行政院國家科學委員會專題研究計畫　成果報告

都市雨水下水道即時控制系統之研究(II)

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（一）中文摘要

都市下水道系統乃是現代化都市基礎建設之一環。下水道系統可分為合流式與分流式等不同形式，合流式下水道系統乃是將污水與雨水以單一管路排除，分流式下水道系統則將污水與雨水分別由不同之管路排除。有研究指出，異常暴雨發生時下水道系統之效能常未能充分發揮，所以容易造成都市內水積淹。因此，一些先進國家對於都市下水道系統乃開始採即時控制(real time control)方式，以期在暴雨來襲時使得下水道系統之效能得以充分發揮。

本研究假設不增加現有的分流式雨水下水道抽水站系統的容量，模擬都市地區雨水下水道系統於人孔中裝置閘門進行最佳化操作所能提升現有抽水站系統之效能，以台北市雨水下水道系統第四分區中港、實踐與保儀木新抽水站系統為研究案例進行最佳化操作模擬。為了達到雨水下水道即時控制之模擬，本研究應用多執行緒技術(multi-thread technology)將美國環保署所發展的暴雨管理模式(Strom Water Management Model，簡稱 SWMM)與GAlib 的基因演算法模式整合在一起，進行即時控制之模擬。經由模擬的結果顯示：(1)各個獨立抽水站系統設置閘門進行最佳化操作均能使其溢流量降低; (2)各獨立抽水站系統裝置閘門，配合不同區域以抽水機調水進行聯合操作模擬，亦能使其總溢流量下降。

關鍵字：都市下水道系統、即時控制、SWMM、基因演算法、多執行緒

（二）英文摘要

Urban drainage systems are the most fundamental facilities in modern developed cities. There are two types of sewer systems in urban drainage systems: combined and separated. The waste water and the runoff caused by rain are drained in a single tunnel or pipe in the combined sewer systems; while the separated sewer systems use two separate systems of tunnels or pipes to drain waste water and runoff respectively. It has been indicated by many researchers that the performance of the sewer systems often can not reach its designed capacity when rainfall with larger return periods occurs. In the developed nations, real time control sewer systems are therefore applied to make the sewer systems more efficient for inundation caused by heavy rainfalls.

The main objective of the research is to simulate the performance (e.g. reduction of the total overflow volume in the drainage system) of the current drainage systems under optimized gate operations without extra capacity imposed to them. This research uses the Zhongang, Shijian, and Baoyi drainage systems of the 4th drainage area of Taipei City to demonstrate the effectiveness of applying real-time control (RTC) in Taiwan’s urban drainage systems. For the purpose of RTC simulation, the multi-thread technology is employed to integrate the Storm Water Management Model (SWMM), developed by US EPA, and a genetic algorithm library, called GAlib, to simulate RTC in the case study areas. The simulated results show: (1) total overflow volume in each pumping system which gates are installed in the manholes reduced under optimized gate operations. (2) These pumping systems with gates installation connected by pumps reduced the total overflow volume under optimized operations.

Keywords: urban drainage systems; real-time control; SWMM; genetic algorithms; Multithread

（三）報告內容

3.1 前言與研究目的

都市下水道系統為現代化都市發展重要基礎建設之一環。英國倫敦是最早建造近代化下水道系統的都市，陸陸續續歐洲各國也紛紛跟進，重要的城市也規劃興建都市下水道系統。早期下水道系統乃為合流式(combined system)，亦即污水與雨水一起流入下水道系統再加以排除，爾後英國倫敦爆發傳染病的流行，歐洲地區的國家遂將合流制下水道加以改進，將污水與雨水分離，分別由不同的系統加以排除，此即為分流式(separated system)的下水道系統。所以目前歐洲地區主要為合流式與分流式聯合運用，平時為分流制，污水與雨水分別由不同的系統處理。當暴雨來臨時無法排除之雨水，則將其導入污水管路形成 CSO(combined sewer overflow)直接排入河流或海洋。

台灣地區主要都市也於第二次世界大戰前建有局部的明溝排水系統，以排除雨水為主要目的。以台北市為例，台北市為配合民生社區之開發，於 1970 年完成分流式下水道系統，即污水與雨水分別由不同的管渠排除。近來由於都市化造成人口過度集中於都市，土地利用的情形大幅度地改變。一般而言，人口成長、道路面積、住宅開發之擴大、森林與農地之減少以及土地利用等地文因子之改變，均會造成集水區入滲量減少，逕流係數增加，導致逕流量增大。加上地球暖化，全球氣溫上升，海面溫度亦隨之提高，平均海水面亦逐年升高。海面溫度高，形成颱風之機率亦相對地增加，此等颱風皆夾帶大量的水汽，造成強度極高之降雨。此外，部分地區因土地開發而改變原來設計之排水系統，加上氣候條件的變遷與都市化導致環境的改變，抽水站當機或超過抽水站之設計容量，遇到颱風期間暴雨來襲，都市內水積淹的情況極易發生。

由於這種種的因素使得原先設計之都市下水道系統，當暴雨來襲時可能無法順利將暴雨排除造成淹水，造成居民的財產損失。然而有研究指出：當異常暴雨事件發生時，下水道系統的效能通常並未充分發揮(Linaza et al., 2002)。本研究的主要目的為假設不增加現有的分流式雨水下水道抽水站系統的容量，模擬都市地區雨水下水道系統於人孔中裝置閘門進行最佳化操作所能提升現有抽水站系統之效能（即抽水站系統內總溢流量降低之程度)。並以實際台北市雨水下水道系統第四分區中港、實踐與保儀木新抽水站系統為研究案例進行最佳化操作模擬，探討研究案例區域實施獨立區域與聯合區域最佳化操作之效益。

3.2 文獻探討

由於國外下水道系統完成之時間很早，因此對於下水道即時控制之相關研究不少。早期研究包括將研究區域加以理想化或簡化，並假設系統的輸出輸入為線性關係，如 Neugebauer et al. (1991)以數學模型簡化下水道即時控制系統，將此即時控制問題轉成一最佳化問題，且由於此控制系統的目標函數為線性，故可以線性規劃法求解此一簡化之系統。Nelen(1993)假想一個理想的網路系統，分析降雨量的時間序列，來模擬降雨事件作用於此假想之網路系統，以出流體積作為控制變數控制與操作此一網路系統，將 RTC 應用於此網路系統其所降低之溢流體積，與以蓄水池儲存等量之溢流體積相比較，從該研究可以瞭解到即時控制應用的潛能。Weyand(1993)則提出了一個簡單的操作策略來控制水流與蓄水體積，並與德國 Ense-Bremen 地區，減低 CSO 連續四年的操作策略做一比較。模式計算的結果與實際控制策略所減低之 CSO 有不同的結果，而其研究指出此等差異主要是因為實際操作上的限制。

