, but due to rainfall changes in recent years, mean rainfall volume change in the past period (1955–1996) and in the past decade (1997–2006) were also analysed. The mean days of rainfall in the past decade (116.5 days) was lower than in the past; however, average rainfall volume increased from 1747.3 mm to 1819.7 mm, which indicates increased rainfall intensity.

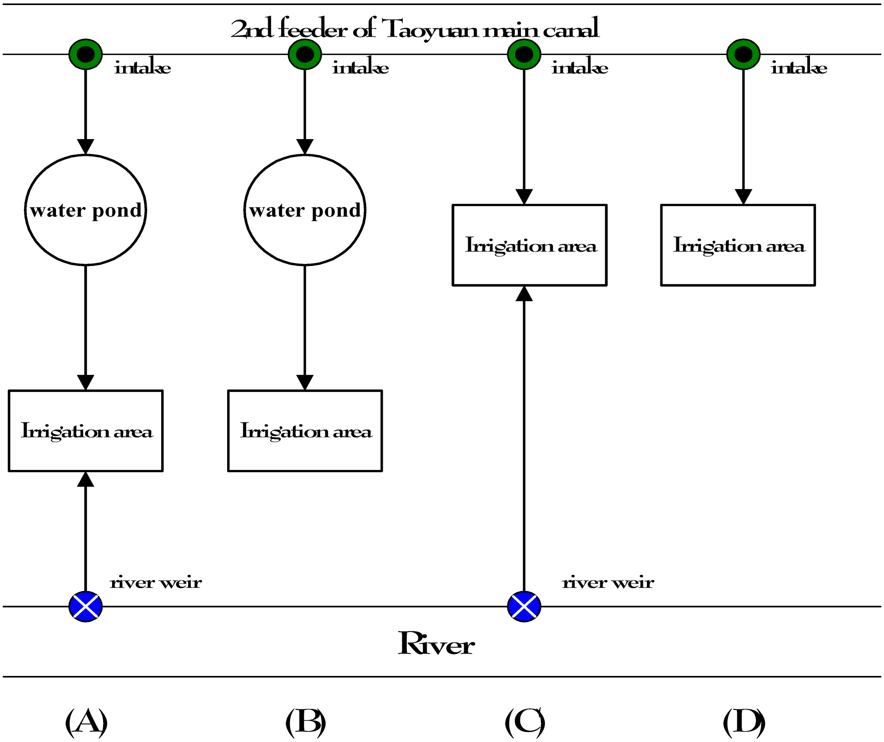


Figure 4 The diagram of supply style to irrigation area.

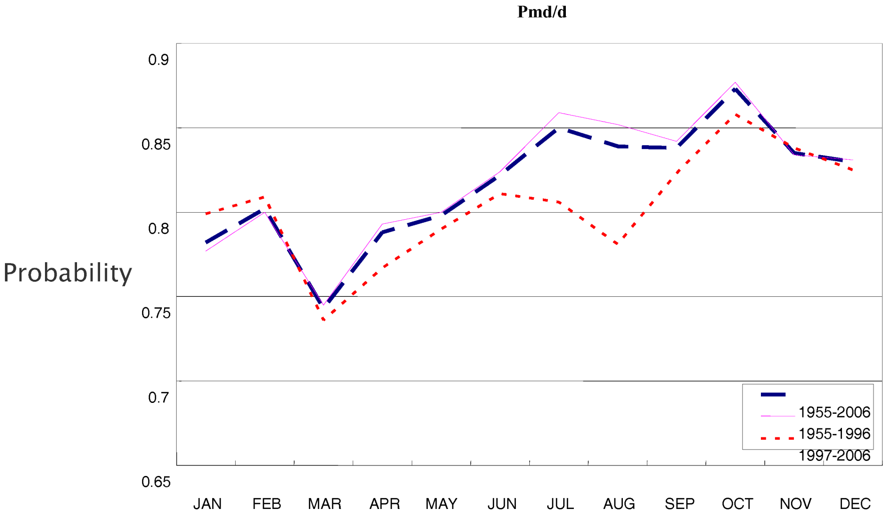
Table 2 and Figure 5 show the results of daily rainfall analysis. The probability distribution of dry seasons, wet seasons or consecutive sunny days was lower in the past decade than before, and the probability of continuous rainfall among the seasons as well as their phases have also changed dramatically.

The 120-day period from 3 March to 30 June every year is an important period for the first season of cultivation and irrigation water usage in the irrigation area. Rainfall is an important factor in irrigation and it supplies the irrigation area with effective rainfall. When rain volume is higher, effective rainfall can satisfy water needs in the irrigation area, and excess can be

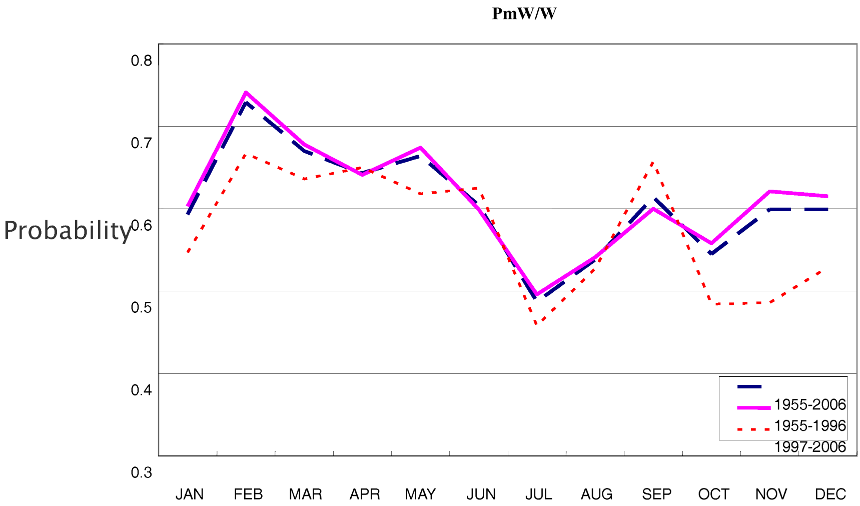
Table 2 Analysis of the second feeder rainfall probability

1955–2006 Rainfall number of days: 117.12 (day) Average wet weather daily rainfall amount: 15.00 mm												
\	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Pmd/d	0.782	0.802	0.743	0.788	0.798	0.822	0.85	0.839	0.838	0.873	0.835	0.83
PmW/d	0.218	0.198	0.257	0.212	0.202	0.178	0.15	0.161	0.162	0.127	0.165	0.17
Pmd/W	0.407	0.271	0.33	0.357	0.336	0.396	0.513	0.462	0.386	0.455	0.401	0.401
PmW/W	0.593	0.729	0.67	0.643	0.664	0.604	0.487	0.538	0.614	0.545	0.599	0.599
1955–1996 Rainfall number of days: 117.26 (day) Average wet weather daily rainfall amount: 14.90 mm												
\	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Pmd/d	0.777	0.8	0.745	0.793	0.8	0.824	0.859	0.852	0.842	0.877	0.834	0.831
PmW/d	0.223	0.2	0.255	0.207	0.2	0.176	0.141	0.148	0.158	0.123	0.166	0.169
Pmd/W	0.397	0.259	0.322	0.359	0.326	0.401	0.504	0.459	0.4	0.442	0.379	0.385
PmW/W	0.603	0.741	0.678	0.641	0.674	0.599	0.496	0.541	0.6	0.558	0.621	0.615
1997–2006 Rainfall number of days: 116.5 (day) Average wet weather daily rainfall amount: 15.38 mm												
\	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Pmd/d	0.799	0.809	0.736	0.767	0.79	0.811	0.806	0.781	0.823	0.858	0.838	0.825
PmW/d	0.201	0.191	0.264	0.233	0.21	0.189	0.194	0.219	0.177	0.142	0.162	0.175
Pmd/W	0.453	0.333	0.364	0.35	0.382	0.375	0.542	0.473	0.343	0.516	0.514	0.471
PmW/W	0.547	0.667	0.636	0.65	0.618	0.625	0.458	0.527	0.657	0.484	0.486	0.529

stored in the fields, but when rain volume is low, the irrigation area still require man-made irrigation. The highest and the lowest rainfall volume in the past decade have been 1152.5 mm and 350 mm, respectively.



(a)



(b)

Figures 5 Analysis diagram of the second feeder rainfall probability.

Data for rainfall volume in the past decade (3 March – 30 June) from the rainfall station shows that total rainfall has increased in volume and intensity, but considering the data from this irrigation area during the irrigation season, rainfall volume is decreasing, as shown in Figure 6. This data is crucial for the analysis of effective rainfall.

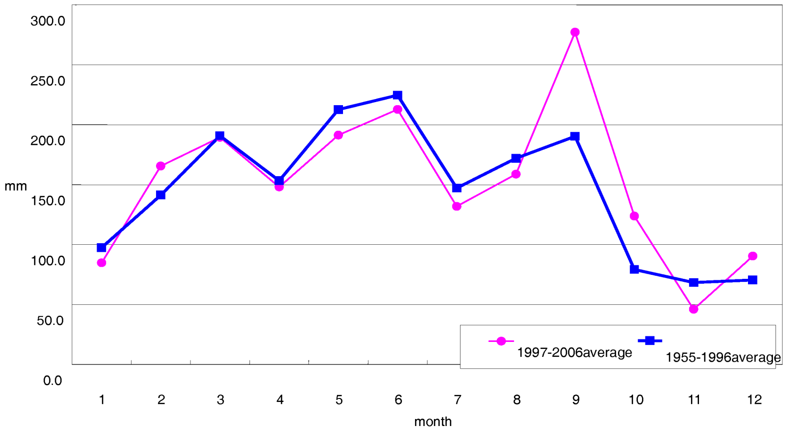
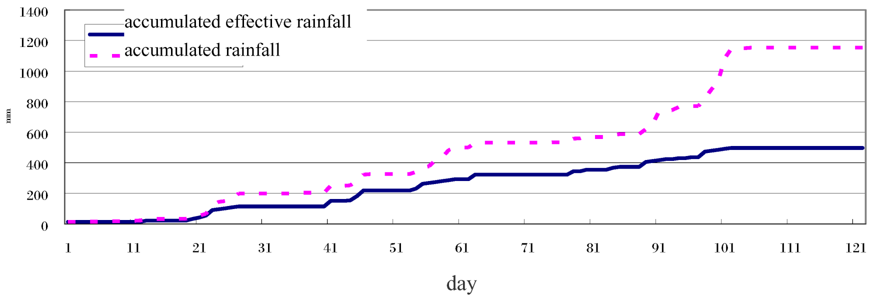


Figure 6 Analysis diagram of the second feeder rainfall distribution history.

