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Annotated Bibliography of Urban Wet Weather Flow Literature from 1996 through 2006

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drainage and highway runoff in cold climates. Other papers at the conference addressed the implementation of stormwater treatment practices for urban snowmelt and winter runoff quality. Many of these conferences produced summary papers of what is known and where the knowledge gaps still exist. Moeller (2003) reviewed the "frontiers of research" in stormwater as seen by the Water Environment Research Foundation based on their survey of stormwater program managers, consultants and others. The paper also addressed WERF's efforts to advance stormwater research based on the identified needs. Delleur (2003) summarized the evolution of urban hydrology from 6000 B.C. to modern times and advocated the industry moving away from compartmentalized views of the environment (especially as it related to computerized models) and toward an integrated approach based on sustainability of water resources.

Major proceedings related to wet-weather flow (WWF) published during 2002 were the following: (1) Engineering Foundation Conference "Linking Stormwater BMP Designs and Performance to Receiving Water Impact Mitigation" (ASCE, 2002); (2) "Global Solutions for Urban Drainage," Ninth International Conference on Urban Drainage (ASCE, 2002); (3) WEFTEC, 2002, 75th Annual Conference and Exposition (WEF, 2002); (4) Best Modeling Practices for Urban Water Systems, Monograph 10 (CHI, 2002); (5) Watershed, 2002 Conference (WEF, 2002); (6) WEF/CWEA Collection Systems, 2002 Conference

Based on the past 30 years of research on urban WWF water quality, impact, modeling, control, and treatment demonstrated results, Field *et al.* (1997a) delineated a framework of future research directions for risk management of urban WWF.

Characterization

WISE (Watershed Improvements through Statistical Evaluations) Model was designed to link the watershed pollutant correlation in concentration between COD and SS and biochemical oxyegen demand (BOD) and SS. The study further discussed the most appropriate way to characterize the quality of the outflow comparing average concentration and accumulated event mass methods (Larsen *et al.*, 1997a).

Numerous papers at the 7th International Conference on Urban Storm Drainage held in Hannover, Germany (Sieker and Verworn 1996), presented broad-based stormwater data from throughout the world, including data from Denmark and the Netherlands (Grum *et al*., 1996), from Poland (Bartkowska and Królikowski, 1996), and from Japan (Uchimura *et al.*, 1996).

Bannerman *et al.* (1996) conducted a study for the USGS in conjunction with the Wisconsin Department of Natural Resources in which water-quality data from four urban stormwater-monitoring projects conducted between 1989 and 1994 were compiled. Concentrations of many of the constituents including Pb; Zn; Cu; Ag (silver); Cd; nine PAHs (polycyclic aromatic hydrocarbons); bis(2-ethylhexyl) phthalate; DDT; atrazine; alachlor, 2,4-D; SS; chlorides; total rainfall events, design storms, IDF curves and long-term continuous simulation). Walter, *et al*. (2003) demonstrated that Hortonian flow (which was assumed to occur whenever the rainfall exceeded the soil permeability) was not a dominant process for undeveloped areas in the New York City watersheds.

Ragab, *et al.* (2003a) investigated the effect of slope and aspect on the proportion of the rainfall that was captured by residential roofs and that evaporated from the roof. Noticeable differences in rainfall, runoff and evaporation were found for different roof slopes, aspects and heights. The authors also (2003b) investigated the effect of road infiltration and evaporation on the proportion of rainfall on UK residential roads that became runoff. Six to nine percent of the annual rainfall infiltrates through the road surface while evaporation removes 21-24% of annual rainfall.

Current forecasting systems from meteorological offices have not been well suited for accurate rainfall forecast in urban areas (Aspergren et al., 2001). This project provided a short-term small-scale prediction of rain based on radar images. The extrapolation part of the methodology, based on a sophisticated cross correlation of images, was optimized by a neural network technique. Three different application sites in Europe have been used to validate the system. Burian et al.

Sheeder et al. (2002) investigated the hydrograph responses to dual rural and urban land uses in three small watersheds. Two important conclusions were deduced from this investigation. First, in all cases, the re was most evident on small plots and during extreme events, such as when rain occurred on frozen, snow-free ground.

In the On-Cheon Stream watershed in Pusan, Korea, the peak discharge of runoff increased and the mean lag time of the study area decreased due to urbanization over the past two decades (Kang et al.,1998). It was not possible to determine a priori what mechanism dominated storm runoff in suburban and forested basins (Burges et al., 1998). While 12—30% of annual precipitation became runoff in the forest basin, 44—48% became runoff in the suburban basin, emphasizing the need to consider surface flow from all sources in the catchment when evaluating mitigation measures. An evaluation of precipitation records revealed that the majority of storms at most locations are relatively small and produce less precipitation and runoff than is often used in the design of traditional drainage networks (Urbonas, 1998). These storms need to be targeted when attempting to mitigate the effects of urbanization on the receiving waters.

Rainfall errors and flow forecasting

Kawaguchi et al. (1999) presented a case study of short-term rainfall characteristics that showed considerable changes in rainfall intensity during the past 40 years, where the 20-minute rainfall intensity having a 10-year return period increased by 20 mm/hr. This increase in the design storm characteristics has a profound effect on the performance of urban drainage

One of the most unappreciated tasks associated with stormwater characterization is an understanding of urban-rainfall patterns and rainfall-monitoring requirements. The Danish Meteorological Institute (Mikkelsen *et al.*, characterized urban runoff quality and load estimations in Canada. Both a site mean concentration approach and a multiple variable regression analysis were used to quantify pollutant loads in urban runoff. The urban runoff in two catchments in Macau was characterized by Huang et al. (2006a). The commercial-residential urban catchment showed high levels of COD, TN, and TP, while the park urban catchment had high TN and TP concentrations.

First-flush and composite storm analyses were conducted by Hudak et al. (2006) in small urban and rural watersheds in north-central Texas. Observed concentrations of most parameters were low. Fecal coliforms and lead were detected in most samples, with the highest lead concentrations observed in the most developed watershed. Dry weather pollutant buildup and subsequnet washoff was investigated in Australia by Ashraf and Khan (2006). They concluded that total dissolved oxygen (DO) and associated pollutants present significant temporal and spatial variations.

Managaki et al. (2006) investigated the 3-D distributions of sewage markers such as fluorescent whitening agents (FWA) in Tokyo Bay. In summer, FWAs predomin

urban runoff. Tests of differences in composition of benthic communities among estuaries showed that the two urban estuaries were not significantly different, but that they differed from both rural estuaries. Noble et al. (2003) compared total coliform, fecal coliform and enterococcus bacterial indicator counts along the southern California shoreline. The results suggested that replacing the total coliform standard with an enterococcus standard would lead to a five-fold increase in failures during dry weather and a doubling of failures during wet weather, while replacing the total coliform standard with one based on all three indicators will lead to an eight-fold increase in failures.

Fan et al. (2003) presented procedures for estimating solids pollutant loads in stormwater, including equations for litter and flotables, solids on highways, sand for highway-ice control, and solids due to resuspension of sediment in urban sewers with the results demonstrating the significant contribution due to resuspension of solids in combined sewers during storm events. Cristina and Sansalone (2003) investigated the solids (between 2 and 75 μm) loading in runoff from a transportation facility. Their results showed that particle delivery was not associated with a "first flush" but instead continued throughout the storm and followed the storm hydrology.

typical pollutants, i.e., Fe, Zn, nickel (Ni), nitrate as nitrogen (NO_3-N), and nitrite as nitrogen (NO_2-N), leaving a highway construction site near Houston, Tex.

Thomson *et al.* (1997a) examined the relationships between surrogate parameters (i.e., SS, TDS, total volatile solids, and TOC) and other constituents of interest (e.g., metals, ionic species, and nutrients) by using the Minnesota highway stormwater quality database for regression analysis. The findings indicated that the metal and nutrient constituent relationships were limited to urban sites with similar environmental conditions. Further, statistical model analysis of monitoring results (Thomson *et al.*, 1997b) concluded that approximately 15 — 20 samples are required to prouab-lre4.8(en)n14.503 -

Both the range and the absolute values of TP content tend to increase with an increase in the level of urbanization and industrialization.

Ball and Abustan (2000) investigated the phosphorus export from an urban catchment in Sydney, New South Wales, Australia, and derived a relationship between inorganic suspended solids and particulate phosphorus for this catchment. These results were to be used to predict the performance of detention ponds and/or wetlands for treating this runoff.

Sixteen largely agricultural watersheds in the upper portion of the North Bosque River of central Texas were reported by McFarland and Hauck (1999). The proportion of total P (TP) in runoff represented by soluble reactive P (SRP) also increased as the percent of dairy waste application fields above a sampling site increased.