有關求解下水道即時控制系統的即時操作策略研究方面，有不少研究者嘗試使用基因演算法(genetic algorithm, GA)與類神經網路(artificial neural network, ANN)等人工智慧(artificial intelligence，AI)方法，配合模式模擬工具，進行即時控制，如 Hajda et al.(1998) 使用基因演算法和類神經網路做為下水道即時控制之工具。該研究主要是以馬斯金更法(Muskingum method)作為模式模擬工具，控制器選用混合 DLD(delay-loop diversion)控制演算法，並以基因演算法找出一適當之控制策略，將多次以 GA 所得到之控制策略利用類神經網路建立系統的輸入與控制策略之關係。經研究發現若改以此模式取代現存之即時控制模式可以降低抽水量達 50-80%。不同於傳統降雨逕流模式都是以離線 (off-lines) 的方式單獨進行計算模擬。Cassar et al. (1999)為了達到即時控制的目的，結合了著名的降雨逕流模式 HYSTEM/EXTRAN 和決策搜尋模式 (decision finding model) INTL，進行即時操作。Cluck et al. (1999) 則提出了一個即時控制的模型，用來控制逕流與都市排水系統交互影響的問題。此模型包含即時流量預測、一套驗證模式參數的演算法、與系統輸出有關的下水道操作策略和轉換函數，此轉換函數是一個概念式參數化的轉換函數(conceptually parameterized transfer function, CPTF)，主要的作用為描述系統的輸入與輸出之關係。Parker et al. (2000) 引進 SewerNet 應用程式，該應用程式使用基因演算法作為在給定限制條件下，下水道設計與復原最佳化的分析工具。SewerNet 為一物件導向(object-oriented)的 framework，包含了 OpenNet network 模式、基因演算法函式庫、水力模式模組。Linaza et al. (2002) 提出一全域管理工具整合下水道水力與生物模式。Schütze et al. (2002) 使用模擬工具 (SYNOPSIS) 提出了評估都市污水系統執行 RTC 的潛能的法則。Rauch et al. (1999) 藉由基因演算法應用在非線性模式預測控制 (nonlinear model predictive control) 分析一些假設性的問題，有良好的預測效果。

實際都市雨水下水道系統龐大且複雜，不易進行即時控制之研究。一般先採用理想化或簡化之區域進行研究，且將目標函數加以簡化為線性(Neugebauer et al.; Nelen)以利求解。模擬下水道系統輸入與輸出之關係，則採用較為簡單之方法(Hajda et al)，或不同的模式(Cassar et al.)。然而決定控制策略的效率也將影響是否可進行即時控制，因此近來的研究採取基因演算法決定最佳控制策略(Hajda et al.; Rauch et al.; Parker et al.)。

3.3 研究方法

圖 1 顯示本研究進行雨水下水道最佳化操作模擬的基本架構。整個架構包括：水理模式(flow routing model)—模擬雨水下水道系統水理特性隨時間的變化關係，最佳化方法(optimization method)—求解最佳的操作策略以期滿足所欲達到的目標（objective function）。藉由水理模式的輔助，最佳化的求解過程中，可以改變不同的控制策略，由水理模式下水道模擬系統的狀態，以期找到最佳的操作策略。

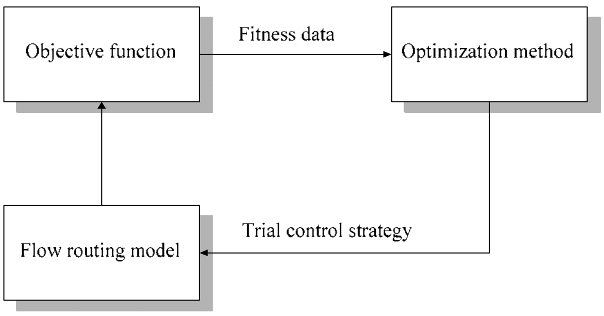

圖 1 雨水下水道即時控制模擬示意圖

本研究選用美國環保署所開發之暴雨管理模式 4.4 版(Huber *et al.*, 1988)作為雨水下水道水理模式。其自從 1969-1971 年發展以來即受到廣泛的應用(Liong *et al.*, 1995; Zaghloul, 1997,1998; Park *et al.*, 1998; Zhong, 1998; Noto *et al.*, 2001; Campbell *et al.*, 2002)。SWMM 包含許多模式，本研究採用其降雨逕流模式 RUNOFF 與管線輸水模式 EXTRAN。EXTRAN 模式主要是利用顯示差分法配合修正式歐拉法(modified Euler's Method)求解一維淺水波方程式(one-dimensional shallow water equation)又稱為 de Saint Venant 方程式(Abbot, 1979; Chow *et al.*, 1988; Chaudhry, 1993)，此方程式用來描述河道

或下水道的流況。由於原始的 SWMM-EXTRAN 已經提供許多種類的水工結構物可以模擬離線(off-line）狀態水工結構物對於下水道系統管路流況的影響，這些水工構造物均可以用來作為控制下水道系統的控制裝置。然而，SWMM-EXTRAN 並未提供閘門(並非是與河川或海洋交界的潮汐閘門)的操作模擬，本研究提出虛擬抽水機(virtual pumps，簡稱 VP)的概念用以模擬閘門操作，利用抽水機模擬在滿管流時閘門調節流量使人孔溢流體積不再持續增加的方法稱為虛擬抽水機。圖 2 中所顯示為雨水下水道滿管流的情況，由連續方程式可知，部分關閉閘門調節流量使人孔溢流體積不再持續增加，因此其抽水量Q_{vp}可以下式決定

$$Q_{vp} = Q_{in} - (Q_2 - Q_1) \tag{1}$$

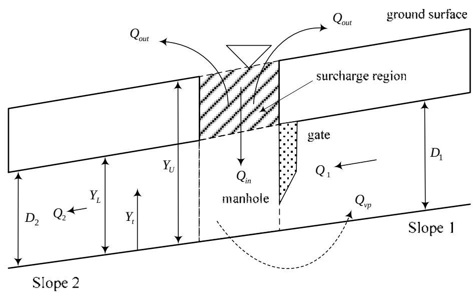

圖 2 雨水下水道滿管流閘門關閉示意

近來的研究採取基因演算法決定最佳控制策略(Hajda 等人, 1998；Rauch 等人, 1999; Parker 等人, 2000）。本研究中即採用基因演算法作為最佳化操作策略的求解方法。基因演算法的基本概念(Holland, 1975; Goldberg, 1989)為「優勝劣敗，適者生存，不適者淘汰」，藉由一開始選擇的樣本解(population)進行演算，最終生存下來者即為最佳解。整個搜尋最佳解的演算流程包含：將推估的解與相關之參數表示成二進位字串(string)形式的樣本，並且將目前的樣本根據演化的法則(包括突變，交換與選擇等)決定下一個世代的樣本。演化則為決定目前何者為最適宜的推估解，以作為新一代的推估值，如此一直重複下去直到達到終止條件。目前已有許多 GA 套裝程式或程式庫，本研究採用 GAlib(Wall, 1996)程式庫，此程式庫以 C++語言實作。該程式庫最大的特色即是將基因演算法與基因組加以分離，容易使用、彈性大、效能高且免費取得，目前的版本是 2.4，可以在多種平台上執行，例如：MS Windows、MacOS、UNIX 等。