With regard to irrigation, the rain from effective rainfall is crucial. For example, in Figure 7 the daily volume of rain is represented by a dotted line, and daily effective rainfall is expressed as a solid line. This study hypothesized that irrigation is shallow in the analysed area. Low rainfall volume would be effective rainfall, and the accumulated effective rainfall would approximate rainfall volume. However, when rainfall volume is high, exiting the irrigation area would overflow with water; therefore, not all rain should be considered effective rainfall, which means that the return flow water is ineffective, and accumulated effective rainfall would be less than that of rainfall volume.



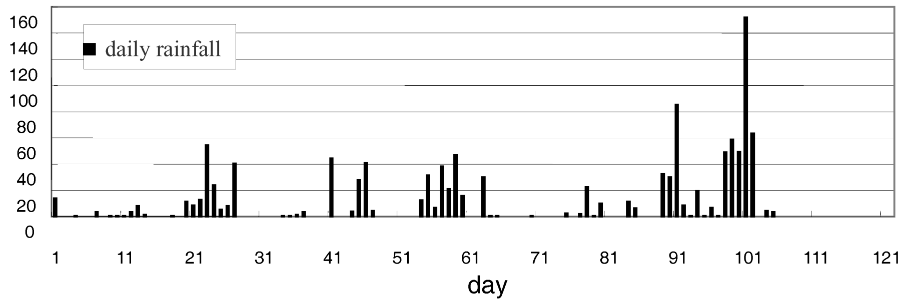


Figure 7 Accumulation diagram of the second feeder rain and effective rainfall in 2007.

The daily rainfall mode is based on the Markov chain theory and the Fortran mode, and was divided into a daily rainfall analysis mode and a daily rainfall prediction mode. Since the mode possess random variations (0 – 1) as uncertain climate factors, the mode calculates only one set of data for analysis, which can create bias; therefore, this study generated one hundred sets per circumstance for analysis and research (one year per set) to predict and represent the possible area of occurrence.

During mode confirmation, the rainfall probability and regional rainfall volume were based on historical data for daily rainfall analysis mode. The above results were then entered into the daily rainfall prediction mode to observe the one hundred sets of data and the changes in the historic record. The confirmation section is discussed according to various research findings.

Using daily rainfall mode to analyse historical data from the rainfall probability analysis of 1997–2006, the mean value of one hundred sets and the mean value of historical data is shown in Figure 8. The confirmation results exhibited acceptable bias.

The analysis of accumulated effective rainfall showed that in the past decade, during a total of 120 days from 3 March to 30 June, the highest recorded volume was 524 mm in 1999, and the lowest was 285 mm in 2002. Within the envelope of highest and lowest accumulated effective rainfall, the hypothesis can be drawn for accumulated effective rainfall distribution in the past decade.

In the range of predicted rainfall probability based on historical data, groups of ultimate rainfall volumes were selected from the estimated rainfall volumes (one from each maximum and minimum rainfall were selected) to calculate effective rainfall volume. Figure 9 shows the accumulated effective rainfall.

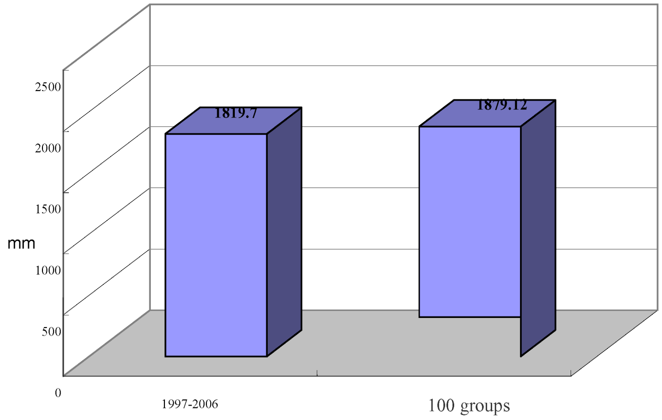


Figure 8 Confirmation of the second feeder daily rainfall mode.

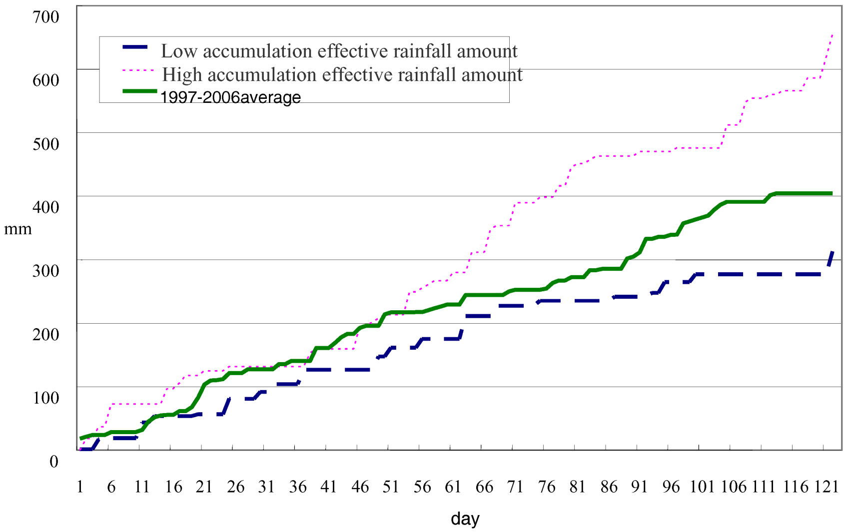


Figure 9 Accumulated effective rainfall diagram of the second feeder imitated prediction.

Respective rainfall volumes were used to simulate shallow water irrigation in the entire second feeder section where water was lacking for at least 120 days in the first season. The analytical results showed that inadequate water supply in the second feeder occurred mainly in the middle and downstream regions as the upstream had priority access to water; therefore, the irrigation water source was able to provide the required water supply, but no downstream areas received an adequate water supply. The table below shows all deficiencies in water distribution. The analytical results showed that if effective rainfall increases by 25 cm, then the middle downstream region increases by approximately 885 000 m^3 of water.

Table 3 Prediction of accumulated water lack

Irrigation area	Accumulation water lack (m^3)		
	Average of 1997–2006	Maximum effective rainfall simulation	Minimum effective rainfall simulation
2–17	168788.7	–	310808.6
Three stone	304842.3	125319.6	372073.9
No.14	157002.2	96184.9	179778.4
2–3	184343.3	87030.6	220787.1
Sha Lun rever water	196634.8	53037.7	250412.2
2–1	284437.5	49125.0	372562.5

6. CONCLUSIONS

The purpose of this study was to analyse the relationships between rainfall characteristics and effective rainfall using the stochastic method, as well as to evaluate how climate change impacts irrigation management. The irrigation water for crops in northern Taiwan is supplied from rainfall and man-made water supply systems. For example, in the Taoyuan irrigation area, the total irrigation area covers about 24,579 hectares and the main crop is paddy rice. The irrigation system is comprised of the Shihmen Reservoir, river weirs and several irrigation ponds. Moreover, the effective rainfall, which is the rain used directly for crops or stored in the soil or ground, is an estimated 93.8 million tons, about 18 per cent of the total paddy water requirement, based on the 2005 irrigation plan of the Taoyuan Irrigation Association. Clearly, rainfall is vital for irrigation in this area.

Historical rainfall data for the Taoyuan region was used in this study to estimate daily rainfall using the Markov chain theory in order to elucidate changes in effective rainfall due to climate change. According to the simulation results, although the average days of rainfall (116.5 days) in the past decade was lower than before, mean rainfall volume increased from 1747.3 mm to 1819.7 mm, indicating increased rainfall intensity. However, in the first season from March to June, rainfall volume comparatively decreased. Effective rainfall in the past decade was 404.5 mm. In simulated conditions of high effective rainfall, the extra 25 cm effective rainfall and the water shortage in the middle and downstream irrigation region of the second feeder improved tremendously, and were able to provide an additional 885000 m^3 of water.

This irrigation system mode was established by considering the time distribution of water usage by the second feeder of the main canal. It provides a simplified estimate of actual agricultural water usage in the irrigation area; however, estimation parameters for the irrigation system are rather complicated. Some parameter settings did not consider limitations and corrections and did not assume that predicted rainfall would be affected by climate changes. Therefore, many parameters and modes are still inconclusive. Hence, accurately simulating uneven rainfall during alternating periods of rainfall abundance and drought awaits further model refinements.

REFERENCES

1. Chang, Y.C.; Kan, C.E.; Lin, G.F.; Lee, Y.C. and C.L. Chiu 'Potential Benefits of Increased Application of Water to Paddy Fields in Taiwan', Hydrological Processes, Vol. 15, No. 8. 2001, 1515–1524.
2. Chen, C.T.; Kan, C.E. and G.F. Lin, 'An Irrigation Water Distribution Model for Area of Mixed Cultivation', Journal of The Chinese Institute of Engineers, Vol. 27, No. 3. 2004, 343–356.
3. Chien, C.P., 'Study on the infiltration and return flow in paddy field', Ph.D. thesis (in Chinese), N.C.U. 2003.
4. Hsieh, S.Y. 'Study on Promoting Water Supply Capacity of Farm Ponds in Taoyuan Irrigation Area', presented at the Taoyuan Canal Academic Conference on Water Resources and Management. 2004, 173–190.
5. Kan, C.E.; Chen, C.T. and T.K. Chen, 'Study on the Suitability of Consumptive Use Estimation Methods for Taiwan Area', Journal of Chinese Agricultural Engineering, Vol. 42, No. 2. 1996, 8–19.
6. Kan, C.E., 'Irrigation Principles and Practices', Design of Irrigation and Drainage Engineering, Taiwan Water Conservancy Bureau. 1978, 18–50.

7. Masakazu, M., 'Development of Paddy Field Engineering in Japan', Advanced Paddy Field Engineering, Japanese Society of Irrigation, Drainage and Reclamation Engineering. 1999, 1–9.
8. Monteith, J.L., 'Proposed Calculation Procedures for ET0 Combination Formula', Bulletin of International Commission on Irrigation and Drainage, Vol. 43, No. 2. 1994, 39–82.
9. Tsao, Y.S., 'Study on the electronic accounting machine computation paddy field effective rainfall', Taiwan Water Conservancy Bureau, Vol. 19, No. 2. 1971, 7–29.