Fluxes of total phosphorus (P), total phosphate, and total organic P from seven small watersheds on the Atlantic Coastal Plain of Maryland for up to 25 years were reported by Correll et al. (1999), indicating cropland watershed's P flux were much higher than forested watershed and increased significantly with precipitation. The Bear Brook Watershed in Maine (BBWM) was the sight of a paired watershed study in which the West Bear (WB) catchment was being artificially acidified with 1,800 eq ha^{-1} y^{-1} of $(NH_4)_2SO_4$ resulting in changes in the soil and stream chemistry, while the East Bear (EB) serves as the control (Norton et al., 1999). P chemistry in streams was evaluated at the pair watershed study at the BBWM, indicating the export of Al and P was greater from the treated watershed because the induced acidification was translocating more Al from soils to the streams and the export of P was related to acid-soluble Al particulate material (Roy et al., 1999). One hundred and sixty-two rainfall-induced soil erosion tests were conducted to assist in predicting soil loss and subsequent increase in total suspended solids, indicating soil loss was dependent upon rainfall intensity, and the soil's shear and compressive strength (Liu et al., 1999). After six years of monitoring flow and water quality Jaynes et al. (1999) conclude nitrate appears to be the primary agriculturally related pollutant of concern in Walnut Creek, California thus management practices designed to reduce NO_3 leaching from fields and increase removal within the watershed/stream system should receive primary consideration.

Microorganisms

Traister and Anisfeld (2006) examined the variability of indicator bacteria at different time scales in the upper Hoosic River watershed. Bacterial levels were higher in more developed watersheds; higher in summer than in winter months; higher in storms compared to baseflows; and higher in early morning compared to afternoon runoff periods. Shanks et al. (2006) evaluated the dynamics of fecal sources and contamination in an Oregon bay. Fecal sources were statistically linked more closely to ruminants than to humans; there was a 40% greater probability of detecting a ruminant source marker than a human source marker across the basin. In southern Lake Michigan, rainfall events were found to increase E. coli counts in the near-shore sands and lake waters, but they rapidly declined to pre-rain concentration. The authors said that when examining indi discharged from the rivers. River discharge was significantly associated with bacterial levels at 20 out of 22 beaches, with the strongest associations at sites next to rivers. The results indicated that urban river discharge is a primary source of Southern California's coastal water pollution and, as a result, swimming at beaches near rivers may pose a significant public health risk. Paul et al. (2002) reviewed the Bacterial TMDL for impaired water bodies in Texas. The primary aim of the study was to explore the possibility of clustering the waterbodies into groups having similar watershed characteristics. Studying the watersheds as a group would reduce the number of required TMDLs and thereby will help in reducing effort required for restoring the health of the impaired waterbodies in Texas. The main characteristics being considered for the classification of waterbodies were designated use of the waterbody, sources of pathogens, frequency of water quality violation, location and type of the waterbody, and the size of the watershed.

Jeng et al. (2002) investigated the fate of indicator organisms (fecal coliforms, E. coli, and enterococci) in stormwater runoff when the water enters brackish recreational waters. Results indicated that satisfactory water quality of Lincoln Beach was observed during dry weather periods. Concentrations of indicator organisms in both water column and sediment, however, significantly increased during and after heavy stormwater runoff, particularly at sites near the Jahncke Canal discharge point. However, the elevat

time (less than 30 minutes) could result in a majority of the heavy metal mass remaining in solution at the edge of the pavement with trends in partitioning only approaching equilibrium conditions towards the end of the event as heavy metals partition to entrained solids.

Fatoki et al. (2002) investigated trace metal pollution in the Umtata River. High levels of Al, Cd, Pb, Zn and Cu were observed, which may affect the "health" of the aquatic ecosystem. Generally the sources of the metals in the river appeared to be diffuse, including rural, urban and agricultural runoff sources in the catchment. Tuccillo (2002) analyzed heavy metals in stormwater at six outfalls draining nonindustrial land uses in Monmouth County, New Jersey. Of the heavy metals, only Cu and Zn were found in all samples, mostly in dissolved form. Larger colloids (≥0.45 μm) were composed mostly of Fe, Al, and Si. Organic colloids were found mostly in the 0.01-0.45-μm-size range. Wardas et al. (2002) investigated the levels of heavy metals in sediments of the water and wastewater system in Cracow. Estimation of the quantity of metals in samples was done based on sediment samples from "Rudawa", "Dlubnia" and "Raba" drinking water plants and "Plaszow" and "Kujawy" sewage treatment plants.

Buffleben et al. (2002) investigated the concentrations of hazardous metal pollutants associated with the aqueous and suspended solids phases entering Santa Monica Bay from the Ballona Creek watershed during wet weather flow. Other objectives of this study were to evaluate during a storm event the relationship between (1) soluble and sorbed metals, (2) storm flow and pollutant loading, including a determination of a first flush was present, and (3) total mass loading of pollutants and relative pollution loading from three watershed sub-basins. The results indicated the suspended TJ-15.29s.6(o)-9ws

structures rich in Si, Al, and Fe. Colloids were mostly composed of silica during periods of dry weather flow and at the maximum of the stormwater flow, while carbon dominated the colloidal fraction at the beginning and declining stages of the storm events. Garnaud et al. (1999) examined the geochemical speciation of particulate metals using sequential extraction procedures for different runoff sources in Paris, France. They found that most metals were bound to acid soluble particulates in the runoff but that copper was almost entirely bound to oxidizable and residual fractions.

Datta and Subramanian (1998) report that despite a very dense population in its watershed, the lower Ganges-Brahmaputra-Meghna drainage basin remains relatively-unperturbed alluvial basin with regards to heavy metal pollution, due in part to a very high rate of sediment deposition.

A study by Sansalone and Buchberger (1997) analyzed stormwater runoff at five sites on a heavily traveled roadway in Cincinnati, Ohio. They found that the the event-mean concentrations (EMC) of Zn, cadmium (Cd), and copper (Cu) exceeded surface-water-quality-discharge standards. Further, it was noted that Zn, Cd, and Cu are mainly in the dissolved form while other metals, i.e., lead (Pb), Fe, and aluminum (Al) are mainly bound to particles.

Analytical techniques were used to determine the speciation of Cu and Ni in point and non-point source (NPS) discharges and found that the existence of a strong metal-complexing ligand in wastewater effluent, and to a lesser degree, surface runoff must be accounted for when evaluating metal treatability (Sedlak *et al.*, 1997).

Organic toxicants

Hwang and Foster (2006) characterized the PAHs in urban runoff flowing into the tidal Anacostia River. Most PAHs were associated with the particle phase and the higher molecular weight PAHs were ascribed to automobile-originated pyrogenic PAHs. A comparison of agricultural, industrial and urban area runoff was performed by Masco et al. (2006). In this study, the industrial and agricultural sources were predominant. Wada et al. (2006) investigated the characteristics of refractory dissolved organics in stormwater runoff. Treatment by soil infiltration reduced their concentrations.

Suarez et al. (2006) examined the levels

catchments, with the median concentration in combined sewer overflows of 204 ng/L. Phenanthrene, anthracene, fluoranthene and pyrene were the most observed compounds. The results indicated that atmospheric deposition was an

Several stormwater-runoff samples were accurately evaluated for oil and grease with an alternative analysis method using octadecyl siloxane (^{18}C) solid-phase-extraction columns. The amount of the solvent was reduced and more reproducible results were obtained using this alternative method (Lau and Stenstrom, 1997).

Crunkilton and Devita (1997) investigated the concentrations of freely dissolved polycyclic aromatic hydrocarbons (PAH) in an urban stream at high flow and baseflow by an equilibrium partitioning model (EPM) and by use of lipid-filled semipermeable membrane devices (SPMD). The results, compared to direct measurements made on bulk (unfiltered)

Andral et al. (1999) analyzed particle sizes and particle settling velocities in stormwater samples collected from eight storm events from the A9 motorway in the Kerault Region of barite from automobile brake, or rare earth ohi3.7(hd)-17(hes)7.2(f)5troca hal3.7(hy4.3ra)3.7(hi3.7(hc)2(exhaus)3.7(h)6(opi3.7(hpes)7.

easily eroded by small storm events. A second publication by Ahyerre et al. (2001b), as part of the same sewer investigation, reported that the erosion does not occur only locally but along the entire length of the section evesa(nc(h)-1.8(t)3.6(aesa

8(nse)7occ2-4.2fac(nt)9an 5(nse)4.2kAimmsam5 5(dgt)9.6f a (5(rcc2-57(nt)9kept b)83byn)d 4431( )]TJ30 -1.0012 5D0.00121-0.00th

coefficient, the lift coefficient, solid de

Barber et al. (2006) identified the sources and impacts of organic and inorganic contaminated in the Boulder Creek Watershed using a holistic watershed approach. The report documented a suite of potential endocrine-disrupting chemicals in a reach of stream with native fish populations showing indication of endocrine disruption. Hao et al. (2006) analyzed the quality of the runoff in Beijing and found that roadway runoff was oversaturated with respect to calcium carbonate while rainwater was undersaturated. Tournoud et al. (2006) investigated the origins of nitrogen into a French coastal lagoon. Compared to the other sources investigated, urban runoff was found to be a negligible source.