為了達到即時控制的模擬，必須整合水理模式(SWMM-EXTRAN)與最佳化模組(GAlib)。本研究使用多執行緒的技術(multithread technology)，一個執行緒執行 SWMM-EXTRAN，而另一個執行緒等待 SWMM-EXTRAN 所模擬的結果，當需要進行即時控制模擬時，便令 SWMM-EXTRAN 先暫停執行，由另一個執行緒取得 SWMM-EXTRAN 的模擬結果(排水區域內人孔溢流量等資訊)，進行最佳化演算，再將最佳化控制策略回饋給 SWMM-EXTRAN，以進行下一時刻的演算。本研究整合軟體所使用的程式語言分別為 Fortran 90(Adams et al., 1997)與 C++(Stroustrup, 2000)，開發工具則選用 Compaq Visual Fortran 6.5(Etzel *et al*., 1999)與 Borland C++ Builder 6(Holling *et al*., 2003)。

3.4 結果與討論

圖 為案例研究區域圖。由上往下的順序，由右往左的分別是中港系統上、中、下游(ZU，ZM，ZD)，實踐系統上、中、下游(SU，SM，SD)，以及保儀木新系統上、中、下游(BU，BM，BD)。對於每一個獨立系統選擇最佳的控制區域(上、中、下游)，其二對於各獨立系統所選定之控制區域進行聯合抽水站系統最佳化操作之模擬，各個抽水站系統以單向抽水機連接(如圖 3 中箭號虛線所示)。5 年 90 分鐘設計降雨之控制時間為 5 分鐘，而 5 年 24 小時颱風降雨則為 1 小時。

表 1 顯示 5 年 90 分鐘降雨下之各區獨立最佳化操作之總溢流量，保儀木新系統則

在無控制時表現較佳，加入控制後已無法再提昇其效能。其主要的原因為：由於在最佳化操作模擬過程中，並未將未來雨水下水道系統之狀態列入限制條件中，以致於有可能導致操作後無法在提升其效能，若欲避免此種情況，必須將未來系統狀態列入模式限制條件中。表 2 為 5 年 90 分鐘設計降雨聯合操作各系統總溢流量比較（m3），總體來說，三個抽水站系統聯合操作時，能有效使三個區域內之總溢流量有消減之趨勢，以閘門在配合不同區域用抽水機調度能更進一步提升抽水站系統之效能。表 3 與表 4 分別為 5 年 24 小時降雨下之各區獨立最佳化操作與聯合最佳化操作之總溢流體積。中港系統原始條件與聯合最佳化操作之條件下相比較，其總溢流量削減約 10%，實踐系統削減量約為 4%，保儀木新系統約為 11%，而三個區域之總溢流量約消減 9%。顯示出聯合操作配合不同區域以抽水機調水，能提升抽水站系統之效能，降低排水區域內之總溢流量。

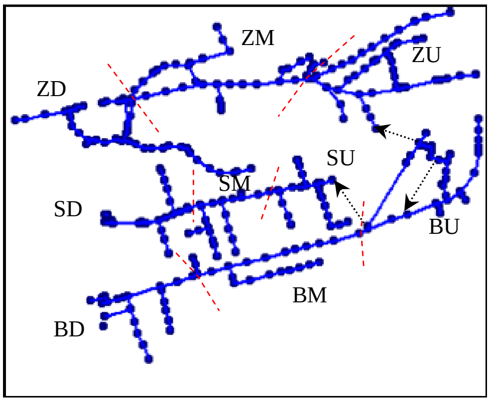

圖 3 研究案例

表 1 5 年 90 分鐘降雨下之各區獨立最佳化操作之總溢流量（m^3）

	無最佳化控制（O）	上游設置閘門進行最佳化控制（U）	中游設置閘門進行最佳化控制（M）	下游設置閘門進行最佳化控制（D）	上中下游設置閘門進行最佳化控制(UMD)
中港系統（ZG）	55308	43312	48992	52315	**42533**
實踐系統（SJ）	450	253	150	**40**	305
保儀木新系統（BY）	**22156**	23155	23209	24127	23299

表 2 5 年 90 分鐘設計降雨聯合操作各系統總溢流量比較（m^3）

	中港系統	實踐系統	保儀木新系統	三個系統總溢流量
原始條件	55308	450	22156	77914
不同系統加入調水 Pumps	45973	1141	19832	66946
加入閘門及最佳化操作（ZG-UMD. SJ-D, BY-O）	41172	0	15773	56945
加入閘門及最佳化操作（ZG-UMD. SJ-UMD, BY-O）	40397	0	12198	52595

表 3 5 年 24 小時降雨下之各區獨立最佳化操作之總溢流量（m^3）

	無最佳化控制（O）	上游設置閘門進行最佳化控制（U）	中游設置閘門進行最佳化控制（M）	下游設置閘門進行最佳化控制（D）	上中下游設置閘門進行最佳化控制（UMD）
中港系統（ZG）	310719	291430	300962	290626	**220330**
實踐系統（SJ）	**99332**	100209	101223	99550	107485
保儀木新系統（BY）	122130	116155	113651	132207	**113170**

表 4　5 年 24 小時設計降雨聯合操作各系統總溢流量比較（m^3）

	中港系統	實踐系統	保儀木新系統	三個系統總溢流量
原始條件	310719	99332	122130	532181
聯合最佳化操作 (ZG-UMD. SJ-O, BY-UMD)	291786	95498	109890	487174

（四）參考文獻

Abbot, M. B. (1979). *Computational Hydraulics. Elements of the Theory of Free Surface Flows*, Pitman Publishing, Ltd., London.

Adams, J. C., Brainerd, W. S., Martin, J. T., Smith B. T., and Wagener, J. L. (1997). *Fortran 95 Handbook : Complete ISO/ANSI Reference*, MIT Press, U.S.A.

Åstrom, K. J., Wittenmark, B. (1990). *Computer-Controlled Systems: Theory and Design, 2nd Edition*. Englewood Cliffs, Prentice-Hall, New Jersey, USA.

Campbell, C. W., and Sullivan, S. M. (2002). "Simulating Time-Varying Cave Flow and Water Levels Using the Storm Water Management Model," Engineering Geology, Vol. 65, pp. 133-139.

Cassar, A. and Verworn, H. R. (1999). "Modifications of Rainfall Runoff and Decision Finding Models for On-Line Simulation in Real Time Control," *Water Science and Technology*, Vol. 39, No. 9, pp. 201-207.

Chaudhry, M. H. (1993). *Open-Channel Flow*, Prentice-Hall, New Jersey, U. S. A.

Chow, V. T., Maidment, D. R., Mays, L. W. (1988). *Applied Hydrology*, Mc Graw Hill, New York, U.S.A.

Cluckie, I. D., Lane, A. and Yuan, J. (1999). "Modelling Large Urban Drainage System in Real Time," *Water Science and Technology*, Vol. 39, No. 4, pp.21-28.