附　錄　二

第 **20** 屆國際灌溉排水研討大會論文發表

The Evaluation of Compensation Price for Agricultural Water Transfer during Drought in Taiwan

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Lahore 2008

Seminar
S.02

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Ming-Young Jan[3] and Yuan-Chuan Lee[4]

EVALUATION OF COMPENSATION PRICE FOR AGRICULTURAL WATER TRANSFER DURING DROUGHT IN TAIWAN

EVALUATION DE LA COMPENSATION POUR TRANSFERT D'EAU AGRICOLE LORS DE LA SECHERESS AU TAIWAN

ABSTRACT

This article evaluates the compensation price, which farmers are willing to accept (WTA) for transferring irrigation water to non-agricultural users during water-shortage seasons in the Tao-Yuan area of Tam-Shui River in northern Taiwan. A sampling survey with questionnaire was conducted in

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two irrigation associations of the area, the Tao-Yuan and Shih-Men irrigation associations and the Contingent Valuation Method (CVM) was employed to determine the compensation of transferring irrigation water for alternative uses. It is expected that the result of this study could provide a basis for the proposition of a reasonable water—transferring system, so that a win-win situation could be achieved where the transaction cost could be lowered, the interests of all water users promoted and the efficiency of water utilization increased.

RESUME

Ce rapport fait une évaluation de compensation que les fermiers réclament de la région de Tao-Yuan où est situé le bassin de la rivière Tam-Shui (nord du Taiwan) pour le transfert de l'eau d'irrigation aux usagers non agricoles lors des saisons de pénurie. Une enquête a été menée auprès deux Associations d'irrigants - Tao-Yuan and Shih-Men – de cette région, et la Méthode d'estimation aléatoire (CVM - Contingent Valuation Method) a été utilisée pour déterminer la compensation pour le transfert de l'eau d'irrigation aux autres usagers. Il est espéré que le résultat de cette étude servira de base d'une proposition pour la mise en place d'un système plus judicieux de transfert d'eau - système à but multiple permettant de réduire le coût d'opération, promouvoir l'intérêt de tous les usagers et accroître l'efficience dans l'utilisation d'eau.

1. INTRODUCTION

Although the average annual rainfall in Taiwan is 2,515 mm, and the total volume reaches 90.5 billion m^3, which is approximately 2.7 times of the world average, Taiwan is considered a country experiencing water scarcity as the annual allocated water per capita is only around one-eight of the world average due to the dense population as well as uneven distribution of rainfall, as shown in Figure 1. Tao-Yuan area is a major productive agricultural district in Ta-Han River, which is the main tributary of Tam-Shui River, the largest river basin in northern Taiwan. There are two irrigation associations in the area: Tao-Yuan and Shih-Men, as shown in Figure 2. In addition to the fast-growing demand of non-agricultural water resources, Tao-Yuan area has also experienced droughts and water-scarcity problems over the past decades. Moreover, a deficit of 0.19 MCM/day was projected in non-agricultural sectors (municipal or industrial) in this area for 2011, and the transfer of agricultural water is the most likely alternative. Hence, the cooperation of the farmers, who are also members of irrigation associations, is important.

Figure 1 Annual isohyetal map of Taiwan.

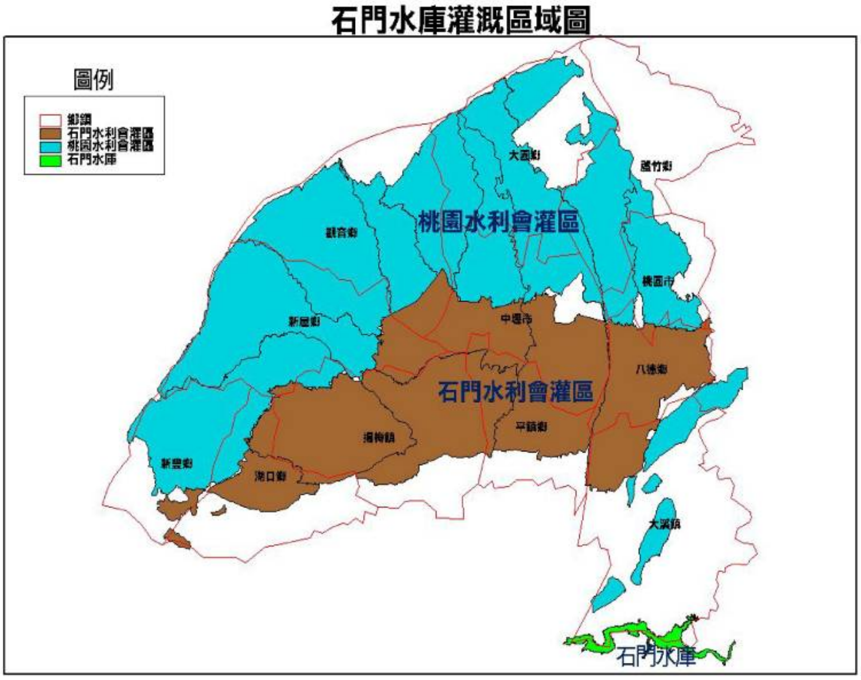

Figure 2 Irrigation associations in Tao-Yuan area.

2. CONTINGENT VALUATION METHOD

The Contingent Valuation Method (CVM), which combines the survey method and theory, is applied in this study. The method was commonly used in the 1970s, and studies on the evaluation of economic benefits of natural resources by CVM have since greatly produced the issuance of the Forest Law of UK and the President Order 12291 of US. In 1989, the CVM drew wide attention and credibility when the US Federal Court sentenced the indemnity based on CVM valuation in the Exxon oil spill incident. In 1993, an evaluation guideline for CVM was promulgated by the US Government as natural resources related public policies had commonly adopted CVM for decision support. Mitchell & Carson (1989) and Hutchinson et al. (1995) have pointed out that CVM could be a reliable valuation tool, provided that the questionnaire was properly designed.

The valuation of CVM could be estimated by using the Random Utility Model by Hanemann (1984) or the Expenditure Function Model by Cameron (1988). In this study, the closed-form dichotomous-choice questions were applied in the design of the questionnaire, and the agricultural transfer function was approached with the Expenditure Function Model.

In order to find the valuation of the farmers to release irrigation water through interviews, a farmers' hypothetical water market needs to be established first, and a bid function is then created according to individual socio-economic characteristics as well as bidding amount.

The price of general goods P_X, the price of domestic rice products P, and the income of M under the given level of agriculture protection Q are all independent variables that have an influence on the demand of the household. Following Freeman (1993), the indirect utility function U_0 of the household could be shown below

$$U_0 = V(P_X, P, Q, M) \tag{1}$$

In light of the fact that utility function is immeasurable while expenditure functions can be easily observed through the household behaviours, the correlation between the functions of indirect utility and expenditure can help convert Eq. (1) into the expenditure function below

$$E = E(P_X, P, Q, U_0) \tag{2}$$

Under the assumptions of a fixed utility level (U_0) and a constant price for $X(P_X)$, the interaction between P and Q can be reflected through the expenditure function. As proposed by Bradford (1970) in his individual bid curve theory, a certain trade-off exists between the rise in the prices of domestic rice products and the environmental multifunctionality values of paddy fields and thus creates the bid curve E_0. In other words, putting up with high prices of domestically produced rice products is necessary if paddy fields are to be maintained and the environmental multifunctionality benefit of paddy fields is to be enjoyed.

The environmental multifunctionality benefit of paddy fields increases as the axis of abscissa extends to the right and decreases as it moves to the left; the price of domestic agricultural products rises as the axis of ordinate stretches upward and drops as it goes down. Therefore, any given point along the bid curve E_0 will generate the same level of utility, making the bid curve the consumer's indifference curve between the environmental benefit and the agricultural prices. When the environmental function improves and reaches a higher level of $Q+$, consumers' willingness-to-pay (WTP) equals the difference between the later price and the original price, or the result of

P_1 minus P_0, or $CQ+$. This is also called the compensating surplus (C_S) for consumers. C_S denotes consumers' WTP to maintain the original bid level of E_0 if they are to enjoy a better environmental benefit level of $Q+$ as the environmental benefit changes, expressed in the function of expenditure below.

$$E(Q_0, P_0) = E_0 = E(Q+, P_0 - C_S) = E(Q+, P_0 - \text{WTP}) \quad (3)$$

The questionnaire of this study is designed to estimate the respondents' bid function $B\ (Q_0, Q_1, U_0, W)$ in response to the restored environmental benefit of agriculture in the hypothetical market as the economic benefit of environmental protection improves as shown below

$$B(Q_0, Q_1, U_0, W) = E(Q_0, U_0, W) - E(Q_1, U_0, W) \quad (4)$$

In other words, the bid function is the difference between two expenditure functions,

$$W = W(P, P_X, V) \quad (5)$$

where the independent variable V is the vector of the individual socio-economic characteristics.

The LIMDEP software is used in this study. The bid function can be approached in two ways: one, according to Cameron & James (1987) and assuming u takes the form of normal distribution with the mean of 0 and variation of 1, the bid function may be approached by the probit model; two, according to Cameron (1988) and assuming u takes the form of logistic distribution, the bid function can be approached by the logistic model. The two methods generate similar coefficients, but different scaling (Greene, 2000).

3. QUESTIONNAIRE SURVEY

3.1 Design of Questionnaire

The questionnaire comprises four parts.

The first part of the questionnaire has focussed on the farmers' agricultural production characteristics, including crop area, types, soils, and irrigation water sources, followed by the survey of farmers' response measures upon water shortage. The main purpose of the interview in this part is to investigate the production cost as well as the fallow and crop-change situations for the first and second crops. Major investigation content includes current rice-paddy cultivation area, fallow area, direct as well as indirect cost during cultivation process, crop-change types, and related information regarding cost as well as profit for the crop type. This information is needed for the verification and estimation of farmers' cost and profit concerns.

The second part of the questionnaire briefly describes the impact of variations of irrigation water on crop growth. Various hypothetical scenarios of various rice-paddy growth periods, as well as response measures upon water-shortages are designed in order for the verification and estimation on the category of farmers' intrinsic values. These hypothetical scenarios are:

Scenario 1: fallow conducted before rice seedlings,
Scenario 2: group fallow conducted before rice seedlings,
Scenario 3: incentive for group fallow,
Scenario 4: crop-change conducted before rice seedlings,
Scenario 5: fallow conducted upon rice seedlings (land preparation), and
Scenario 6: invest money which farmers are willing to improve water-intake facilities in the whole year.

The third part of the questionnaire is to interview the farmers for which sector among the government, domestic, or industrial sectors should be responsible for the compensation, and how the compensation ratio should be distributed if a portion of the agricultural water could be saved from the application of fallow or crop-change, and could be shifted to domestic or industrial sectors. The purpose of this interview is to investigate farmers' understanding about which sector should be responsible for the compensation when their agricultural water is shifted.