Sabin et al. (2006b) examined the dry deposition of trace metals in the coastal region of Los Angeles, California. Mean concentrations and fluxes were significantly higher at urban sites compared with the nonurban sites, although differences between urban and nonurban sites were reduced when sampling took place within 5 d after rainfall. An analysis of a wastewater treatment plant influent by Rule et al. (2006) showed that the heavy metals entered the plant from many diffuse sources. Runoff concentrations were higher in the light industrial samples than in the residential samples for all the heavy metals.

Stein et al. (2006) showed that PAHs exhibited a moderate first flush effect in Los Angeles, California, urban runoff. The relative distribution of individual PAHs demonstrated a consistent predominance of high-molecular-weight compounds indicative of pyrogenic sources.

Surbeck et al. (2006) fingerprinted fecal bacteria and suspended pollutants in runoff in a southern California coastal watershed. The different flow fingerprints observed for fecal pollutants and for TSS reflected different sources and transport pathways for these stormwater constituents. Scopel et al. (2006) examined the influence of nearshore water dynamics and pollutant sources on beach monitoring results in Lake Michigan. Areas near a stormwater discharge and a CSO outfall had E. coli levels above the recommended EPA limits for recreational waters.

The division of Biscayne Bay (Florida) into five zones of water quality based on contributing land use was reviewed by Caccia and Boyer (2005). Influencing water quality were sewage treatment plants, agriculture and general urban runoff. Zeng and Rasmussen (2005) used multivariate statistics to characterize water quality in Lake Lanier (Georgia). Tributary

facility’s stormwater outfall. Sediment samples taken belo were minor sources of sterols and anionic surfactants. Toombes and Chanson (2005) investigated the air-water mass transfer on a stepped waterway. Stepped waterways have been incorporated in storm water systems to improve the oxygen aeration efficiency. Van Der Velde et al. (2005) discussed the benefits of air pollution control on improving the water supply in the Netherlands. The primary benefit was the reduction of acidification of the water.

Sabin et al. (2005) studied the contribution from atmospheric deposition to the trace metal loadings in stormwater runoff in an impervious urban catchment. Atmospheric deposition accounted for over half, up to almost all, of the total trace metal loads in the runoff. Local anthropogenic sources were found to be substantial contributors to wet deposition of mercury in southern Florida (Dvonch et al. 2005). Higher concentrations were also found during the spring and summer compared to winter. Wang et al. (2005a) investigated the exchange flux of mercury from coal-burning power plants in China. Mercury accumulation was measurable in waters, soils and plants.

Rossini et al. (2005) investigated the atmospheric fall-out of persistent organic pollutants in an industrial district in Italy. The results showed that the atmospheric input was the same order of magnitude as that due to watershed runoff and approximately half of the direct industrial discharge.

Schiff and Stolzenbach (2003) investigated the heavy-metal contribution of atmospheric deposition to Santa Monica Bay and compared the atmospheric deposition loading to the loading from other sources. The annual atmospheric deposition of chromium, copper, lead, nickel and zinc exceeded the estimated annual effluent loads from industrial and power generating stations to Santa Monica Bay.

Yunker et al. (2002) investigated the sources of PAHs in the Fraser River Basin (British Columbia). PAH ratios and total concentration data revealed a basin lightly impacted by a variety of sources in its remote regions, especially near roads, but heavily impacted in urban areas, particularly near Vancouver. Contamination sources shift from biomass (e.g. wood and grass) burning to vehicle emissions between remote and urban locations. Stormwater and wastewater discharges appeared to collect PAH from urban areas and release them as point sources. In all cases the examination of a variety of PAH indicator ratios that encompass a range of masses is necessary for a robust interpretation.

Ahn and James (2001) report that atmospheric deposition is a substantial source of phosphorus to the Florida Everglades.

Florida's aquatic system. Outliers were detected by field notes, derived from visual inspection of the samples, and statistics, based on simple linear regression used for additional screening. Based on detected outliers in the data from 115 monitoring sites, a lumped cutoff value, used for further quality control, of 130 Fg/L was determined (Ahn, 1999).

Garnaud et al. (1999) studied heavy metal concentrations in dry and wet atmospheric deposits in Paris, France, for comparison with urban runoff. Samples were continuously collected for 2 to 13 months at each of four test sites. Comparisons of median values of metal concentrations showed that rainwater contamination with heavy metals was only slightly higher in the center of Paris than at Fontainebleau (48 km SE of the city) which illustrates the medium range transport of atmospheric contamination.

Atasi et al. (1999) used specialized sampling equipment and ultra-clean analytical methodology to quantify the concentrations or fluxes of mercury, cadmium, and polychlorinated biphenyl in ambient air, precipitation, runoff, sanitary sewage, and treated sewage in Detroit, significant contributors of metals to runoff, although Zn-covered roofs released Zn and Ti, while Slate roofs mainly released Pb, Ti and Cu. Near chimney stacks, Ni and V concentrations were elevated. Liu et al. (2004) proposed a new coating of Zn-Ca phosphating/acrylic resin-SiO2 which can stabilize the rusting of steel.

Clark et al. (2003) studied the potential pollutant contributions from commonly-used building materials (roofing, siding, wood) using a modified Toxicity Characteristic Leaching Procedure (TCLP) test. Results of particular interest included evidence of elevated levels of phosphate, nitrate and ammonia in the leachant following exposure of common roofing and siding materials to simulated acid rain.

Polkowska et al. (2002) presented the results of testing roof runoff waters from buildings in Gdafisk, Poland. More than half of the samples (25) were found to be toxic, with inhibition exceeding 20%. The toxicity was weakly correlated to the levels of organonitrogen and organophosphorus pesticides in runoff waters. It was established that at least in some cases the roofing material affected the levels of the pollutants found in the samples. Heijerick et al. (2002) investigated the bioavailability of zinc in runoff from roofing materials in Stockholm, Sweden. Chemical speciation modeling revealed that most zinc (94.3-99.9%) was present as the free Zn ion, the most bioavailable speciation form. These findings were confirmed by the results of the biosensor test (Biomet™), which indicated that all zinc was indeed bioavailable. Analysis of the ecotoxicity data also suggested that the observed toxic effects were due to the presence of Zn^{2+} ions. Gromaire et al. (2002) investigated the impact of zinc roofing on urban pollutant loads in Paris. On an annual basis, runoff from Parisian zinc roofs would produce around 34 to 64 metric tons of zinc and 15 to 25 kg of cadmium, which is approximately half the load generated by runoff from all of Paris.

Karlen et al. (2002) investigated runoff rates, chemical speciation and bioavailability of copper released from naturally patinated copper roofs in Stockholm, Sweden. The results show annual runoff rates between 1.0 and 1.5 g/m^2 year for naturally patinated copper of varying age with rates increasing slightly with patina age. The total copper concentration in investigated runoff samplings ranged from 0.9 to 9.7 mg/l. The majority (60 – 100%) of the released copper was present as the free hydrated cupric ion, $Cu(H_2O)6^{2+}$, the most bioavailable copper species. The copper-containing runoff water, sampled directly after release from the roof, caused significant reduction in growth rate of the green alga. Wallinder et al. (2002) studied the atmospheric corrosion of naturally and pre-patinated copper roofs in Singapore and Stockholm. Measured annual runoff rates from fresh and brown prepatinated were 1.1-1.6 g/m^2 and 5.5-5.7 g/m^2, in Stockholm and Singapore, respectively. Naturally aged copper sheet (130 years old) and green pre-patinated copper sheet showed slightly higher (1.6-2.3 g/m^2), but comparable runoff rates in Stockholm. In Singapore, runoff rates from green pre-patinated copper sheet were 8.4-8.8 g/m2