Duchesne, S., Mailhot, A., and Villeneuve, J. P. (2004). "Global Predictive Real-Time Control of Sewers Allowing Surcharged Flows," *Journal of Environmental Engineering*, Vol. 130, No. 5, pp. 526-534.

Etzel, M., Dickinson, K. (1999). *Digital Visual Fortran Programmer's Guide*, Digital Press, M.A., U.S.A.

Gamma, E., Helm, R., Johnson, R. and Vlissides, J. (1995). *Design Pattern: Elements of Reusable Object-Oriented Software*, Andison-Wesley., U. S. A.

Goldberg, D. E. (1989). *Genetic Algorithms in Search, Optimization and Machine Learning*. Reading, Mass.: Addison-Wesley, U. S. A.

Hajda, P., Novotny, V., Feng, X., and Yang, R. (1998). "Simple Feedback Logic, Genetic Algorithms and Artificial Neural Networks for Real-Time Control of A Collection System," *Water Science and Technology*, Vol. 38, No. 3, pp. 187-195.

Holland, J. (1975). *Adaptation in Natural and Artificial Systems*. Ann Arbor: University of Michigan Press

Holling, J., Swart, B., Cashman, M., and Gustavson, P. (2003). *Borland C++ Builder 6 Developer's Guide*, Sams, U.S.A.

Huber, W. C. and Dickinson, R. E., *Storm Water Management Model. User's Manual Ver. IV* (1988). U. S. Environmental Protection Agency.

Li, J., and McCorquodale, A. (1999). "Modeling Mixed Flow in Storm Sewers," *Journal of Hydraulic Engineering*, Vol. 125, No. 11, pp.1170-1180.

Linaza, M. T., Salterain, A., and Ayesa, E. (2002). "Real Time Control Modules for Sewer Simulations," Water Intelligence Online (http://www.iwapublishing.com/).

Liong, S. Y., Chan, W. T., and ShreeRam, J. (1995). "Peak-Flow Forecasting with Genetic Algorithm and SWMM," *Journal of Hydraulic Engineering*, Vol. 121, No. 4, pp.613-617.

Nelen, F. (1993), "On The Potential of Real Time Control of Urban Drainage Systems," *Water Science and Technology*, Vol. 27, No. 5-6, pp. 111-122.

Neugebauer, K., Schilling, W., and Weiss, J. (1991). "A Network Algorithm for the Optimum Operation of Urban Drainage Systems," *Water Science and Technology*, Vol. 24, No. 6, pp. 209-216.

Noto, L., and Tucciarelli, T. (2001). "DORA Algorithm for Network Flow Models with Improved Stability and Convergence Properties," *Journal of Hydraulic Engineering*, Vol. 127, No. 5, pp. 380-391.

Park, H., and Johnson, T. J. (1998). "Hydrodynamic Modeling in Solving Combined Sewer Problems: A Case Study," *Water Research*, Vol. 32, No. 6, pp.1948-1956.

Parker, M. A., Savic, D. A., Walters, G. A., and Kappelan, Z. (2000). "SewerNet: A Genetic Algorithm Application for Optimizing Urban Drainage Systems," *Proceedings of the 1st International Conference on Urban Drainage in Internet*.

Rauch, W. and Harremoës, P. (1999). "Genetic Algorithms in Real Time Control Applied to Minimize Transient Pollution from Urban Wastewater Systems," *Water Research*, Vol. 33, No. 5, pp. 1265-1277.

Schütze, M., Butler, D., Beck, M. B., and Verworn, H. R. (2002). "Criteria for assessment of the Operational Potential of the Urban Wastewater System," *Water Science and Technology*, Vol. 45, No. 3, pp. 141-148.

Stroustrup, B. (2000). *The C++ Programming Language special ed.*, Addison-Wesley, Massachusetts, U.S.A.

Tanenbaum, A. S. (2001). *Modern Operating System 2/e*, Prentice-Hall, NJ, U.S.A.

Weyand, M. (1993). "Real Time Control Within A Combined Sewer System : Comparison of Practical and Theoretical Results," *Water Science and Technology*, Vol. 27, No. 5-6, pp. 123-132.

Wall, M. (1996). http://lancet.mit.edu/ga/.

Zaghloul, N. A. (1997). "Unsteady Gradually Varied Flow in Circular Pipes with Variable Roughness," *Advances in Engineering Software*, Vol. 28, pp.115-131.

Zhong, J. (1998). "General Hydrodynamic Model for Sewer/Channel Network Systems," *Journal of Hydraulic Engineering*, Vol. 124, No. 3, pp.307-315.

台北市政府工務局養護工程處，「台北市排水系統調查檢討及資料建檔(第一分區：文山區、內湖區、南港區、信義區、松山區、中山區)」，2002 年 6 月。

台北市政府工務局養護工程處，「台北市排水系統調查檢討及資料建檔(第四分區：中正區、

中山區、大同區、萬華區、大安區、士林區)」, 2002 年 8 月。
台北市政府工務局養護工程處,「台北市排水系統檢討規劃-後續工作(士林、北投區)」, 2003 年 2 月。

（五）計畫成果自評

本計畫的研究成果已寫成一篇國際會議論文，也有一篇 SCI 論文即將出版:

- S.-S. Lin, L.-P. Wang, S.-H. Hsieh, J.-T. Kuo, and Y.-C. Chen, "An Approach for Modeling Gate Operations under Surcharge in Urban Drainage Systems," *Proceedings of the International Conference on Monitoring, Prediction and Mitigation of Water-Related Disasters*, Kyoto, Japan, January 12-15, 2005, 203-208.
- Lin, S.-S., Hsieh, S.-H., Kuo, J.-T., Liao, Y.-P., and Chen, Y.-C., "Integrating Legacy Components into a Software System for Storm Sewer Simulation," *Environmental Modeling and Software*, in press.

由於目前國內關於都市雨水下水道實施即時控制的相關研究非常少見，雖然國外，尤其是歐洲地區的國家，在過去 20 年間很多學者致力於都市下水道系統即時控制的相關研究，同時也有很多研究成果發表在期刊中。這些相關的研究成果涵蓋了計算水力學、最佳化控制理論、軟體技術與決策支援系統等方面。然而，國內的雨水下水道系統與歐洲國家的下水道系統不一樣，且水文條件也不相同，整個即時控制的目標也和歐洲國家不同。本研究的成果已發表在國際會議論文，並已投稿 SCI 論文，這些研發成果涵蓋了計算水力學與資訊整合技術，對於日後國內這些方面的研究，應具有參考價值，同時對於雨水下水道即時控制的相關研究，也應有所貢獻。