The last part of the questionnaire is to ask the social and economic characteristics of the farmers, their personal characteristics, which include sex, age, and education, as well as involvement in agricultural practice, whether full-time, part-time, or second job farmers, and number of family members, adults, expenses, income, etc.

3.2 Sampling Design and Survey

In the sampling design, the work stations from the two irrigation associations with potential water-shftiing pressures were selected for survey. A number of members in work stations are selected according to certain ratios by the Stratified Proportion Sampling Method. The interview targets on rice farmers and uses the method of one-on-one and face-to-face interview with lowest bias. A minimum of 200 sample are accepted under 95 per cent confidence interval and with below 5 per cent sampling error. As a result, a total of 300 samples were determined in the Tao-Yuan area in which six work stations from the Tao-Yuan Irrigation Association and four from Shih-Men Irrigation Association were allocated.

3.3 Number of Valid Questionnaire

In the Tao-Yuan Irrigation Association, 30 farmers from each of Hsin-Wu, Ta-Po, Ta-Chu, Tao-Yuan, Hu-Kou and Kuan-Yin work stations were interviewed with an expected total of 180 copies. However, the valid number of questionnaire is 159 due to Typhoon Terry, and the valid ratio is 88.3 per cent.

In the Shih-Men Irrigation Association, 30 farmers from each of Pa-Teh, Chung-Li, Fu-Kang, and Yang-Mei work stations were interviewed with expected total of 120 copies. The valid return is 113 with valid ratio of 94.2 per cent.

4. BASIC BACKGROUND OF INTERVIEWED RICE FARMERS

From the survey results, it was found that 98.2 per cent of the interviewed farmers were male, ages range from 26 to 86 with the average of 66, 86.94 per cent of the farmers were full-time, 4.05 per cent were part-time and 9.01 per cent were second-job.

Educationwise, uneducated and illiterate farmers were at 5.41 per cent, 56.31 per cent were educated till the elementary school level, and 19.37, 11.26, 1.35, 0.90, and 0 per cent for the junior high school, senior high school, vocational, college, as well as graduate school respectively.

The number of family members ranges from 1 to 26 with the average of 7 – 8, and the number of age over 18 is 5 – 6 on the average. Average monthly expenses are NT$32,748 (approximately US$936 when US$1 = NT$35), and monthly income is NT$50,275 (US$1,436) on the average.

5. CALCULATION OF INDIFFERENCE PRICE

5.1 First Crop of Rice

The results from the 272 questionnaires distributed in the Tao-Yuan area show that the average planting area for each farmer for the first crop is 1.186 hectares, average yield per hectare is 14,467 Taiwanese kilogram and average fallow area is 0.432 hectare with 0.0112 hectare used for crop-change to watermelon or cabbage.

As far as land rents and loans are concerned, NT$35,560 (US$1,016) per hectare of land rent is the average for the first crop in Tao-Yuan area, and NT$34,220 (US$977) for loans. In addition, there is another NT$49,600 for production cost.

5.2 Second Crop of Rice

The results from the 272 questionnaires in the Tao-Yuan area show that the average planting area for each farmer in the second crop is 1.003 hectares, average yield per hectare is 8,050 Taiwanese kilogram, and average fallow area is 0.488 hectare with 0.008 hectare used for crop-change to watermelon, sweet yam or cabbage.

Regarding land rents and loans, NT$38,023 (US$1,086) per hectare of land rent is collected on an average for the second crop in the Tao-Yuan area, and NT$7,500 (US$214) for loans. In addition, there is another NT$43,218 for production cost.

6. VERIFICATION ANALYSIS OF INTRINSIC VALUES FOR RICE FARMERS

In association with the scenarios, the following conclusions were made from the results of the questionnaire survey.

(1) *Fallow Conducted before Seedlings*

   (1) For the first crop, the WTA intrinsic compensation value for the rice farmers to conduct fallow, owing to water-shift is NT$54,864 (approximately US$1,568 when US$1 = NT$35) per hectare.

(2) For the second crop, the WTA intrinsic compensation value is NT$53,969 (US$1,542) per hectare.

(2) *Crop-change Conducted before Seedlings*
  (1) For the first crop, the willing-to-accept (WTA) intrinsic compensation value for the rice farmers to conduct crop-change owing to water-shift is NT$39,641 (US$1,133) per hectare.
  (2) For the second crop, the WTA intrinsic compensation value is NT$37,822 (US$1,081) per hectare.

(3) *Fallow Conducted upon Seedlings*
  (1) For the first crop, the WTA intrinsic compensation value for the rice farmers to conduct fallow owing to water-shift is NT$78,334 (US$2,238) per hectare.
  (2) For the second crop, the WTA intrinsic compensation value is NT$66,940 (US$1,913) per hectare.

(4) *Group fallow conducted before seedlings.* For either crop, the WTA intrinsic extra incentive value for the rice farmers to conduct group fallow owing to water-shift is NT$8,259 (US$236) per hectare.

(5) *Group fallow incentive.* The estimated result is negative, which shows that farmers in Tao-Yuan area are not willing to share extra loading for group fallow.

(6) *Average investment which farmers are willing to improve water-intake facilities in the whole year.* Farmers in Tao-Yuan area are willing to invest NT$144,156 (US$4,119)/hectare to avoid water-shortage risk. The high value could be related to the recent water breakdown.

7. CONCLUSIONS

From the evaluation results of the cost-benefit aspect and the intrinsic benefit aspect, it is found that the compensation value of conducting fallow or crop-change from the cost-benefit aspect is higher than that from farmers' intrinsic benefit aspect. Comparing these results with the socio-economic structures of the interviewed farmers, it is concluded that:

(1) The average age of the interviewed farmers in the study area is 64, which is considered to be old, and their farming intention is comparatively lower.

(2) In the cost-benefit aspect, only the ratio between the compensation for fallow or crop-change and actual farming income was considered. However, in the intrinsic benefit aspect, the additional non-agricultural income after conducting fallow or crop-change was very likely to be included in the farmers' considerations.

(3) The results could provide for references in policy planning. If the planning for transferring agricultural water could be initiated prior to the occurrence of droughts, it is believed that the policy cost would be much lower.

REFERENCES

Boyle, K.J. and R.C. Bishop, 'Welfare Measurements Using Contingent Valuation: A Comparison of Techniques', *Journal of the American Agricultural Association,* February 1988, 20–28.

Cheng, C.C.; Lee, Y.C.; Jan, M.Y.; Chiueh, Y.W. et al., 'Study on the Enhancement of Water Resources Utilization by the Adjustment of Cultivation on Farm-Lands in Tao-Yuan Area', presented at the Ching-Yun University, Water Resources Planning Institute, Taiwan. 2005.

Chiueh, Y.W. and M.C. Chen, 'The Establishment of Local Water Resources Distribution Mechanism—Theoretical and Verification Model of Water Bank', *Journal of Agricultural Economics*, Vol. 77. 2005, 171–202.

Chiueh, Ya-wen, 'Evaluation the Compensation to Farmers for Paddy Irrigation Water Transferring in Kaohsiung Area', *Journal of Hsinchu University of Education*. 2007.

Goldar, B. and S. Misra, 'Valuation of Environmental Goods: Correcting for Bias in Contingent Valuation Studies Based on Willingness-to-Accept', *American Journal of Agricultural Economics,* Vol. 83. 2001, 50–156.

Hanemann, Michael W., 'Willingness To Pay and Willingness to Accept: How Much Can They Differ?', *The American Economic Review*, Vol. 81(3), June 1991, 635–647.

附　錄　三

第 **20** 屆國際灌溉排水研討大會論文發表

Intelligent control for modeling multiple purpose reservoir operation in Taiwan

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Twentieth Congress
Lahore 2008

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INTELLIGENT CONTROL FOR MODELING MULTIPLE PURPOSE RESERVOIR OPERATION IN TAIWAN

SYSTEME DE CONTROLE INTELLIGENT POUR MODELISATION DE L'EXPLOITATION DU RESERVOIR A BUT MULTIPLE AU TAIWAN

ABSTRACT

Reservoir operation has emerged as an important and difficult task to be studied for the sustainable utilization of water resources in Taiwan. Intelligent control is a state-of-the-art technology that resembles the human thinking process in decision making and strategy learning. The intelligent control system presented here combines two major procedures: the genetic algorithm (GA) and the adaptive network-based fuzzy inference system (ANFIS). The GA is used to search the optimal reservoir operating histogram, which can be recognized as the base of optimal input-output

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training pattern for the intelligent control system. From these training patterns, the ANFIS is then built to construct a suitable network and then estimate the optimal water release according to the current reservoir watermark and inflow situation. Analysis will be based on the Shihmen reservoir, Taiwan, which is a multiple purpose reservoir over forty years old. The research will address the methodology and the benefit of efficiency and effectiveness of the proposed method. The results demonstrate that this new approach, in comparison with the currently used M-5 rule curves, has superior performance with regard to the prediction of total water deficit and Generalized Shortage Index (GSI).

RESUME

L'exploitation du réservoir devient maintenant une tâche difficile qu'il est nécessaire d'étudier en priorité pour l'utilisation durable des ressources en eau au Taiwan. Le système de contrôle intelligent est une technologie de l'Etat-de-l'Art qui ressemble au processus de réflexion de l'homme sur la prise de décision et la stratégie à apprendre. Nous présentons ici une méthodologie de contrôle intelligent pour l'exploitation du réservoir. Ce système combine deux procédures importantes : L'Algorithme Génétique (GA) et le Système Logique d'Inférence imprécis à base de réseau capable d'adaptation (ANFIS).

Le GA est utilisé pour chercher l'histogramme de l'exploitation optimale du réservoir qui peut être pris comme base du processus de formation optimale entrée-sortie pour le système de contrôle intelligent. Le ANFIS est ensuite mis en place pour créer un réseau approprié, et faire une évaluation du lâcher optimal de l'eau selon la ligne d'eau et le débit d'entrée du réservoir. L'analyse sera faite en prenant comme base le réservoir à but multiple de Shimen du Taiwan qui date de quarante années. La recherche portera sur la méthodologie et le bénéfice de l'efficience et de l'efficacité de la méthode proposée.

Les résultats montrent que cette nouvelle méthode s'avère meilleure par rapport à « M-5 Rule Curve » pour ce qui concerne la prédiction du déficit total de l'eau et l'Index Général d'Insuffisance (GSI).