Foerster (1999) and Foerster et al. (1999) reported on studies investigating roof runoff as stormwater pollutant sources. Runoff samples were taken from an experimental roof system containing five different roofing materials and from house roofs at five different locations in Bayreuth, Germany. It was found that local sources (e.g. PAH from heating systems), dissolution of the roof systems' metal components, and background air pollution were the main sources of the roof-runoff pollution. They found that the first flush from the roofs often was heavily polluted and should be specially treated. They concluded that roofs having metal surfaces should not be connected to infiltration facilities as concentrations of copper and zinc far exceed various toxicity threshold values. They also examined a green (vegetated) roof for comparison. These roofs were found to act as a source of heavy metals which were found to be in complexes with dissolved organic material. Leaching from unprotected

Particle-associated PAHs in the first-flush runoff from a highway were investigated by Aryal et al. (2006). In general, the fine-particulate fraction was greater in the runoff, although the coarse fraction increased as the runoff volume increase. In addition, PAH loadings to the fine particulates was less variable than the loadings to the coarse particulates. Motelay-Massei et al. (2006) applied a mass balance to PAHs in an watershed in France. A comparison of atmospheric deposition and runoff output showed the importance of street deposits as a source in urban areas. Simon and Sobieraj (2006) reviewed the potential contributions of common sources of

The applied composts generally contained much greater pollutant concentrations than the conventional treatments for soluble and adsorbed Zn, P, and K, and adsorbed Cr and Cu. However, when comparing mass loads, compost performed as well as the two conventional soils used for highway embankments.

Kayhanian et al. (2003) investigated the relationships between annual average daily traffic (AADT) numbers and highway runoff pollutant concentrations from California Department of Transportation highway sites. No direct linear correlation was found between highway runoff pollutant event mean concentrations (EMCs) and AADT, but multiple linear regression showed that AADT, as well as antecedent dry period (ADP), drainage area, maximum rain intensity and land use, influenced most highway runoff constituent concentrations.

Mishra et al. (2003) developed hysteresis and normal mass rating curves were developed for runoff rate and mass of 12 dissolved and particulate-bound metal elements from Cincinnati, OH. Zinc was found to increase with antecedent dry period (ADP). Shinya et al. (2003) evaluated the factors influencing diffusion of highway pollutant loads in urban highway runoff. Particulates (suspended solids, iron and TP) were inclined to be washed off in heavier rainfall; event mean runoff intensity and cumulative runoff height were correlated with cumulative runoff load of the constituents except TN. ADP and traffic flow volume were not correlated with cumulative runoff load (except TN).

Sutherland (2003) investigated the lead in six grain-size fractions of road-deposited sediment from Oahu, HI. Significant of traffic activities and winter maintenance on the behavior of particulates in the runoff. They found that urban snow has a much greater capacity to accumulate traffic-related pollutants, et al. (2000). This presentation included an evaluation of past work on stormwater runoff from transportation facilities and a prioritization of future research in this area.

Walker et al. (2000a) reviewed the on-going water quality assessment program implemented by the San Diego region of the California Department of Transportation (Caltrans). Constituents of concerns were being targeted for monitoring and potential remediation. The thermal enhancement of stormwater runoff by paved surfaces was investigated by Van Buren et al. (2000a and 2000b). The results from the test-plot studies were used to help develop, calibrate and verify the wet-weather model TRMPAVE, a mathematical model that uses an energy balance to predict the temperature of the runoff. Glenn et al. (2000) found that the snow residuals along highways had high levels of particulate and solid matter, likely from nearby vehicular traffic. Snow also accumulated traffic-based pollutants to a greater degree.

In the Kerault Region of France, the effects of pollution were studied using solid matter from a section of the A9 motorway. This study analyzed both settled sediments from collecting basin and characteristics of sediments in the water column during and after eight storm events between October 12, 1993, and February 6, 1994. Settled sediments were used to measure particle sizes, mineral content, and related characteristics, whereas water samples were used to document total suspended solids, mineral content, and heavy metals (Andral et al., 1999).

Runoff from highways contains significant loads of heavy metals and hydrocarbons, according to German regulations it should be infiltrated over embankments to support groundwater recharge. To investigate the decontaminating effect of greened embankments, soil-monoliths from highways with high traffic densities were taken. Soils were analyzed to characterize the contamination in relation to distance and depth for lead, zinc, copper, cadmium, PAH and MOTH (Dierkes and Geiger, 1999).

The quality of highway runoff monitored in the Austin, Tex. area at three locations on the MoPac Expressway were similar in constituent concentration to median values compiled in a nationwide study of highway runoff quality (Barrett et al., 1998a). A grassy swale at one site which had a lower runoff coefficient due to infiltration reduced concentrations of most constituents in runoff. The pollutants available for transport during storm events of a suburban road in the eastern suburbs of Sydney, Aust. were significantly different from published data for North Am. (Ball et al., 1998). Both rain and wind events lowered the available pollutant constituent mass on the road surface. Fourteen composite samples of Marinette, Wis. stormwater, as well as baseflow samples, were analyzed to determine requirements for a National Pollutant Discharge Elimination System (NPDES) permit and the results indicated similarity to stormwater found in other communities (Scholl and Lauffer,1998). Measurements of conductivity and turbidity taken in a study of the Crum Creek which runs through the suburbs of Philadelphia, Pa. indicated two stages during the first three hours of wet weather runoff: a dissolved solids flush followed by a suspended solids (SS) flush (Downing and McGarity, 1998).

In San Francisco, Calif., vehicle emissions of both ultrafine (< 0.12 m) and accumulation mode (0.12 —2 m) particulate polycyclic aromatic hydrocarbons (PAH) are derived from diesel vehicles while gasoline vehicles emit higher molecular weight PAH primarily in the ultrafine mode. Heavy duty diesel vehicles were found to be important sources of fine black carbon particles (Miguel et al., 1998). In a European study, 90% of the particles from a contaminated highway runoff catchment were smaller than 100 m. The constituents of the contaminants smaller than 50 m were further analyzed by X-ray diffraction, thermogravimetry and specific mass and contained 56% clay, 15% quartz, 12% chalk, 9% organic matter, 5% feldspars, and 2% dolomite (Roger et al., 1998).

Several researchers investigated roadway storm runoff as a nonpoint pollution source and reported their results at the 7th International Conference on Urban Storm Drainage in Hannover (Sieker and Verworn, 1996). Wada and Miura (1996) examined storm runoff from a heavily traveled highway in Osaka, Japan. A significant “first-flush” for COD was found and the amount of small rubber pieces from tire wear in the highway storm runoff was more than 20 times greater than for an “ordinary” road. The primary factors affecting storm runoff concentrations were the amount of traffic (and related exhaust emissions and tire wear) and the fraction of the total traffic that was comprised of trucks and buses. Montrejaud-Vignoles *et al.* (1996) collected storm runoff from a heavily used six-lane motorway in the Mediterranean area of France. The very irregular rainfall in this area and associated very-long dry periods can result in storm runoff that is much more polluted than elsewhere in France. As an example, during the one-year study, a single rain of only 10 mm but having an antecedent-dry period of 35 days, produced more than 12% of the annual COD discharges. Ball *et al.* (1996) examined roadway pollutant accumulations in a suburb of Sydney, Australia. It was concluded that the local heavy winds have a significant effect on pollutant accumulations that commonly available stormwater models do not consider, and that historical United States’ data on roadway-pollutant accumulations are much greater than found in their area. Sansalone and Buchberger (1996) studied metal distributions in stormwater and snowmelt from a major highway in Cincinnati, OH. Zn and Cd were mostly in filterable (dissolved solids) forms in the storm runoff, while lead was mostly associated with particulates.

Deicing Discharges and other Cold Weather Sources

Reinosdotter and Viklander (2006) discussed the handling of urban snow in Sweden with regards to water quality. The results showed the importance of both the location and time of the snow, i.e., what happens to the snow while it stays on the ground. Richardson and Tripp (2006) studied the boundary shear stresses and pollutant detachment mechanisms of four chloride salts from impervious surfaces during simulation urban runoff. In general, higher overland flow rates produced lower boundary shear and lower washoff coefficients. Corsi et al. (2006) characterized aircraft deicer in airport snowbanks and snowmelt runoff. The results showed that glycol was not a good tracer to predict fate and transport of the de-icing and anti-icing products.

Mericas (2005) reviewed recent advances in airport stormwater management and in particular, how this relates to deicing of aircraft and surfaces. Research is ongoing into alternatives to glycol-based deicing fluids. Dillon and Merritt (2005)

Wastewater, Combined Sewer Overflows (CSOs), and Sanitary Sewer Overflow (SSO) Sources

Pollutant associations in stormwater in combined sewers were investigated by Anta et al. (2006) in Galicia (Spain). Measurements of pollutants in the combined sewage were correlated with event parameters and were compared with measurements in other catchments. Li and Li (2006) studied the characteristics of high-density residential CSOs in Shanghai. BOD was lognormally distributed, and correlations between EMCs of COD, suspended solids and the ratio of antecedent dry weather to rain duration were good.