出席「MPMD2005 國際會議」報告

謝尚賢、汪立本、林旭信
國立台灣大學土木工程學系

會議簡介

MPMD2005 國際會議（International Conference on Monitoring, Prediction and Mitigation of Water-Related Disasters）由日本京都大學（Kyoto University）的災害防治研究中心（Disaster Prevention Research Institute，簡稱 DPRI）主辦，會議地點就在京都大學的百週年時計台紀念館（Clock Tower Centennial Hall）內，會議時間從 2005 年 1 月 12 日到 1 月 15 日，共計四天的時間。有鑑於目前全世界與水有關的災害（包括水災、旱災、土石流、水質問題等）相當嚴重，加上全球氣候變遷與亞洲及非洲人口快速成長，更加深了問題的嚴重性，因此，此會議希望能結合新科技與傳統智慧，並透過政策執行與國際合作來尋求更好的水災害（water-related disasters）管理方法，並提供一個能讓全世界從事水災害監測、預測與防治相關研究與實務的自然與社會科學家、工程師、教授與學者、政策制訂者與政府官員等，一同交流分享與討論的機會與平台。此會議亦提供一個參觀日本的水災害管理系統的機會，且在會議之後，緊接著又有參加聯合國世界防災會議（UN World Conference on Disaster Reduction）的機會（Kobe, January 18-22, 2005）。

此次會議在徵求投稿論文摘要階段，共收到來自世界 28 個國家 150 篇的投稿，最後於會議期間，共有來自 20 個國家的 144 人與會，有一篇 Keynote 論文及 124 篇技術論文的發表，對於一個特定專業主題的國際會議而言，應算是十分成功。本次會議在第一天(12 日)早上開幕典禮後，隨即安排了一場由京都大學 Kaoru Takara 教授主講的 Keynote 演講：「Monitoring, Prediction and Mitigation of Water-Related Disasters」，接著稍做休息後，便展開爲期兩天半的論文發表，每個時段幾乎皆有三個平行的分項主題論文發表同時舉行。現整理論文發表場次的標題如下（每個主題都有 2-3 個場次）：

- Real-Time Monitoring and Forecasting Systems / Prediction Uncertainty
- Crises in Ecological Systems
- Floods and Severe Storms
- Remote Sensing, Geographical Information Systems and Distributed Hydrological Modeling
- Risk Management
- Multidimensional Modeling of Hydrodynamic Systems
- Integrated Water Resources Management
- Sediment Disaster Mitigation
- Integrated Coastal Zone Management

大會在第三天下午則安排了Technical Tour，去參觀日本Biwa湖及Yodo 河兩個區域，實地參觀日本在水災害防治上之努力，當天晚上則安排了會議晚宴，讓與會者在輕鬆的晚宴中盡情交誼。大會在最後一天早上（即15日）特別爲

南亞海嘯安排了一場研討會，研討內容包含了對南亞海嘯最新的調查報告，並由受波及國家的與會者報告各國之災情及應變，也以此事件爲案例討論災害之監測、預測與防治。接著，又進行了一個小時的MPMD2005國際會議的綜合討論，整個會議才在DPRI中心主任Tomotsuka Takayama教授的閉幕致辭後結束。

論文發表

此次筆者投稿發表的論文被安排在第二天（13 日）下午的Multidimensional Modeling of Hydrodynamic Systems場次，由論文作者之一的汪立本同學代表發表論文。此次筆者所發表的論文爲：

- "An Approach for Modeling Gate Operations under Surcharge in Urban Drainage Systems," by Shiu-Shin Lin, Li-Pen Wang, Shang-Hsien Hsieh, Jan-Tai Kuo, and Yen-Chang Chen

汪同學表現優異，發表過程皆圓滿順利，也得到與會學者專家的肯定與指教。

會議心得

首先要感謝國科會的補助，使筆者得以順利於此次國際會議中發表論文。此次會議所得到的收穫很多，現將主要的略述如下：

1. 此次會議筆者所發表的論文爲筆者執行國科會計畫（NSC 92-2211-E-002-044）之部分成果，於開會期間與各國學者交流，不僅得到相當的肯定與鼓勵，更得到許多寶貴的建議。

2. 此次參與會議發現，歐美日先進國家對防災科技與管理十分重視，各國政府都投入相當多的研發與工程經費，也十分關心如何透過產官學研之整合來提升防災科技與管理之相關議題，很值得我國參考與借鏡。

3. 此次會議提供了讓本人的研究生親身參與及體驗國際學術活動的機會，並讓其上台發表學術論文，磨練語文表達能力，又能親濡各國學者專家之風采，相信對其未來不管是繼續深造或就業都能有很好的啓發與影響。

An Approach for Modeling Gate Operations under Surcharge in Urban Drainage Systems

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ABSTRACT: This paper presents an approach for modeling rapid gate operations in urban drainage systems (UDS) when surcharge occurs. The approach uses a virtual pump to simulate the effect of rapid gate closing in surcharged flow and is therefore named the virtual pumps approach. An in-house software tool, RTCFT, which employs the Extended Transport (EXTRAN) module of the Storm Water Management Model (SWMM) as the solver for solving one-dimensional de Saint-Venant equations, is extended to incorporate the proposed approach for flow simulation in UDS with rapid gate operations under surcharge condition. An idealized drainage system is used to verify and demonstrate the proposed approach. It has been shown that the proposed virtual pumps approach can successfully model the rapid gate operations in UDS under surcharge condition.

1 INTRODUCTION

Extreme storm events always come with disasters that threaten the resident's life and wealth in urban area. Flooding is the most common disaster in urban area under unexpected storms. One of the major reasons for flooding to occur is the insufficient capacity of urban drainage systems (UDS) under such extreme storms. During the last two decades, many research reports have indicated that the capacity of UDS can be best utilized if some control systems are employed (Schilling et al., 1989; Neugebauer et al., 1991; Nelen, 1993; Rauch et al., 1999). Consequently, to investigate the potential use of control systems in UDS, some research efforts are needed in the prediction and simulation of flow conditions in the UDS with control systems.

The flow conditions in the UDS can be described by the full one-dimensional de Saint-Venant equations, which are also known as the shallow water equations (Chaudhry, 1993). The Extended Transport module of the Storm Water Management Model (SWMM-EXTRAN) (Huber and Dickinson, 1988) is a well-known solver of shallow water equations for storm sewer flow. It supports simulation of flow situation in UDS with several kinds of flow control devices, including orifices, weirs, pumps, and outfalls. However, it currently does not support the use of internal control gates (not the tidal gates at the boundary of UDS). That is, SWMM-EXTRAN can not be used to simulate the flow situations in UDS under rapid operations of control gates.

In this work, an approach that uses the concept of virtual pumps is proposed for modeling the rapid operations of control gates (either fully opened or partially closed) in UDS when surcharge occurs. An in-house software tool for storm sewer simulation, named RTCFT (Lin et al., 2004), that accommodates the SWMM-EXTRAN solver, is extended to incorporate the proposed approach for simulating rapid gate operations in UDS. The pump control device in SWMM-EXTRAN is employed with some modifications on the SWMM-EXTRAN source code to implement the virtual pumps in the flow simulation of SWMM.