1. INTRODUCTION

Taiwan is known as Formosa, which means a beautiful and plentiful island. The annual average rainfall is around 2,500 mm with high seasonal variability. Compared with other countries, Taiwan should have plentiful water, but owing to the characteristics of Taiwan's watersheds, most of the water runs directly into the sea, leaving only 20 per cent water to be stored for use. Water resources are important issues in Taiwan because of the continuous increase in water demand accompanying economic growth. Consequently, reservoirs have become the most important and effective man-made water storage facilities for distributing water among different users in Taiwan. Multiple purpose storage reservoirs play a pivotal role in integrated water resources management. They not only provide domestic and industrial water supply, hydroelectric energy and irrigation, but also smooth out extreme inflows to mitigate flood or drought. Therefore, it is very important to determine an optimal reservoir operating schedule for effective water distribution. Real-time reservoir operation is a continuous decision-making process under the inherent variability of natural phenomenon. The operation must be based on the operating policy or predefined rules and cannot violate a great number of constrain to try to make the best satisfaction for all the users. Apparently, this task can be very complex and difficult.

Intelligent control is a state-of-the-art technology that resembles the human thinking process, and its outstanding ability has been well-recognized in controlling complex systems. In the last decade, artificial intelligence (AI) techniques, such as artificial neural networks (ANN), genetic algorithms (GA) and fuzzy theory have also been increasingly applied to tackle some of the issues related to hydrological and water resources systems (Chang et al., 2004; Maier and Dandy, 2001; Chang et al., 2007). Recently, some attempts have been made to address storage reservoir optimization and operation through AI techniques. Raman and Chandramouli (1996) and Chandramouli and Raman (2001) proposed the use of ANN to generate operational strategies based on the optimal results from a deterministic Dynamic Programming (DP) model, for the case of single and multiple reservoir systems, respectively. Cancellier et al. (2002) developed a neural network model to derive the operational strategies for an irrigation supply reservoir. The authors (Chang and Chang, 2001 and Chang et al., 2005) developed an Intelligent Reservoir Operating system, where the genetic algorithm is used to search optimal reservoir operating histogram, and based on these training patterns, a fuzzy inference neural network is then built to construct a suitable network to estimate optimal water release according to the current reservoir watermark and inflow situation. Chaves and Chang (2008) presented intelligent reservoir operation systems based on evolving artificial neural networks.

In this paper, an intelligent system is presented and applied for the optimizing operation of a multiple purpose reservoir in Taiwan. The methodology of intelligent control system and its included theorems, i.e. GA and ANFIS are first briefly introduced. In section three, the results of different types of models are presented and compared with those of traditional M-5 rule curves operation. Last, a conclusion of this study is given.

2. METHODOLOGY

Artificial Intelligence is a branch of science which deals with helping machines find solutions to complex problems in a more human-like fashion. This generally involves borrowing characteristics from human intelligence, and applying them as algorithms in a computer friendly way. An artificial intelligence system could be built through a number of emerging information technologies inspired by the qualitative nature of biologically based information processing. An intelligent system should include the ability to learn and to execute. Consequently, an intelligent system has its own main objective, as well as senses and actuators. To reach its objective it chooses an action based on its experiences, and to learn by generalizing the experiences it has stored in its memories. In this study, we proposed an intelligent reservoir operation strategy, which includes GA and artificial neural network. GA is a heuristic iterative search method that attempts to find the best solution in a given decision space based on the mechanics of natural selection and genetics. ANFIS can help extract the fuzzy if-then rules from input-output data pairs when expert knowledge is not directly available. In the following sub-sections we present the main features of the techniques used here (GA and ANFIS).

2.1 Genetic Algorithm

Evolutionary computation applies biologically inspired concepts such as populations, mutation and survival of the fittest to generate increasingly better solutions to the problem. One of the most popular evolutionary optimization techniques is surely the GA. In recent years, GA has been widely used to solve a great number of hydrological and water resources related problems (Sharif and Wardlaw, 2000; Chang et al., 2005). Some of the advantages of GA models are: (a) a powerful capability to deal with non-linear systems global optimization, and (b) a robust ability to solve highly non-linear, non-convex problems. Normally, GA uses four main types of operators to create, at each new GA generation, a new GA population based on the previous one. These operators are elitism, selection, crossover and mutation. Elitism operators can guarantee that the best individuals of a population will proceed automatically to the next generation. Selection operators are responsible for the selection of individuals (the so-called 'parents') in which the following two operators are applied. Crossover operators combine two 'parents' to form children for the next generation. And finally, mutation operators apply random changes to individual 'parents' to generate 'children' for the next generation.

2.2 Adaptive Network-based Fuzzy Inference Systems (ANFIS)

The ANFIS model was proposed by Jang (1993) and has been applied successfully to many problems (Chang and Chang, 2001). It can serve as a basis for constructing a set of fuzzy if-then rules with appropriate membership functions to generate the preliminary stipulated input-output pairs. This section briefly introduces the basics and architecture of the model. An adaptive network is a multilayer feed-forward network with supervised learning scheme. The functions corresponding to nodes of the same layer are similar. For simplicity, the first-order Sugeno fuzzy model is considered as a fuzzy inference system. Suppose that the model contains two inputs x and y, one output F and four fuzzy if-then rules.

Rule 1: If x is A_1 and y is B_1, then $f_1 = p_1x + q_1y + r_1$;

Rule 2: If x is A_1 and y is B_2, then $f_2 = p_2x + q_2y + r_2$;

Rule 3: If x is A_2 and y is B_1, then $f_3 = p_3x + q_3y + r_3$;

Rule 4: If x is A_2 and y is B_2, then $f_4 = p_4x + q_4y + r_4$.

The simplified ANFIS architecture is shown in Figure 1. It has five layers, namely (1) input nodes, (2) rule nodes, where the T-norm operators are employed to perform the multiplications of the incoming signals to generate the outputs of this layer, (3) average nodes, (4) consequent nodes, and (5) output nodes, where a defuzzification inference is used to transform the fuzzy results of this model into a crisp output.

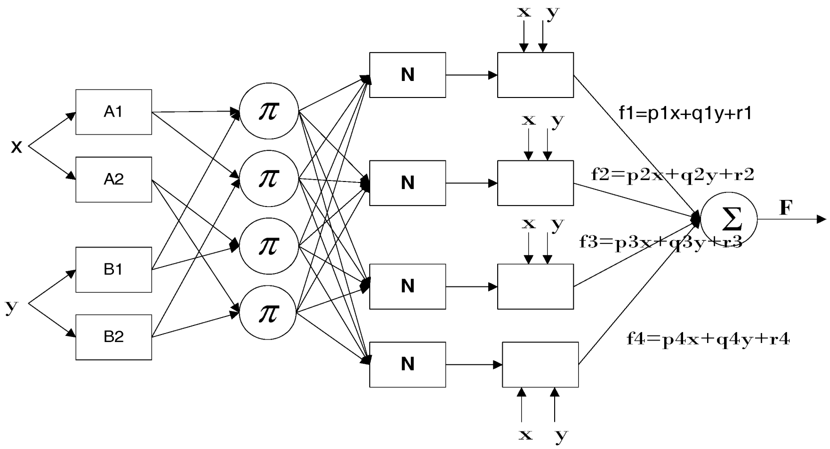

Figure 1 ANFIS architecture for two-input Sugeno fuzzy model with four rules.

3. APPLICATION: SHIHMEN RESERVOIR

The above intelligent control is applied to the operation of Shihmen reservoir, which is one of the largest water reservoirs in Taiwan. The Shihmen reservoir, located upstream of the Tahan river (Figure 2), is a multipurpose reservoir for irrigation, hydroelectric energy, public water supply, flood control and tourism. The watershed covers an area of 763.4 km^2 with storage capacity of 2.51×10^8 m^3. Inflow data for the past thirty-six years are obtained. A period of ten days, which is a traditional reference time frame in the Chinese agricultural society, is used as a time step.

According to this scale, each month has three time steps, and every year has thirty-six. Consequently, we have 1296 (36 × 36) inflow records. In the case study, 1.2 times the water demand in the year of 2001 is adopted to represent the requirement for the simulation period, a total of 1329×10^6 m^3/year.

3.1 Intelligent Control of Reservoir Operation

To build up an intelligent control system of reservoir operation, the system objective and its constraints shown must be identified first. For long-term reservoir operation, water shortage is considered to be the main index for assessing reservoir performance. A water surplus, on the other hand, is usually ignored, since the water surplus happens mostly during typhoons

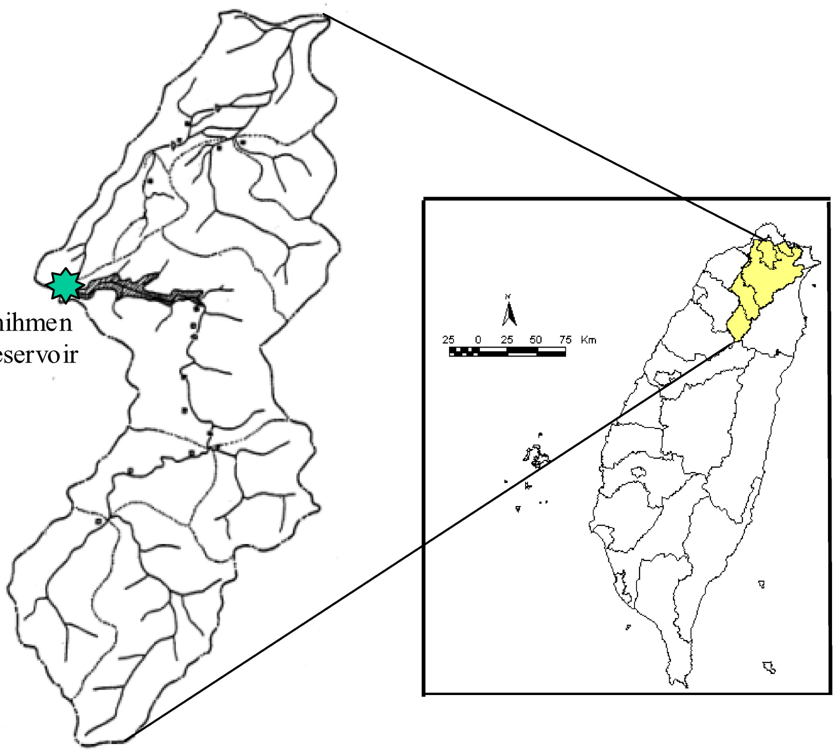

Figure 2 The location of Shihmen reservoir.

and lasts for less than 72 hours. In this study, we use water shortage to assess the long-term performance of reservoir operation; hence, the objective function of reservoir operation is defined as

$$\min(objFunc) = \min\left(\sum_{i=1}^{36}\left[\max\left(0, \frac{D_{i}' - O_i}{D_i}\right)\right]^2 \times n_i\right) \quad \text{... (1)}$$

The mass balance equation and the physical or boundary conditions for reservoir operation are discussed as follows.