Lawler et al. (2006a) examined the dynamics of suspended sediment for storm events in an urbanized river in the United Kingdom. In this catchment, first flushes of sediment from the combined sewers were not seen, with turbidity peaks lagging the flow maximum. This result was likely influenced by CSOs or wastewater treatment works, which discharge high flows late in the storms.

Arnone and Walling (2006) studied Cryptosporidium and Giardia concentrations, as well as more traditional indicator organisms, in combined sewer overflows (CSOs). CSOs were not found to be a significant contributor of Cryptosporidium, but were a Giardia source. Bai et al. (2006) modeling enterococci in the tidal area of the Christina River. The model results revealed that the enterococci concentrations were due to wash off of manure from agricultural lands in the watershed during storms and direct deposits of animals into the waterway. CSOs only affected limited areas around the outfalls since the dilution is strong in the tidal Christina River.

Hochedlinger et al. (2006) used UV/VIS-spectroscopy to correlate absorbance and CSO pollutant load concentrations. The correlations/regressions were incorporated into a model, with the model results showing that the complexity of the model did not affect the quality of the results. Gasperi et al. (2006) examined the spatial variability of PAH loads in CSOs. The runoff contribution to the PAH load was constant, while the dry weather flow load increased with increasing
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Woodward et al. (2004) reviewed the water-quality monitoring portion of the Overflow Abatement Program in Nashville, Tennessee. The purpose of the program was to understand the relationship betw indicated that sediments proximate to the CSO outfalls were contaminated with a range of chemicals including toxic metals, PAH, PCB, pesticides, and other organic chemicals. The spatial distribution of these contaminants strongly suggested that the CSO were the primary source of contamination in sediments near these outfalls (Iannuzzi *et al.*, 1997).

Fan et al. (2003) reviewed the sewer sediment control projects conducted by the Wet-Weather Research Program of the US EPA. The projects focused on the relationship between wastewater characteristics and flow-carrying velocity, on the abatement of solids deposition and solids resuspension in sewers, and on the sewerline flushing systems for removal of sewer sediment.

Goodwin et al. (2003) investigated the temporal and spatial variability of sediment transport and yields in the Bradford Beck catchment (UK). The results demonstrated that for individual storms the sediment yields from (y)4.6(resa)]TJ22.9(t)3.9aseT]TJ2

Sauer et al. (1999) reported that grazing animal excretions were not as significant a source of nutrients to runoff water as was poultry litter; such treatments receiving poultry litter had significantly higher losses of nutrients, including those most commonly associated with surface water indices.

Mass balance calculations for a treated and untreated watershed at the BBWM in Maine showed that annual and concentrations from high-density residential areas were higher than those associated with low-density residential and landscaped commercial areas. Concentrations of organisms were significantly affected by the season during which the samples were collected.

Tobiason et al. (2002) performed stormwater bacteria source tracing at Seattle-Tacoma International Airport using the microbial source tracking (MST) technique. The results showed that more than 90% of the fecal contamination in runoff was attributable to animals. More than 60% of the “fingerprints” matched bird sources and 30% matched small mammals and domestic pets. Pigeons accounted for 20 to 25% of the bird sources for two outfalls in particular, and were most likely linked with a pigeon colony found on the terminal rooftop. Overall, less than 10% of the isolates matched human sources, and these were limited to certain sampling stations and events. Overall, the MST study showed that human sources were present sporadically for two airport outfalls and two stream locations, but occurred in small numbers relative to animal sources.

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the maximum contamination being found with the high winter rainfalls and near the outfalls. The occurrence and possible sources of *Giardia* and *Cryptosporidium* in Paris rivers were investigated by Rouquet et al. (2000). The results showed that non-point sources likely influenced parasite concentrations in the rivers. Parasite sedimentation was high, as was the potential for resuspension by urban runoff. Ramirez Toro et al. (2000) presented the study design for investigating water quality in La Parguera in relation to onshore development, stormwater outfalls, and mangroves and sewage treatment toxicity (WET) tests, when combined with traditional chemical analyses, were beneficial in locating sources of toxicity within a watershed.

Pitt et al. (1999) investigated typical toxicant concentrations in stormwater, the origins of these toxicants, and storm and landuse factors that influenced these toxicant concentrations. Nine percent of the 87 stormwater source area samples analyzed were considered extremely toxic (using the Microtox toxicity screening procedure). Thirty-two percent of the samples exhibited moderate toxicity, while fifty-nine percent of the samples had no evidence of toxicity. Vehicle service and parking area runoff samples had many of the highest observed concentrations of organic toxicants. All metallic toxicants analyzed were found in the analyzed samples. Marsalek and Rochfort (1999) also investigated the toxicity of urban stormwater and CSO. Acute toxicity, chronic toxicity and genotoxicity of stormwater and CSO were studied at 19 urban sampling sites in Ontario, Canada, using a battery of seven bioassays. Most frequent responses of severe toxicity were found in stormwater samples (in 14% of all samples), particularly those collected on freeways during the winter months. Compared to r-34.8623 -1.146ei8(o)4.4(xi)3.8(ci)3.8(t)3.8(7(t)3.i7eoo stuon stu sev001 Tw[mucit8(o)4.4, ad gec

estuaries were found to have sediment metals concentrations that were related to the degree of urbanization/industrialization in the watershed. High metals concentrations, including Pb and Zn in Port Jackson (Sydney, New South Wales) which were at levels expected to have adverse environmental/biological effects, were found in the fluvial sediments, indicating that metals are still being added to the estuaries, potentially through stormwater runoff (including land reclamation leachate). Webster et al. (2000) analyzed the sources and transport of trace metals in the Hatea River catchment and estuary in New Zealand. They found that the recently deposited estuarine sediment has elevated levels of Cu, Pb, and Zn from the more densely-populated areas, city stormwater drains and the Cu-containing antifoulants used in the marina. All metals samples obtained from the mixed-land-use areas.

Cadmium. van Geen and Luoma (1999) conducted a five-year study of dissolved Cd in San Francisco Bay, California and adjacent coastal waters. They showed that the composition of surface waters towards the mouth of the estuary was determined largely by the effect of coastal upwelling. However, surface samples collected throughout San Francisco Bay confirmed an internal Cd source unrelated to river discharge. The Cd content of a benthic foraminifer (*Elphidiella hannai*) in a dated sediment core from San Francisco Bay was measured to determine if the water column Cd enrichments in San Francisco Bay could be related to the rapid development of the watershed.

Copper. Copper mine spoil from Touro, A Coruna, Sp. was used in the construction of rural roads and tracks in the surrounding area. Roadside soils, sediment in drainage ditches, and water from first-order streams were analyzed to determine both total Cu content and the Cu fraction susceptible to uptake by plants. Despite some high soil concentrations of total Cu, Cu fraction susceptible to uptake was low in most samples, and no water samples were found to exceed European Community legislation thresholds for drinking water and for supporting fish (Arias et al., 1998).

Lead. Davis and Burns (1999) examined lead concentrations in runoff from painted surfaces. In many tests, high lead concentrations were found (using 100 mL of wash water over 1600 cm^2 of surface). Lead concentrations from 169 different structures followed the following order (median concentrations in the wash water): wood (49 μg/L) > brick (16 μg/L) > block (8.0 μg/L). Lead concentration depended strongly on paint age and condition, with the lead levels from washes of older paints being much higher than from freshly painted surfaces. Lead from surface washes were found to be 70%, or greater, in particulate lead form, suggesting the release of lead pigments from the weathered paints.

Mercury. Bonzongo et al. (1999) studied the impacts of land use and physicochemical settings on methyl mercury levels in the Mobile-Alabama River system. In the Coastal Plain portion of the state, Hg concentrations above the FDA's safe limit have been found in tissues of some fish species in both Fish River and Mobile Bay, Alabama. These rivers/streams receive most of their Hg from NPS (e.g. atmospheric deposition and inputs related to land use within the watersheds). They reported results of detailed investigations aimed to study the biogeochemistry of Hg and other trace metals, specifically the impact of different land-use types within the watersheds on Hg speciation. Glass and Sorensen (1999) examined a six-year trend (1990-1995) of wet mercury deposition in the Upper Midwest of the United States. The annual wet mercury deposition averaged 7.4 μg Hg/m^2-yr and showed significant variations between sites and illustrated significant increasing trends over the monitoring period. Warm (rain) season wet mercury deposition was found to average 77% of total annual wet deposition.