The remaining sections in this paper are organized as follows. Section 2 (CONTROL SIMULATION FRAMEWORK) briefly explains the control simulation framework. In Section 3 (MODELLING GATE OPERATION USING VIRTUAL PUMPS APPROACH), the virtual pumps approach for modeling the gate operations when surcharge occurs is proposed. Section 4 (APPLICATIONS) uses an idealized UDS to verify and demonstrate the proposed virtual pumps approach.

2 CONTROL SIMULATION FRAMEWORK

The framework for UDS control simulation in RTCFT is composed of four components, namely, the Simulator, Program Controller, Visualizer, and Adaptor as shown in Fig. 1. The Simulator employs SWMM to simulate the storm sewer flow. The Program Controller manages the flow of simulation. A multi-thread technology is employed to support on-line storm sewer simulation (Lin et al., 2004). In RTCFT, the Program Controller suspends the execution of the Simulator at the end of every time step and receives information, such as the computed water-stages at the junctions in the storm sewer system, from the Simulator through the help of the

Adaptor. It then calls the Visualizer to display the received information immediately. In addition, the messages (i.e., control actions) passing between different components in the framework can also be achieved through the Adaptor for real-time control simulation.

Although several types of flow control devices (i.e., orifice, weir, pump, and outfall) are supported by SWMM-EXTRAN and can be used in the framework, they can only be used in flow simulation with regulation in an off-line manner and do not include the devices of internal gates. In the present RTCFT framework, flow conditions in UDS under control can be simulated not only in an off-line but in an on-line manner. With some modification on the SWMM-EXTRAN source code, the pump device in SWMM is extended to model rapid operations of gates under surcharge condition using the virtual pumps concept and a set of predefined parameters for the pump (e.g., the pumping rate of pumps) and the control actions (e.g., the water stages for pumps to be turned on or off, pumping rate of pumps, etc.). More discussions on how to model rapid gate operations in the surcharged flow using the virtual pumps concept are provided in the next section.

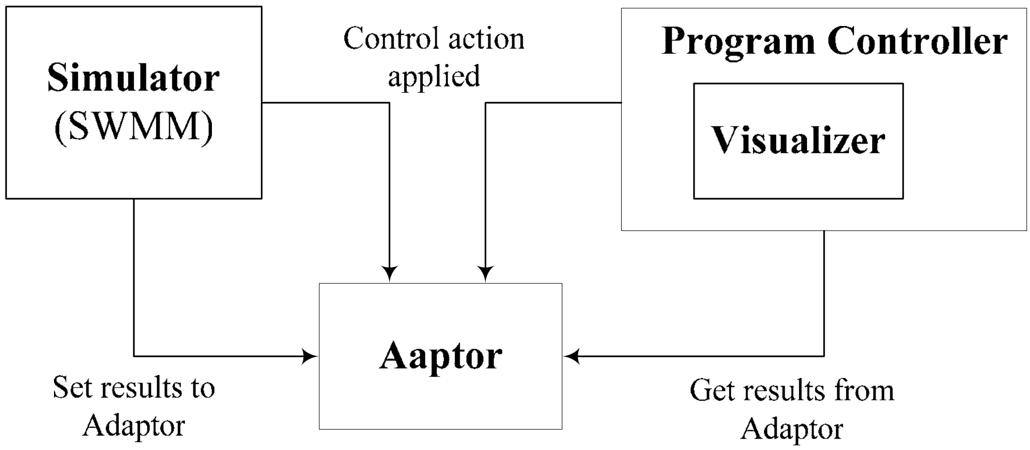

Figure 1. Control simulation framework in RTCFT

3 MODELLING GATE OPERATION USING VIRTUAL PUMPS APPROACH

The flow in UDS can be open channel or pressured pipe flow. When the surcharge occurs, the flow in UDS becomes pressured pipe flow. Briefly speaking, surcharge is the situation in which all pipes entering a manhole (junction) are full or water surface at the manhole lies below the ground surface and above the elevation of the crown of the conduit (Huber and Dickinson, 1988). Flooding can be regarded as a special case of surcharge in which overflow volume of water comes out from the sewer manhole and goes to the ground surface (Huber and Dickinson, 1988). The surcharge condition, as shown in Fig. 2, can be described by the following equation:

$$Y_L \le Y_t \le Y_U \tag{1}$$

in which Y_L represents the diameter of conduit; Y_t is the water depth of the conduit at time *t*; and Y_U denotes the distance between the crown of the conduit and the ground surface.

The hydraulic effects of the rapid gate operations (from fully opened to partially closed and vice versa) are different in the free-surface and pressured UDS flows. When the UDS flow is changing from the free-surface flow to the pressured flow (often caused by closing the control gate), a very complex transition state of flow occurs. The transition state is usually accompanied by surge flow, mix-bubble flow, and water-hammer. Yen (1978) indicated that the transition from free-surface to pressured flow as one type of hydraulic instability that requires more detailed studies. Also, the occurrence of water-hammer may damage the structures of UDS. Therefore, many researchers have tried to model this transient phenomena in storm drainage systems (e.g., Chaudhry, 1993; Guo and Song, 1991; Li and McCorquodale, 1999). However, if the rapid gate operations are performed when the flow is already under surcharge condition, the transient state of the instable hydraulics can be neglected. In this work, the gate is allowed to be fully opened or partially closed rapidly only when the surcharge occurs. Therefore, the virtual pumps approach proposed below for modeling gate operations under surcharge condition does not take transient state into account.

Figure 2 shows the concept of the proposed virtual pumps approach. A gate is installed upstream to the manhole. Assume that the upstream and downstream slopes of the manhole are the same and the diameters of the upstream and downstream conduits are the same. This means that the flow rate in the upstream conduit (i.e., Q_1) is equal to the flow rate in the downstream conduit (i.e., Q_2). If the UDS flow becomes a surcharged flow (i.e., the water surface lies in the surcharged region), there can be overflow volume out of the UDS. In this surcharge situation, the overflow rate of the manhole can be reduced to zero (i.e., $Q_{out} = 0$) by partially closing the gate to reduce the upstream flow rate to $Q_1 - Q_{in}$. The effect of the gate closing is equivalent to the use of a pump (called a **virtual pump, VP**, in this work) to transfer the inflow of the manhole at the rate of Q_{in} to the nearest upstream manhole. This means that the pumping rate of the VP (i.e., Q_{vp}) is equal to Q_{in} (the inflow rate of the manhole). Hence, in the surcharged flow condition, partially closing the gate to reduce the overflow rate to zero is equivalent to turning on the corresponding virtual pump, while opening the gate is equivalent to turning off the corresponding virtual pump.