(1) Mass Balance Equation (water balance at reservoir) or continuity equation

$$S_i = S_{i-1} + I_i - O_i$$

(2) The initial storage $S_0 = 50$

(3) The variable S_i can vary only between the maximum and the dead storage of the reservoir $0 \le S_i \le 235.745$

(4) Conditions on final stage of reservoir storage $0.9S_0 \le S_{36} \le 1.1S_0$

where D_i is the water demand of the i^{th} ten-day period,

O_i is the outflow of the i^{th} ten-day period;

S_i is the effective storage of the i^{th} ten-day period;

I_i is the inflow of the i^{th} ten-day period;

n_i is the number of ten-day periods in a continuous deficit in the i^{th} ten-day period. The purpose of the variable, n_i in the objective function is to enlarge the effect of continuous deficiency and to avoid continuously occurring deficiency.

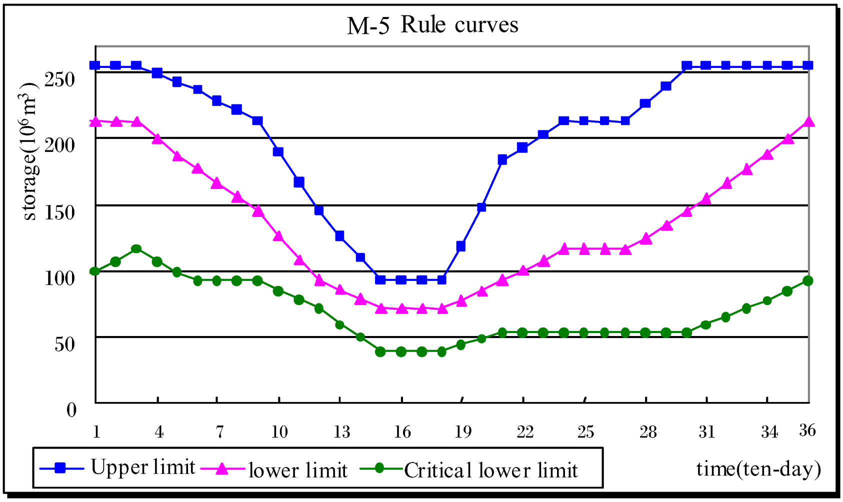

Figure 3 The M-5 rule curves of Shihmen Reservoir.

In Taiwan, most reservoirs are operated according to rule curves, which were obtained through intensity simulation analysis based on inflow data and water demands. Because the rule curve is the official way for guiding the reservoir operation, it is crucial to learn its performance and using the performance as the base of comparison. The operation curves (M-5 rule curves) of Shihmen reservoir are shown in Figure 3. The 36 years of historical inflow data are divided into three independent sets: training, verification, and testing sets, respectively. To derive suitable input-output patterns, the GA method is applied and presented as follows.

The historical inflow data are obtained from the Water Resource Agency, Taiwan. The GA is first employed to search the optimal release series based on a specific water demand series and the inflow series in each year during the training period (1966–1988). The optimal results of the GA and another result of operating by traditional M-5 rule curves are summarized in Tables 1 and 2 . It can be found that GA has much better performance in terms of lower GSI (Generalized Shortage Index, defined in the following Equation 2) value than M-5. Consequently, the optimal reservoir operating histogram obtained from GA can be recognized as the training pattern in the next step.

3.2 Application of the ANFIS

Given the input-output patterns from GA, the ANFIS models are built to create the fuzzy inference system and then to estimate the optimal water release based on given input patterns. In the GA case, there are five input variables. Since each variable might have several values (in terms of rule), and each rule includes several parameters of membership function in layer 2, these will be a huge number of parameters to determine as the rule is increased. To solve this problem, the subtractive fuzzy clustering is used to establish the rule base relationship between the input and output variables (detailed explanation can be found in Chang and Chang, 2001). Several numbers of clustering have been evaluated. The results are shown in Figure 4, which indicates 17 cluster rules can have lowest RMSE (root mean square

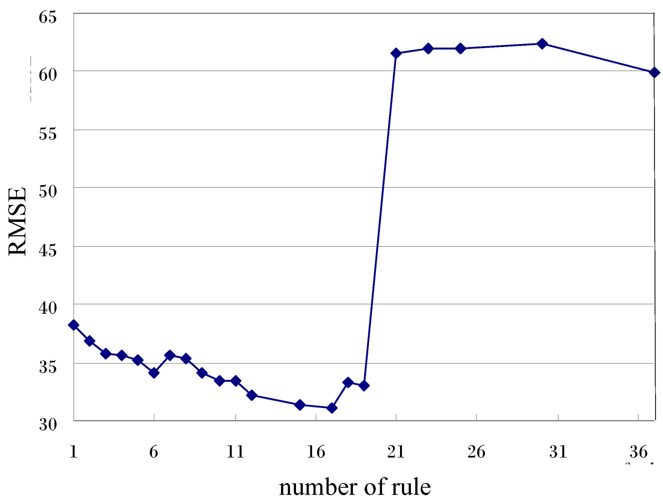

Figure 4 The relationship between RMSE of the training procedure and number of fuzzy rules in ANFIS models.

error). Since there are only 17 clusters, the inference system becomes quite simple. That is as we give the five input variables' values, we can calculate their membership function value for each cluster, and then through the fuzzy inference system the result can be obtained.

4. RESULTS

To construct and test the ANFIS model, the 36 years, (1966~2001) historical inflow data are divided into three independent sets: training, verification, and testing, respectively. Parameters and weights of these models are determined through an optimizing process based on training data set. The best interesting system structure and corresponding parameters and weights are chosen based on verification data set. Without any modification, the reliabilities of these systems are investigated by testing the data set.

For comparison, the simulation results of the M-5 rule curves and the optimal searching results by GA are given. The overall results of M-5 rule curves, GA, and ANFIS are presented in Tables 1 and 2. The results show that the ANFIS model could only be trained to obtain similar results to the GA method.

We believe this is mainly because the optimal result obtained by GA is based on being given the full series of input patterns to search the optimal operating strategy (output) for the series, while the ANFIS model is only based on previous and current (t–1 and t) inflow and water level information. Consequently, it is reasonable the ANFIS could only produce similar results to the GA method. The root mean square errors (RMSE) are within the range of 20 to 40 in all cases. To evaluate the model performance in terms of the severity and length of water deficit, the generalized shortage index (GSI) (Hsu, 1995) is used and is shown as follows.

$$DPD = \sum (DDR(\%) \times NDC) \quad \text{... (2)}$$

$$GSI = \frac{100}{N} \sum_{i=1}^{N} \left(\frac{DPD_i}{100 \times DY_i} \right)^k$$

where *DPD:* deficit per cent ten-day period index

DDR: ten-day period deficit rate

NDC: number of ten-day period in a continuous deficit

DY: number of ten-day period in a year, i.e. 36

N: number of sample years

k: coefficient, usually taken as 2.

In Table 2, it is easy to find that the ANFIS model produces much better performance in terms of small GSI values than the M-5 rule curves in all cases. These results demonstrate that this new approach, in comparison with the traditional M-5 rule curves, has superior performance with regard to the generalized shortage index.

From Tables 1 and 2, we find results obtained from GA and ANFIS models are comparable in all cases. These results seem to provide interesting evidence that the ANFIS model has the ability to learn from GA input-output pattern.

Table 1 The results of M-5, GA and ANFIS models in different stages

Set	Years	M5	GA	ANFIS
Training	1966–1988	394	33	157
Verification	1989–1994	952	54	238
Testing	1995–2001	633	67	171

Table 2 The results of three ANFIS models and M-5 rule curves in testing stage

Year	M-5 rule curves			ANFIS		
	(1)	(2)	(3)	(1)	(2)	(3)
1995	42	3	0.74	249	21	32.3
1996	602	32	4256	611	31	417.3
1997	218	12	66.0	359	21	249.1
1998	35	8	3.13	258	17	32.1
1999	290	14	49.0	457	21	378.7
2000	119	13	56.3	330	24	44.7
2001	11	1	0	292	23	45.9

(1) Total water shortage (10^6 m^3)

(2) The number of water shortage period within the 36 periods of one year

(3) GSI

Artificial Intelligence (AI) techniques, such as artificial neural networks, fuzzy theorems and genetic algorithms have been used in the last decades for constructing intelligent systems for optimal operational strategies. A methodology for the construction of intelligent systems for reservoir operation has been developed in this study. The system is based on two popularly used AI techniques: the genetic algorithm and the adaptive network-based fuzzy inference system (ANFIS). The GA is used to search the optimal reservoir operating histogram based on a given inflow series which can be recognized as the base of input-output training patterns in the next step. The ANFIS is then built to create the fuzzy inference system, to construct the suitable structure and parameters, and to estimate the optimal water release according to the reservoir depth and inflow situation.

Multiple purpose reservoirs play a pivotal role in integrated water resources management. The Shihmen reservoir is a multiple purpose reservoir for irrigation, hydroelectric energy, public water supply, flood control and tourism. The practicability and effectiveness of the proposed approach is tested on the operation of the Shihmen reservoir. For the purpose of comparison, the simulation results by the traditional M-5 rule curve method are obtained. The results demonstrate that the developed intelligent control system produce much better performance, in terms of lower GSI values than the M-5 rule curves. The intelligent control system can learn to make decisions for reservoir operation through the optimal input-output training patterns obtained from GA. The results suggest that given the reasonable initial sets, GA has produced superior results. Learning from the input-output patterns obtained from GA, the ANFIS model can estimate the reservoir release in predefined conditions. The ANFIS model, once given sufficient information to construct the fuzzy rules, has more efficient operation of the reservoir than the rule curve based model. Our study of the Shihmen reservoir operation demonstrates both the intelligent capability and superior performance of this framework in contrast to the traditional rule curve operating strategy.

5. SUMMARY AND CONCLUSIONS

Taiwan is known as Formosa, which means a beautiful and plentiful island. It is located in the North Pacific Ocean subtropical jet stream monsoon district with a land area of 36,000 km^2. The annual average rainfall is around 2,500 mm with high seasonal variability. Compared with other countries, Taiwan should have plentiful water. But owing to the characteristics of Taiwan's watersheds (erodible soil, uneven rainfall, steep slopes and high mountains), most of the river flows run directly into the sea, leave only 20 per cent of it to be stored for use. Water resources is becoming an important issue in Taiwan because of the continuous increase in water demand due to economic growth and strong opposition to the construction of new reservoirs following the rising awareness about environmental protection. At the same time, the serious reduction in storage capacity of existing reservoirs caused by sedimentation makes water resources management even more complicated. Unless reservoir operation can be improved drastically, water shortages will occur more frequently. It is thus natural that reservoir operation has emerged as an urgent and difficult task to be studied for the sustainable utilization of water resources in Taiwan.