Platinum. Schaefer et al. (1999) studied the increasing concentrations of Pt, Rh, and Pd in urban areas associated with increased use of catalytic converters on automobiles. At a typical urban site, the daily deposition rate of Pt in airborne dust was up to 23 ng/m^2.

Organic toxicants

Pedersen et al. (2006) investigated the presence of organophosphorus pesticides in agricultural and residential runoff. On an area basis, the loads from residential areas may exceed those from row crop sites, and no first flush effects were detected.

The presence of diazinon in rural and urban streams before and after its ban was investigated by Banks et al. (2005). The ban has resulted in substantial reductions in

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A study of methyl tert-butyl ether (MTBE) in an alpine lake in the Sierra Nevada, Calif. suggested that neither highway parameters, with fluoranthene and pyrene having the highest concentrations for any of the organic toxicants (site-median concentrations were about 5 μg/L).

Pitt and Burton (2002) reviewed methods available for the assessment of urban wet-weather flow impacts. The data from the past decade has shown, during numerous receiving water assessment studies that no one single approach (e.g., chemical-specific criteria, benthic microorganisms, or habitat surveys) can routinely be used to accurately determine

h and beneficial use impairment. Each assessment approach or component has associated strengths

llection of specific assessment tools and goals would be highly dependent on local conditions and

02) reviewed the comprehensive long-term monitoring and assessment plan for the San

presented results of field tests of pollutant removal efficienci

Mexico. Site selection was constrained by access, distance, technology and cost, but in spite of these limitations, the

The design of a system for managing rainfall information for sewer system management was described by Vieux and

Fogle and Taraba (2003) overviewed systematic sampling and storm chasing in karst basins. It was determined that storm sampling was not required because the flow-composited storm nitrate-N and total solute sample concentrations were comparable to the systematically collected grab sample concentrations both in value and trend.

Barton et al. (2003) reported on the data analysis tools used by the Metropolitan Sewer District of Greater Cincinnati for portable flow monitoring. Stevens et al. (2003) reviewed Atlanta's procedures for measuring sewage spills by identifying when flow is missing from a pipe. Using recent data, the system learns a rainfall-to-RDII (Rainfall Dependent Infiltration Inflow) relationship for each monitor basin and is able to predict what current flow should be. Hall (2003) analyzed flow monitoring data collected as part of an I/I study. One common problem was that many wastewater treatment plants did not have sufficient influent flow metering capacity to accurately measure significant wet weather flow events. Kurz et al. (2003) presented a proposal for an industry-wide standardization of I/I calculations. The proposal was based on work done by the Metro Nashville (TN) Department of Water and Sewerage Services and would set a criteria of "a projected I/I volume from a 5-year, 24-hour storm." Reid (2003) reviewed real-time wireless CSO monitoring equipment. The CSO monitors were integrated with wireless rain gauges to check rainfall and differentiate between wet and dry weather events.

A daily rainfall disaggregation method that yields regional hourly rainfall estimates was presented in terms of application to continuous-simulation watershed models (Socolofsky et al., 2001). When compared with hourly data, the method reproduced well the variance, lag-1 autoc

standard gauge for wind-induced undercatch, wetting loss, and trace amount of precipitation was tested at ten climate stations in Alaska during 1982-83. Results showed that daily adjustment increased the gauge-measured annual precipitation by up to 800 mm for the two years (Yang et al., 1998). An accuracy test conducted in the Stephen F. Austin Experimental Forest, Tex. revealed that a U.S. standard gauge, weighing-type recording gauge, a standard gauge fitted with an Alter windshield, and a pit gauge showed each gauge to have an average deficiency greater than 10% when compared to a recording anemometer (Chang and Flannery, 1998). Correction for wind effect on angle of raindrop reduced the deficiency from 11% to 6% leaving the remaining error to wind effects, nonrandom errors and other unknown sources. The procedures were presented for the collection and quality control of rain data from a network of tipping bucket rain gauges in Den. carried out by the Danish Meteorological Institute as input to software packages such as MOUSE and SAMBA for designing sewers and storage basins, and simulating overflows and flooding. Although it is possible to improve the efficiency of the quality control, long term corrections will always be necessary (Jorgensen et al., 1998) .

Spatial and temporal variability in rainfall concentrations of several contaminants were monitored at seven locations in or near the Conodoguinet Creek watershed of south-central Pa. and compared precipitation quality in forested, agricultural and urban areas. The major ion concentrations were related more to regional influences than local while herbicides in precipitation may have had more local influences (Shertzer et al, 1998). Quality checks also indicated that trained volunteers were reliable in collecting data in a timely manner. The Residential Stormwater Monitoring Project, initiated by the Boston Water and Sewer Commission in March of 1997, characterized the seasonal variation in the quality of stormwater discharged from a low density residential area (Schofield and Eggleston, 1998). The project included precipitation monitoring, stormwater qua9(w)-.5(a)-57i(ity conurb)si9(w)d-4.8(ic Tc0.0(M)9.9(w)-3.a1t92b2(si) flow4.9(g)-0(si)8(rb)-

very functional “weight of evidence” approach that provides three levels of certainty (symptomatic, preliminary identification, confirmation) regarding the causative role of fish pathogens. This would allow a cost-effective, phased approach in resolving WET permit compliance issues.

Schiff et al. (2002) discussed using Toxicity Identification Evaluations (TIE) to assist in developing the TMDL for aquatic toxicity in the Chollas Creek and San Diego Bay, California. The primary objective of this study was to identify the effects of transient pollution events, such as

Two years of sampling in San Francisco, Calif. revealed that only certain individual dioxins/furans and PAH were commonly detected in the city's collection system, and may be indicative of specific sources. PAH were also detected more frequently in catchbasin influent than effluent implying that particle deposition in catchbasins may be an effective removal mechanism for PAH (Moore et al., 1998b).

Testing for Chemical Pollution and Pollution Tracers

Sampling for volatile organic chemicals (VOCs) is challenging. Williams et al. (2006) described sampling strategies for VOCs at three karst springs in Tennessee. Results from the study indicated that sampling strategies for karst springs need to be developed on a site-specific basis. The use of fixed sampling intervals (as infrequently as quarterly or semiannually) produced accurate concentration and load estimates at one of the three springs. Marsalek et al. (2006a) described an elutriation apparatus for assessing settleability of CSO pollutants. Solids settling can be measured under dynamic conditions by flow through a series of settling chambers of various diameters.

A continuous fiber optic in-stream transmissometer was used to measure suspended solids concentration mobilized during peak flows in rivers and streams (Campbell et al. 2005). The particle size dependence on transmittance posed a problem for anything but site-specific calibration. The potential of using Sea-viewing Wide Field-of-View Senor to assess the distribution of stormwater runoff plumes in coastal waters was investigated by Nezlin et al. (2005). The backscattering properties of surface waters were found to best characterize the runoff plume, and the resultant data showed that the primary factors regulating the relationship between rainstorm and plume were land-use characteristics, size and elevation.

Lacarra et al. (2004) presented San Diego County's water quality assessment process, which has been shown to be applicable to both wet weather and urban runoff monitoring needs. In addition, this tool is an iterative tool that can be used to evaluate watershed improvements.

assessed included hydrology, geomorphology and water quality. The results were incorporated into models that were incorporated in the final watershed plan. Porto et al. (2005) evaluated the water quality impacts in a small watershed in the Sao Paolo (Brazil) metropolitan area. The results of the modeling showed the different impacts of point and nonpoint sources in the water quality of the river.

Verbunt et al. (2005) investigated the hydrologic impact of land-cover changes and hydropower stations in a Swiss Alpine Rhine Basin. Urbanization was shown through modeling to have a significant impact on local flood events, but its impact was negligible further downstream. Wang et al. (2005b) investigated the long-term impacts of land-use change on nonpoint source loads in the St. Louis (Missouri) metropolitan area. Modeling demonstrated minimal increases in total nitrogen even through three development scenarios. Similar results were seen for total soluble phosphorus and total phosphorus.

Approximately 1,100 communities in the United States have combined sewer and stormwater systems whose capacity may be exceeded during moderate or heavy rainfall. Outflows may occur that can deposit water with varying concentrations of the components of sewage onto public areas, potentially resulting in a range of adverse health effects (Colford et al., 1999). Seasonal

and 25-year recurrence intervals being more than two times greater than the rate during historical conditions.