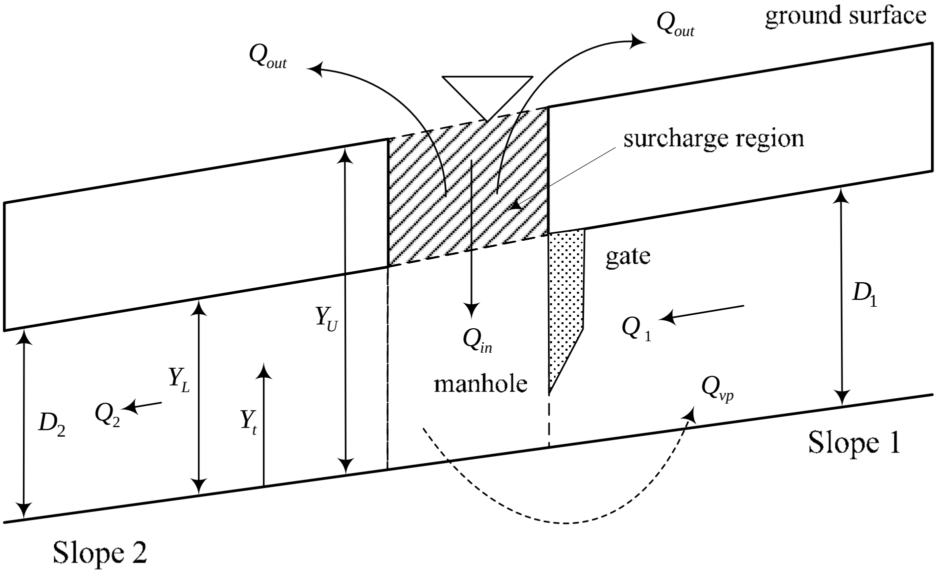

Figure 2. Concepts of gate operations in surcharge condition

4 APPLICATIONS

An idealized drainage system, as shown in Fig. 3, is used as a test case to verify and demonstrate the proposed approach. Each conduit in the system is a circular pipe of 1.5m in diameter and the depth at each junction (or manhole) is 6m. The system has two slopes, 1/500 from Junction 80309 to Junction 82408 and 1/750 from Junction 82309 to Junction 16109. The inflow hydrographs of Junctions 80408, 82309, and 16109 are the same as the one shown in Fig. 4. Two control gates are installed upstream to Junctions 82309 and 16109, respectively. RTCFT is employed for storm sewer simulations with and without gate operations in the idealized drainage system. Figure 5 shows the computed water stage and overflow volume hydrographs at Junction 16109 without any gate operations (i.e., both gates are fully open all the time). It can be seen that the overflow volume reaches the maximum value (i.e., 900 m^3) when the time is at about 12,000 sec. and the flow of the junction becomes surcharged during the time period from 4,000 sec. to 24,000 sec. Figure 6 demonstrates the simulated results when the gate at Junction 16109 is closed at about 8,000 sec. and re-opened at about 10,000 sec. It can be clearly seen that the overflow volume at Junction 16109 stays at the level of 300 m^3 during the gate closing period. This indicates that the proposed virtual pumps approach can correctly simulate the effect of gate closing in UDS so the overflow volume at Junction 16109 does not increase until the gate is re-opened.