Artificial intelligence (AI) is a state-of-the-art technology that resembles the human thinking process in decision making and strategy learning, and it has been well-recognized for its outstanding ability in controlling complex systems. AI techniques, such as artificial neural networks (ANN), fuzzy theorems and genetic algorithms (GA) have been used in the last decades for constructing intelligent systems for optimal operational strategies. We propose an intelligent control methodology for reservoir operation. The methodology includes two major processes—the knowledge acquired and implemented and the inference system by using the genetic algorithm (GA), and the adaptive network-based fuzzy inference system (ANFIS). The GA is based on Darwinian natural selection with the mechanisms of population genetics. Now in widespread use for computational evolution, it has also been applied to solve a great number of water resource problems. The GA was used to search the optimal reservoir operating histogram based on a given inflow series, which can be recognized as the base of optimal input-output training pattern for the intelligent control system. The ANFIS is a five-layer feedforward network, which uses neural network learning algorithms coupled with fuzzy reasoning to map an input space to an output space. The major advantage of this network is that it can tune the complicated conversion of human intelligence to fuzzy systems. From these training patterns, the ANFIS was then used to implement the knowledge, to create the fuzzy inference system, to form the suitable network and then estimate the optimal release according to the current reservoir watermark and inflow situation.

Analysis was based on the case of Shihmen reservoir, Taiwan. The Shihmen reservoir operates for the purposes of water supply for irrigation, industrial and domestic uses, flood control, hydropower generation, and recreation facilities. Its active storage volume is approximately 2.35×10^8 m^3. Inflow data for the past thirty-six years (1966~2001) are obtained. A period of ten days is used as a time step. To construct and test the ANFIS model, the 36 years historical inflow data are divided into three independent sets: training, verification, and testing, respectively. The results demonstrate that this new approach, in comparison with the M-5 rule curves, has superior performance with regard to the prediction of total water deficit and Generalized Shortage Index (GSI). The intelligent control system can learn to make decisions for reservoir operation through the optimal input-output training patterns obtained from GA and the fuzzy rule base extracted from M-5 rule curves regulation. The results suggest that the ANFIS model has good ability to learn from different sources of knowledge, and the system can be more intelligent for reservoir operation, if more information is involved.

ACKNOWLEDGEMENT

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REFERENCES

Cancelliere A., G. Giuliano A. Ancarani. 2002. Rossi G. A neural network approach for deriving irrigation reservoir operating rules. Water Resources Management. 16(1): 71–88.

Chandramouli V., H. Raman. 2001. Multireservoir modeling with dynamic programming and neural network. Journal of Water Resources Planning and Management. 127(2): 89–98.

Chaves P., Chang F.J. 2008. Intelligent reservoir operation system based on evolving artificial neural networks, Advances in Water Resources. (In press).

Chang F.J., L., Chen L.C. Chang. 2005. Optimizing the reservoir operating rule curves by genetic algorithms, Hydrol Process. 19: 2277–2289.

Chang F.J., Y.M., L.C. Chiang. 2007. Multi-step-ahead neural networks for flood forecasting. Hydrological Sciences Journal. 52(1): 114–130.

Chang Y.T, L.C. Chang, F.J. Chang. 2005. Intelligent control for modeling of real-time reservoir operation, part II: artificial neural network with operating rule curves. Hydrol Process. 19(7): 1431–1444.

Chang L.C., F.J. Chang. 2001. Intelligent control for modeling of real-time reservoir operation. Hydrol Process. 15(9): 1621–1634.

Chang Y.M., L.C. Chang, F.J. Chang. 2004. Comparison of static-feedforward and dynamic-feedback neural networks for rainfall-runoff modelling, Journal of Hydrology. 290(3-4): 297–311:

Jang, J.S.R. 1993. ANFIS: Adaptive-Network-Based Fuzzy Inference System. IEEE Trans. on Syst. Man and Cyber. Vol. 23, No. 3: 665–685.

Maier, H.R., G.C. Dandy. 2001. Neural network based modeling of environmental variables: A systematic approach. Mathematical and Computer Modeling. 33: 669–682.

Raman H., V. Chandramouli. 1996. Deriving a general operating policy for reservoir using neural network. Journal of Water Resources Planning and Management. 122(5): 342–347.

Sharif, M., R. Wardlaw. 2000. Multireservoir systems optimization using genetic algorithms: case study. Journal of Computing in Civil Engineering. 14(4): 255–263.

附　錄　四

第 **20** 屆國際灌溉排水研討大會論文發表

Viewing GMS Program from International Water Law Systems

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（李方中 博士）

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Fang-Chung Lee[1]

VIEWING GMS PROGRAMME FROM INTERNATIONAL WATER LAW SYSTEMS

PROGRAMME DE GMS ENVISAGE DANS LE CADRE DE DROIT A L'USAGE D'EAU INTERNATIONALE

ABSTRACT

The Greater Mekong Subregion (GMS) comprises six riparian countries of the Mekong River. They are the Kingdom of Cambodia, the People's Republic of China (Yunnan Province and Guangxi Zhuang Autonomous Region), the Lao People's Democratic Republic, the Union of Myanmar, the Kingdom of Thailand and the Socialist Republic of Viet Nam (see Figure 1). In 1992, the six countries, supported by the Asian Development Bank (ADB), agreed to enhance a programme of economic cooperation in this subregion (Nguyen, 1999). One of the main achievements of the GMS programme is the signing up of the GMS Cross-Border Transport Agreement (CBTA) and the Inter-governmental Agreement on Regional Power Trade (IGA) and their

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subsequent developments. The CBTA entered into came into force in December 2003, while the IGA before the First Meeting of the Regional Power Trade Coordination Committee (RPTCC-1) held in July 2004.

Activities behind the agreements, which related to direct uses of trans-boundary rivers, are the main concern of this paper. The main activities concerned are navigation in cross-border transports and construction and operation of cascade dams along with hydropower plants. Further, there could be interactions between these activities and such actions depend on the conditions of the activities. For example, a dam or a bridge on the mainstream could affect navigation; however, a dam with a lock could be beneficial to navigate upstream to a certain distance.

RESUME

La Sous-région de Mékong Supérieur (GMS) comporte six pays riverains-Royaume du Cambodge, République Populaire de Chine (province de Yunnan et région autonome de Guangxi Zhuang), République Démocratique Populaire de Lao, Union de Myanmar, Royaume de Thaïlande et République Socialiste de Vietnam (voir Figure 1). En 1992, ces six pays ont entrepris en commun un programme pour promouvoir la coopération économique dans cette région (Nguyen, 1999), cette initiative étant soutenue par la Banque du Développement Asiatique (BDA). Les principales activités du GMS étaient marquées par la signature de l'Accord de transport transfrontalier (CBTA), de l'Accord intergouvernemental de commerce régional d'énergie (IGA) et les activités connexes. Le CBTA est entré en vigueur en décembre 2003, alors que l'IGA avant la première réunion du Comité régional de coordination du commerce d'énergie (RPTCC-1) tenue en juillet 2004.

Les activités entreprises dans le cadre de ces accords concernent directement l'utilisation transfrontalière des rivières, ce qui est la préoccupation de ce rapport. Parmi les activités principales, il convient de signaler la navigation transfrontalière, la construction et l'exploitation des barrages de cascade ainsi que des usines d'énergie hydraulique. De plus, il pourrait y avoir des interactions entre ces activités, ces interactions dépendant surtout de la nature des activités. Par exemple, un barrage ou un pont sur le cours principal peut affecter la navigation; cependant, un barrage pourvu d'un dock peut être utile à la navigation en amont sur une certaine distance.

1. MEKONG RIVER BASIN

The Mekong River Basin has three parts, namely, the Lower Mekong Basin, the Mekong Basin (including the Lancangjiang Basin) and the GMS. The Lower Mekong Basin is located in the territories of four downstream riparian countries including Cambodia, Laos, Thailand and Viet Nam. These four countries had established the Committee for the Coordination of Investigations of the Lower Mekong Basin (the Mekong Committee) in 1957, and nearly forty years later, signed the Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin (ACSD) and strengthened the Mekong Committee into the Mekong River Commission (MRC) in 1995, with a much broader mandate. In space, the Lower Mekong Basin is a sub-set of the Mekong Basin formed by nature, and the natural Mekong Basin is within the area of the GMS.

2. TRANSBOUNDARY RIVERS IN GMS

There are many transboundary rivers in the GMS. The most significant ones are the Mekong River (the river position in China named as Lancang-jiang), the Song Hong (also known as the Red River with the river position in China called as Yuanjiang) and the Salween River (the section in China named as Nujiang).

The Mekong River is the biggest river in the subregion and ranked the sixth largest river in the world. The upper river, Lancangjiang, originates from Qinghai Province and then flows mainly in southern direction falling through or by Tibet, Yunnan, Myanmar, Thailand, Laos, Cambodia and Viet Nam, finally falling into the South China Sea. The area of the estuarine portion of the Mekong in Viet Nam is also called the Mekong Delta. The Yuanjiang commences from Yunnan and flows south-east direction through northern part of Viet Nam named as Song Hong into the Gulf of Tonkin. The Salween River (Nujiang) starts from Tibet and runs directly south through Yunnan and Myanmar and into the Gulf of Martaban.

3. PRESENT ACTIVITIES ON TRANSBOUNDARY RIVERS

According to Articles 2 and 8 of the CBTA, there are activities of crossing border by boats and the people of the basin countries transit freely through territories between the six states. Both activities relate to navigation.

Adopted from website of the Asian Development Bank
http://www.adb.org/GMS/img/gmsmap2007.jpg

Figure 1 Map of the Greater Mekong Subregion.

Navigation in Mekong developed fast. Table 1 shows deadweight tonnages for different water levels of the Lower Mekong from river mouth to Houayxay (Wang et al., 2007). The tonnage is over 2,000 DWT for the whole year between Phnom Penh and the river mouth. When the water level is at middle or high, it is up to 400 DWT between Kratie and Kombong Cham in the territory of Cambodia and 300 DWT between Vientiane and Khanthabouly in the section that borders between Thailand and Laos. However, it should be noted that the Khone Falls in Laos near its border with Cambodia, with a total fall of 21 meters in segmented cascades, located 5 kilometers upstream from Veunekham and 736 kilometers from the river mouth, has ended all ideas of navigating from the river mouth straight up to China. To connect the development, China proposed the first navigation chart in 2007 ranging from the No. 243 boundary stone on the China–Myanmar border along the Mekong to Houayxay to improve the safety of navigation.