The hydrological characteristics of the Pearl River Delta (South China) have been greatly impacted by urbanization (Chen lowest water quality designation (Limited Resource Water) in the area of the construction activity. Water quality chemical analyses conducted on samples from upstream and downstream sites verified that these impacts were not from chemical affects alone.

Morrisey et al. (2000) described the sampling program used to confirm a predictive model of metal contaminant build-up (Cu, Pb, and Zn) in the sediments of sheltered urban estuaries in Aukland, New Zealand that have been subjected to urban runoff inflows. The results of their testing showed good general agreement between the model predictions and the observed concentrations of metals in the sediments. The paper by Butcher et al. (2000) described the problems encountered when developing mercury TMDLs for the Arivaca and Pena Blanca Lakes in Arizona. These two lakes lacked point-source discharges of mercury; however, the concentrations of mercury in fish bodies were sufficiently high to trigger TMDL development. The resultant TMDL addressed the problems inherent with controlling pollutants entering the lake when the lake sediment was found to be a primary source of the pollutant. Rate et al. (2000) investigated the concentration of heavy metals in sediments of the Swan River estuary in Perth, Australia. They found that the concentration of lead was elevated near stormwater drain outfalls when compared to areas away from the outfalls, likely due to vehicular material; no similar effect was seen for copper or cadmium. They also noted that since the vast majority of all heavy metals were bound to iron oxides or organic sediments, most of the metals are not bioavailable. The results of the study performed by Rochfort et al. (2000) on the effects of stormwater and CSO discharges on the benthic community showed that the levels of metals and PAHs in sediments below these discharges were high. However, biological effects were not seen - neither the toxicity endpoints nor the benthic community descriptors could be related to the sediment contaminant levels.

Ghani et al. (1999) found that the thickness of a sediment deposit on the bottom of a rigid rectangular channel greatly affects its erodibility of the deposits. They developed channel erosion equations that included terms for the deposit's thickness. Keshavarzy and Ball (1999) studied the entrainment of sediment particles in water and found that the number of entrained particles per unit time per unit area was found to be related to the instantaneous shear stress at the bed. These results were used to modify the Shields diagram. Ashley et al. (1999) investigated the integration of sewer solids' biodegradability into the existing UK waterway protection standards for solids erosion in sewers. This integrated standard would then be used to define the DO criteria in streams and to determine the allowable solids discharge. Rhoads and Cahill (1999) studied the elevated concentrations of chromium, copper, lead, nickel and zinc that were found in sediments near storm sewer outfalls. They noted that copper and zinc concentrations were greater in the bedload compared to the bed material and therefore were more likely to be mobilized during runoff events.

Anecdotal information regarding the impacts of changes in flow on receiving streams were collected, howeverk0019 Tg5 Twfvw[(c3n bioavailable. Custer et al. (2006b) examined the contaminant exposure of barn swallows nesting in an estuary with urban influences in Louisiana and were compared to the same measures at a reference site. Pollutant concentrations in eggs and nestlings were at background levels and DNA damage was not observed. Custer et al. (2006a) determined the presence of stressors in streams receiving urban and agricultural runoff using a benthic in-situ toxicity identification evaluation bioassay (BiTIE). The BiTIE method appeared useful for discerning stressors using indigenous species in-situ.

associated with stormwater runoff to recreational waters, and if enterococci or E. coli can adequately predict the range of possible illnesses that may affect swimmers in contaminated marine waters. Crowther et al. (2001) examined the relationships between microbial water quality and environmental conditions in coastal recreational waters along the Fylde coast, UK. Eight designated bathing beaches continued to exhibit unreliable compliance with the Imperative standards for total coliforms and fecal coliforms, despite significant reductions in geometric mean concentrations following major improvements in the sewerage infrastructure. Fecal streptococci concentrations have remained high. Before the improvements, higher bacterial concentrations were strongly associated with rainfall; and sewage sources were important for TC and FC, but less important for FS. Since the improvements, catchment sources seem to be of greater importance. Pendleton (2001) reported that despite posted warnings and educational campaigns warning about the health risks associated with storm water pollution, swimmers continue to swim in Southern CA coastal areas polluted by stormwater. Passive means of preventing exposure to marine pollution (e.g., posted signs) were found to be more effective if combined with the active management of other beach amenities. Pendleton et al. (2001) further found that despite documented successes in the battle to clean up the coastal waters of Southern California, Los Angeles County residents continue to view the ocean more as a place of pollution than a healthy place for bathing and swimming. Survey results suggest that perceptions of coastal water quality may be influenced less by "current coastal education campaigns" and more by the media and other factors.

One impact of stream habitat degradation that could not be accounted for through chemical and biological monitoring would be the effect of elevated flows on habitat availability. A study by Finkenbine et al. (2000) indicated that restoration of stream health in an urban area was best accomplished by the establishment of a healthy buffer zone and the introduction of large woody debris (LWD) into the stream. They found that, after a stream has reached its equilibrium with the flow, detention pond retrofits had few hydrological benefits.

Bailey et al. (1999) investigated the potential toxicity of stormwater runoff from sawmills in British Columbia to juvenile rainbow trout, and found that the toxicity was related to the divalent cation concentration, especially for zinc. They also determined that the zinc toxicity was directly related to the low hardness in the stream, with the range of LC50 of 72 – 272 µg/L associated with hardnesses of 9 – 100 mg/L. Ambrose and Meffert (1999) investigated the fish assemblages in Malibu Lagoon, a small estuary in California, and found that the species diversity and richness were small compared to large estuaries, but were comparable to other small estuaries with less anthropogenic impacts. Hatch and Burton (1999), using field and laboratory bioassays, demonstrated the impact of the urban stormwater runoff on *Hyalella azteca*, *Daphnia magna*, and *Pimephales promelas* survival after 48 hours of exposure. The significant toxicity seen at the outfall site was attributed to the contaminant accumulation in the sediments and the mobilization of the top layers of sediment during storm events. A comparison of highway runoff toxicity with typical urban runoff toxicity was performed by Marsalek et al. (1999). Their study found that approximately 20% of the samples collected at the edge of a multi-lane divided highway (>100,000 vehicles/day) were severely toxic, while only 1% of the typical urban runoff was severely toxic. Skinner et al. (1999) showed that stormwater runoff produced significant toxicity in the early life stages of medaka (*Oryzias latipes*) and inland silverside (*Menidia beryllina*). Developmental problems and toxicity were strongly correlated with the total metal content of the runoff and corresponded with exceedances of water quality criteria of Cd, Cu, W, and Zn.

Ecotoxicological experiments were used by Delbec and Mouc and similar organisms, evidence suggested that nutrients from agricultural runoff or sewage may stimulate the growth of harmful organisms such as *pfiesteria* stormwater runoff. The accumulation of compounds in muscle tissue, the elimination of bile metabolites, the activity of 7-ethoxyresorufin O-deethylase (EROD) in liver, and morphometric variables were compared at different concentrations and times of sampling. Jennings *et al.* (1997) extracted ten pollutant phenols from an oil-refinery discharge, urban stormwater, and WWTP effluent with the highest concentration found in the WWTP effluent. Bioaccumulation experiments were conducted using the mussel, *Mytilus edulis* and the fish, *Trachurus novaezelandiae* with similar concentrations, and both species depurated all accumulated phenols to concentrations below detection within 24 h when placed in clean seawater. Magaud *et al.* (1997) developed a quantitative model of the instantaneous death probability of juvenile rainbow trout as a function of time, concentrations of unionized ammonia (NH_3), and dissolved oxygen (DO). This model found the survival probability of rainbow trout exposed simultaneously to NH_3 and low DO was lower than the predicted survival probability derived from the simple addition of the individual effects. Moore and Farris (1997) conducted 48-h acute-toxicity tests with *Ceriodaphnia dubia* (cladoceran) and *Pimphales promelas* (fathead minnow) on stormwater runoff, laboratory synthetic water, and irrigation (ground) water with the herbicide Stam®M-4 (active

Claytor (1996a) summarized the

through climate and epidemiological records, demonstrated a potential correlation between extreme precipitation events and waterborne disease outbreaks. The authors found that statistically significant relationships could be developed between large precipitation events and waterborne disease outbreaks for both surface and ground water, although the relationship was much stronger for surface water outbreaks. The impact of urban runoff and the potential resuspension of settled parasites in Paris rivers at the drinking water intakes was investigated by Rouquet et al. (2000). Their results showed that parasite sedimentation was high, but that resuspension due to urban runoff was also likely. Rangarajan et al. (2000) developed a model for the City of Edmonton for predicting the impact of rainfall on combined sewer overflows and hence on river water quality. This model would be used to predict elevated fecal affected by canal (urban drainage), atmospheric and groundwater loadings. Crouch et al. (2006) investigated the impacts of fire retardant on surface water quality. Minimal impacts were found, including for cyanide compounds.