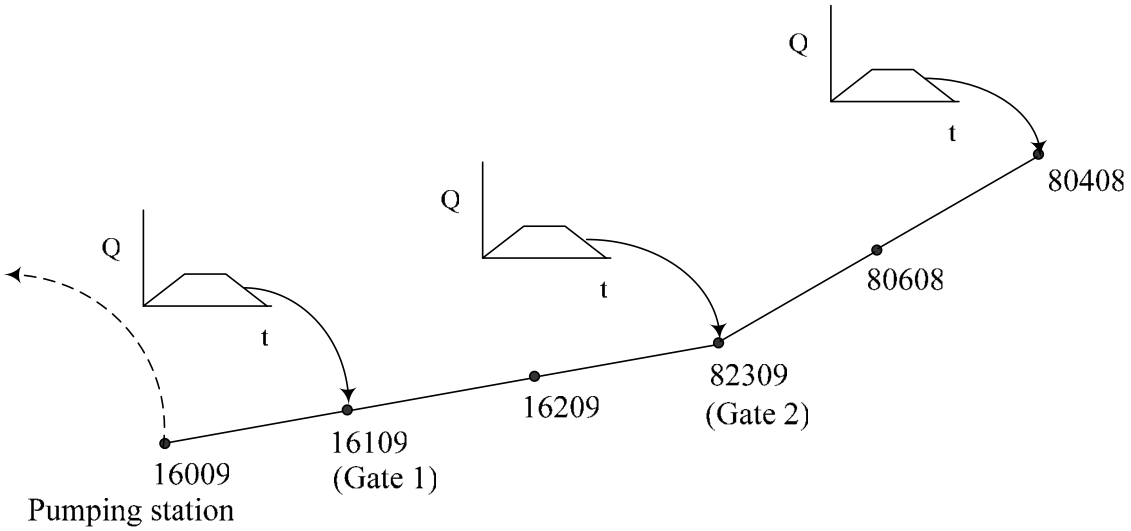

Figure 3. Idealized drainage system

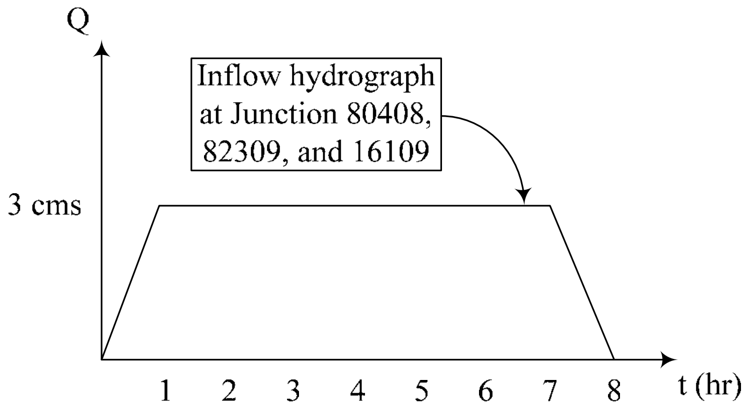

Figure 4. Inflow hydrographs

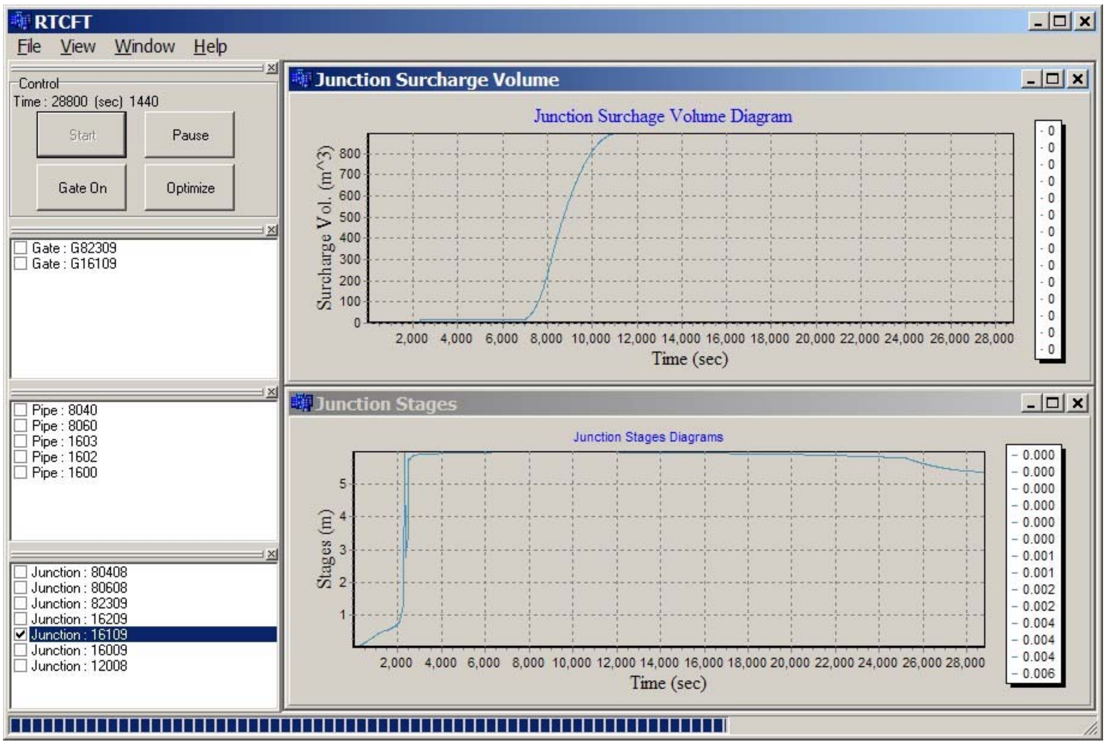

Figure 5. Hydrographs of water stages and overflow volume at Junction 16109 without gate operations

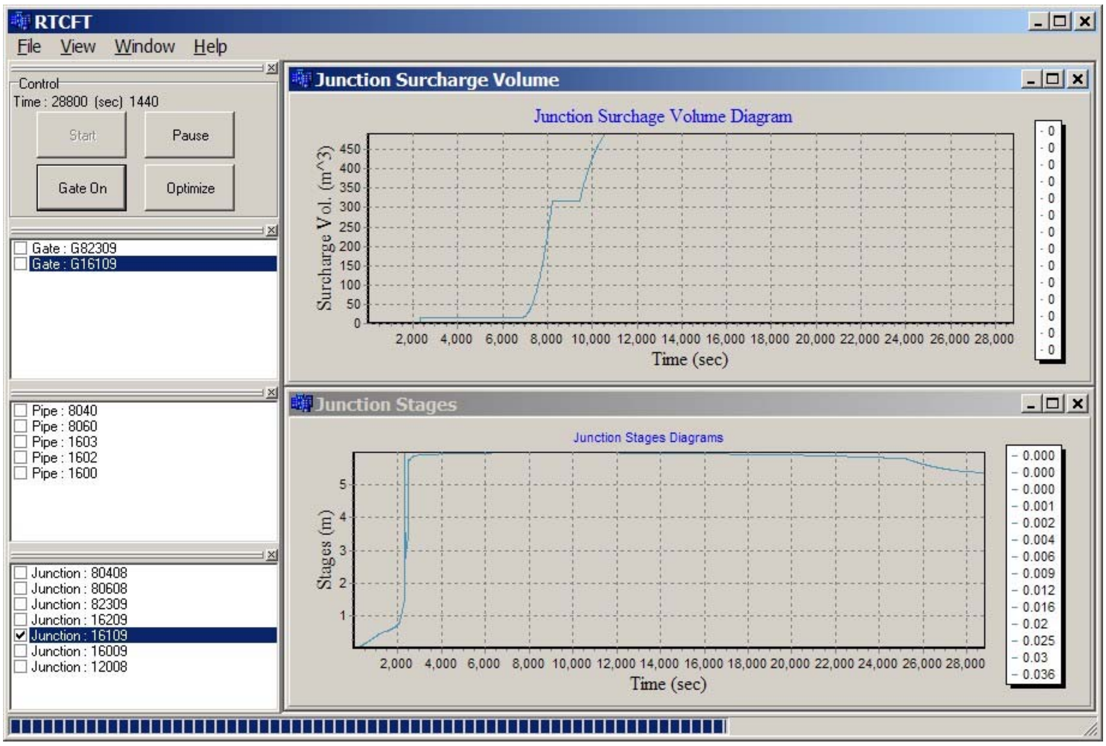

Figure 6. Hydrographs of water stages and overflow volume at Junction 16109 with gate operations

5 CONCLUSIONS

This paper presents an approach, called the virtual pumps approach, for modeling rapid gate operations in the UDS when surcharge occurs. In this approach, the control gate can be fully opened or partially closed in surcharged flow. An in-house software tool, called RTCFT, that employs SWMM-EXTRAN for storm sewer simulation, has been extended to incorporate the proposed approach for simulating UDS flow with gate control in an on-line manner. The proposed approach has been verified and demonstrated using an idealized drainage system. The simulated results show that the gate closing operations modeled by the virtual pumps approach successfully reduce the overflow rate from the manhole to zero.

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7 REFERENCES

Chaudhry, M.H. (1993). *Open-channel flow*. Prentice Hall, Eaglewood Cliffs, N.J.

Guo, Q. and Song, C.S. (1990). “Surging in Urban Storm Drainage Systems.” *Journal of Hydraulic Engineering*. Vol. 116, No. 12, pp. 1523-1537.

Huber, W. C. and Dickinson, R. E. (1988). *Storm Water Management Model. User’s Manual Ver. IV*. U. S. Environmental Protection Agency.

Li, J. and McCorquodale, A. (1999). “Modeling Mixed Flow in Storm Sewers.” *Journal of Hydraulic Engineering*. Vol. 125, No. 11, pp. 1170-1180.

Lin, S.S., Hsieh, S.H., Kuo, J.T., Liao, Y.P., and Chen, Y.C. (2004). “Integrating Legacy Components into A Software System for Strom Sewer Simulation.” *Environmental Modelling and Software* (in review).

Nelen, F. (1993). “On The Potential of Real Time Control of Urban Drainage Systems.” *Water Science and Technology*, Vol. 27, No. 5-6, pp. 111-122.

Neugebauer, K., Schilling, W., and Weiss, J. (1991). “A Network Algorithm for the Optimum Operation of Urban Drainage Systems.” *Water Science and Technology*. Vol. 24, No. 6, pp. 209-216.

Rauch, W. and Harremoës, P. (1999). “Genetic Algorithms in Real Time Control Applied to Minimize Transient Pollution from Urban Wastewater Systems.” *Water Research*, Vol. 33, No. 5, pp. 1265-1277.

Schilling, W. (1989). “Real Time Control of Urban Drainage Systems, The State-of-the-Art.” *IAWPRC Scientific and Technical Reports No. 2*. Pergamino, Oxford, UK.

Yen, B.C. (1978). “Hydraulic instabilities of storm sewer flows.” *Proc. International Conference on Urban Drainage*. University of Southampton, Southampton, U.K., pp. 283-293.