About the IGA, the GMS members aim to coordinate and cooperate to provide reliable electricity through area grids with minimized costs within the subregion. Even before the signing of the IGA in 2002, certain electricity cooperation projects between GMS members had already been set forth. For example, in 2000 China and Thailand signed an investment agreement on the construction and operation of the Jinghong Hydropower Plant sited on Lancangjiang. Regional power trades have already been in practice. For instance, China has successfully sent electricity through a 110 kV wire to Viet Nam since 2004 (Li, 2006).

There are more plans for hydropower plants in the subregion. Two hydropower plants, namely, Manwan and Dachaosan have been constructed in china, along the Lancangjiang. Xiaowan as well as Jinghong are under construction, and Gongguoqiao, Nuozhadu, Ganlanba and Mengsong have been planned. There is a plan for constructing total of 15,200 MW installed capacity and 67.629 million MW.h annual power production. The total volume of the related dams is 40.87 billion m^3. Details of the above hydropower plants are shown in Table 2. Compared to the 23,000 MW hydropower potential of the Lancangjiang, the Mekong has 30,000 MW in potential, where 13,000 MW is on the mainstream. There are 11 existing dams in the tributaries of the Mekong River, while there is not any on the mainstream. The total volume of the existing dams is 13.69 billion m^3 and the total installed capacity is only 2,371 MW. This is less than 14 per cent of its 17,000 MW potential. Compared to the total potential of the Mekong River, the developed capacity is less than 8 per cent (Zhao et al., 2000).

Table 1 Deadweight tonnages for different water levels of Lower Mekong

Place	Houay-xay	Luang-prabang	Vien-tiane	Khantha-bouly	Pakse	Veune-kham	Stung Treng	Kratie	Kombong Cham	Phnom Penh	River Mouth
DWT for H/M Water Level	100	60	300	80	50	70	70	400	–	5,000	
DWT for Low Water Level	70	15	150	10	20	15	20	80	2,000	3,000	

1. DWT: Deadweight Tonnage
2. Source: Zhihong Wang et al., *Mekong River*, Linkingbooks, Taipei, 2007.

Table 2 Hydropower plants in Lancangjiang, Yunnan Province, China

Hydropower Plant	Gongguo qiao	Xiaowan	Manwan	Dachao san	Nuozha du	Jinghong	Ganlan ba	Meng song	Total
Averaged Annual Flows (billion m^3)	31.1	38.5	38.8	42.3	55.2	58.0	59.3	63.8	
Total Volume (billion m^3)	0.51	15.3	0.92	0.94	22.7	1.4	–	–	40.87
Dead Volume (billion m^3)	0.39	0.435	0.668	0.371	10.3	0.81			12.974
Installed Capacity (MW)	900	4200	1500 (1250 for the first stage)	1350	5000	1500	150	600	15200
Annual Power Production (Million MW. h)	4.06	19.17	6.30	5.931	22.4	6.29	0.59	2.888	67.629
Annual Power Production (operated in series) (Million MW. h)	4.724	19.96	7.88	7.02	23.96	7.34	0.915	3.40	75.199
Situation		Under Construction*	Constructed	Constructed		Under Construction**			

*Year of completion was antedated from 2012 to 2009.

**Year of completion was antedated from 2013 to 2009.

4. PLANNED HYDROPOWER PLANTS ON MAINSTREAM OF MEKONG

The idea of developing hydropower on the mainstream of Mekong has not been abandoned. Yet, no dam has so far been constructed on the mainstream. (Hori, 2000). A nine-plant plan, the latest one, proposed in 1994 was a substitute for an earlier seven-plant plan proposed in 1970, which had a total volume of 258.9 billion m^3 and installed capacity 23,300 MW. The 1994 plan mainly replaced high dam projects by dams of much less storage. Details of the 1994 plan are shown in Table 3.

5. INTERNATIONAL WATER LAW AND MEKONG RIVER

The uses of Mekong (the Lancangjiang is not included) shall follow the ACSD as well as the International Water Law, while other transboundary rivers in this subregion, including the Lancangjiang, shall follow the International Water Law. The Convention on the Law of the Non-navigational Uses of International Watercourses, approved by the General Assembly of the United Nations in 1997, has not been brought into force as yet (McMaffrey, 2001). As a result, the activities of direct uses of transboundary rivers shall follow the principles laid down in the Helsinki Rules on the Uses of Waters of International Rivers, adopted by International Law Association in 1966.

Although China and Myanmar are not members of the ACSD, in the following year that the parties signed the agreement, China and Myanmar became dialogue partners of the MRC. As a result, the MRC now provides the GMS members a platform to work together within the legal framework of the International Water Law.

6. NAVIGATION

Freedom of navigation through any international river has never been accepted in practice as a principle of international water law (Sheng and Zhou, 1986). The sovereignty of the riparian states must not be infringed. Only when the riparian states decide to open to each other or to countries not along the river, that freedom of navigation becomes possible. The activities of cross-border transport by boats are based on the freedom of

Table 3 Planned hydropower plants along mainstream of the Mekong in 1994

Hydropower Plant	Pak Beng	Luangpra -bang	Sayaburi	Ban Lao	Pamong A	Bung Kan	Khone Falls Dong Kralor	Stung Treng	Sambor	Total
Installed Capacity (MW)	1,230	970	1,260	1,010	2,030	2,330	240	980	3,300	13,350
Annual Power Production (Million MW. h)	5.67	5.65	5.99	4.84	8.87	10.20	1.64	4.87	14.90	62.63

navigation throughout the mainstream of the Mekong River provided in Article 9 of the ACSD. Article 9 opens the mainstream for navigation to the four parties. However, navigational uses may not violate the obligations of protection of the environment and ecological balance and prevention and cessation of harmful effects provided in Articles 3 and 7 of the agreement, respectively, as well as the obligation of prevention of any new form of water pollution provided in Article X of the Helsinki Rules. It should be noted that although the ACSD opened the mainstream, because of the Khone Falls, neither Laos' nor Thailand's boats can reach Cambodia or Viet Nam, nor boats from Cambodia or Viet Nam can ship upstream of the Falls.

On the other hand, before the CBTA came into force in 2003, China, Laos, Myanmar and Thailand had signed the Agreement on the Commercial Navigation along Lancangjiang-Mekong, which came into force in 2001. This agreement supplemented the gap caused by the fact that China and Myanmar are not parties to the ACSD and provides an important basis for CBTA.

7. HYDROPOWER PLANTS

The construction and operation of cascade hydropower plants with dams in the Lancangjiang will increase flows during dry season and reduce it during wet season. Dams will trap sediments, cause scouring in the downstream of the dams and block the stream. As a result, if most of the dams were built according to the plans, they could lower the water level of the Tonle Sap during the wet season, weaken the stability of certain river channels, diminish the area of the Mekong Delta, and change fishery, ecological system and navigation. The more dams the States build, the more serious the effects. The effects could also happen in the territories of other riparian states. According to the third sentence of Article 6 of the ACSD, member States shall 'enable the acceptable natural reverse flow of the Tonle Sap to take place during the wet season'. Member states shall also aim to the goals of 'protection of the environment and ecological balance', 'reasonable and equitable utilization' and 'prevention and cessation of harmful effects' provided in Articles 3, 5 and 7, respectively.

Article 9 of the ACSD also explained the reason why, despite several plans, being proposed for so many years, no hydropower plant has been built on the Mekong mainstream. Although 'navigational uses are not assured any priority over other uses', the parties also require 'the Mekong

River shall be kept free from obstructions, measures, conduct and actions that might directly or indirectly impair navigability, interfere with this right or permanently make it more difficult'. Article 9 reflects the importance of navigation of the Mekong to the parties. It rejects the possibility of building high dams on the mainstream. However, building hydropower plants with dams on the tributaries of Mekong within each State's own territories is not limited.

Besides the ACSD, the signed parties of GMS shall follow Article IV of the Helsinki Rules. It provides that 'each basin State is entitled, within its territory, to reasonable and equitable share in the beneficial uses of waters of an International drainage basin'. There are 11 factors to be considered as relevant listed in Article V. These include: geography, hydrology, climate, past utilization of waters, economic and social needs, pollution, comparative costs of alternative means, availability of other resources, avoidance of unnecessary uses, practicability of compensation and the degree to which the needs can be satisfied.

8. CONCLUSIONS

The above analysis shows that the enhancement of the CBTA and IGA imposes effects and events related to the International Water Law. The main conflict will arise between the general principles of sovereign equality and territorial integrity and the fact that activities in any section of a transboundary river could affect the rest of the riparian States. Fortunately, the MRC associated with the ACSD provides a platform to coordinate or settle issues within the Mekong River Basin. However, activities upstream of the Mekong River including those in the Lancangjiang will not be bounded by the ACSD. Further, there is lack of mechanism to resolve possible conflicts the Nujiang- Salween River between China and Myanmar and between China and Viet Nam on the Yuanjiang-Song Hong.

The six States sharing the Mekong waters have different needs. China and Myanmar becoming dialogue partners of the MRC was an important and positive beginning to improve the situation. Closer cooperation or being parties will be advantageous. Bilateral agreements between China and Viet Nam for cooperation on the uses of the Yuanjiang-Song Hong and between China and Myanmar on the Nujiang-Salween River, may be expected.

REFERENCES

Li, Mei. 2006. Study on Legal Issues about Economic Cooperation in the Greater Mekong Subregion. University of International Business and Economics Press: 336–349 (in Chinese).

Hori, Hiroshi. 2000. The Mekong Environment and Development. United nations University Press. Tokyo, New York, Paris: 328–372.

McMaffrey, Stephen C. 2001. The Law of International Watercourses, Non-Navigational Uses. Oxford University Press: 301–322.

Nguyen, Thi Dieu. 1999. The Mekong River and the Struggle for Indochina. Water. War, and Peace. Praeger. London: 199–227.

Sheng, Yu and Gang Zhou. 1986. Modern International Water Law. Law Press. Beijing. 74–76.

Wang, Zhihong et al. 2007. Mekong River. Linkingbooks. Taipei: 6 (in Chinese).

Zhao, Chunhou et al., 2000. Worldwide Rivers and Dams. China Water Power Press. Beijing. 112–120 (in Chinese).

附　錄　五

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