Contamination of mangroves sediments and leaves due to urban runoff was examined by Defew et al. (2005). Iron, zinc and lead were found in levels high enough to pose a threat to the regeneration and growth of the mangrove. Ke et al. (2005) examined the spatial and vertical distribution of PAHs in mangrove sediments and found that elevated concentrations were localized. Sources for these elevated concentrations were municipal and industrial wastewater, stormwater runoff, oil leakage from boats and accidental oil spills.

The effect of tubificid worms on the fate of organic matter and pollutants in stormwater sediments was investigated by Mermillod-Blondin et al. (2005). The results showed that the worms increased the release of ammonium, phosphate and dissolved organic matter. Oxygen uptake was also increased. No release of heavy metals or hydrocarbons was noted.

The impact of human activities on the nutrient chemistry of the Pinios River (Greece) was studied by Bellos et al. (2004). Concentrations of nutrients and organic carbon in the water increased as the river flowed past urban areas. DeCarlo et al. (2004) investigated the chemical composition of water in urban drainage canals in Oahu, Hawaii. Pb, Zn, Cu, Ba and Co had increased concentrations in the urbanized portions of the watersheds. Particulate concentrations varied temporally during storms due to road runoff inputs, which containing varying concentrations of these elements.

The relationship between urban density/drainage structure in Melbourne, Australia, and pollutants loads in small urban streams was examined by Hatt et al. (2004). DOC, conductivity, reactive phosphorus and total phosphorus were independently correlated with the degree of drainage connectivity, while pH and TSS could not be related to any of the basin variables (degree of drainage connectivity, impervious waterways. High-volume sampling was used because of the typically-low concentrations in runoff.

Washburn et al. (2003) studied the spatial scales and the evolution of stormwater plumes in Santa Monica Bay. Salinity maps showed that the plumes typically extended 4.7 km offshore and 10 km or more alongshore. Carrasco et al. (2003) assessed the levels of urban and industrial contamination in the Bay of Cadiz, Spain. Physical-chemical data revealed that sediments and waters analyzed were moderately contaminated. No significant differences were found between in rising and ebbing tide conditions. Yang and Carlson (2003) reviewed the evolution of antibiotic occurrence in a Colorado river through pristine, urban and agricultural landscapes. By the time the river had exited the urban area, 6 of the 11 antibiotic compounds th6ea6-7(a)540tnbnin se tm25.3353 -1.1497 T S(r)-4.5andylandpre pristine, urbn anfla3(n ae)(l)0.7(5)-4.7.ywi al. (1999) to contain BOD, COD and suspended solids concentrations at least as strong as typical domestic effluents.

(Alexander *et al.*, 1996). These networks provided some of the best available data for quantifying changes in the water quality of major United States streams during the past 20-30 years, estimating the rates of chemical flux from major continental watersheds of the United States, and investigating relations between water quality and streamflow as well as water quality to watershed characteristics and pollution sources.

Sampling and monitoring of New York City's Jamaica Bay have confirmed the eutrophic state of some areas of the Bay (Fitzgerald *et al.*, 1996). It is known that the probable root causes of this problem are both the extremely high nutrient loading to the Bay from anthropogenic sources as well as the lack of adequate flushing also resulting from human intervention.

Glazewski and Morrison (1996) presented results showing the effects of photoreduction of Cu in urban streams. It was concluded that pollutant speciation and potential toxicity of Cu, Cr, and Fe is greatly affected by photoreduction reactions.

Toxicity
Lewis et al. (2006) used microbial genotoxicity as an environmental indicator of impacts from stormwater runoff. Genotoxicity was observed in one-quarter of the golf course pore water and three-quarters of bayod thcieronm

(1996) described the Toxics Reduction Strategy based on water-column- and sediment-chemical analyses, benthic-community health, and fish-body burdens. More than 40% of the sites have displayed some degree of water-column toxicity and about 70% of the sites have displayed sediment toxicity. Garries *et al*. (1996) further described how the list of Toxics of Concern was developed for Chesapeake Bay.

The need for endpoints for assessments using multiple stressors was discussed by Marcy and Gerritsen (1996). Five watershed-level ecological-risk assessments were used to develop appropriate endpoints based on specific-project objectives. Dyer and White (1996) also examined the problem of multiple stressors aff st ur(1fopasopas d]TJ-35.1078 01.1437 TD-0.00

concentrations are atypically high, with a possibility that toxic effects may be present. Allen (1996) also presented an overview of metal-contaminated-aquatic sediments. This book presents many topics that would enable the user to better interpret measured heavy-metal concentrations in urban-stream sediments.

Pitt *et al*., (1996b) reported on various laboratory-toxicity tests using 20-stormwater and -CSO samples. It was found that the most promising results are associated with using several complementary tests, instead of any one-test method. However, simple screening-toxicity tests are useful during preliminary assessments or for treatability tests.

A number of papers presented at the 7th International Conference on Urban Storm Drainage, held in Hannover, Germany (Sieker and Verworn 1996), described receiving-water studies that investigated organic- and heavy-metal toxicants. Handová *et al*. (1996) examined the bioavailability of metals from CSOs near Prague, Czech Republic. The results were compared with biomonitoring. The metals were ranked according to their mobility as: Cd (95%), Zn (87%), Ni (64%), Cr (59%), Pb (48%), and Cu (45%). The mobile fraction was defined as the metal content that was exchangeable, bound to carbonates, bound to iron and manganese oxides, and bound to organic matter. Boudries *et al*. (1996) and Estèbe *et al*. (1996) investigated heavy metals and organics bound to particulates in the River Seine near Paris, France. The Paris CSOs caused a significant increase in the aliphatic and aromatic hydrocarbons bound to river sediments. The high flows during the winter were associated with lower heavy metal associations with the sediment, compared to the lower summer-flow conditions. These differences were found to be due to dilution of the CSOs in the river and to the changing contributions of rural versus urban SS during the different seasons.

Habitat Management and Restoration

Van Duin and Garcia (2006) investigated the impacts of urbanization on a Canadian Creek. The increased runoff rates were shown to be affecting the fisheries habitat through changed hydrologic regime and stream morphology.

Matsuyama (2005) identified the challenges facing any wetlands restoration in southern California. Many of these challenges were related back to the extensive development in the affected basins. Martinez Fernandez et al. (2005) reviewed how a hydrologic model has been used to simulate the impact of heavy rainfall events on nutrient concentration in a coastal lagoon in the western Mediterranean (Mar Menor). The current research investigated how this increased nutrient load has impacted the aquatic bird communities. Grebe appearance and abundance seemed to follow the nutrient cycle. One of the piscivore birds was not affected by the increased eutrophication.

Schlindwein (2005) placed stream restoration and probability for success into a broader Quarternary classification. This

decreases in the groundwater table, and dramatically decreased times of concentration were found. The peak flowrates increased by about two-fold, about half caused by increased pavement (in an area having only about 5% effective-impervious cover), with the remainder caused by decreased times of concentration.

Environmental Effects of CSO and SSO

Black and Endreny (2006) evaluated the impact of combined sewer separation on stormwater outfall duration, magnitude and volume in Syracuse, New York. The separation increased th traveled to considerable depths in the sediment and oxygen levels in the interstitial water decreased considerably while traveling through the riffle reach. The resulting model is being used to examine the effects of CSO discharges. They found that CSOs may cause anoxic sediment oxygen conditions for extended periods of time. Michels (2001) described a CSO Basin study conducted on the Menominee River, MI, to see if the facility met the Michigan water quality standards and if it provided adequate treatment. Four sets of samples were collected upstream and downstream of the facility for comparison during discharge events. They found that the water quality standards were not violated during overflow discharges to the Menominee River.

CSO and SSO can have damaging impacts on receiving waters. Sanudo-Wilhelmy and Gill (1999) compared current pollutant concentrations in the Hudson River Estuary, New York with concentrations measured in the 1970's. The concentrations of Cu, Cd, Ni, and Zn have declined, while concentrations of dissolved nutrients (PO_4) have remained relatively constant during the same period of time, suggesting that wastewater treatment plant improvements in the New York/New Jersey Metropolitan area have not been as effective at reducing nutrient levels within the estuary. Rather than inputs from point sources, the release of Pb and Hg from watershed soils, and Ni and Cu from estuarine sediments, may represent the primary contemporary sources of these metals to the estuary. Approximately 1,100 communities in the United States have combined sewer and stormwater systems whose capacity may be exceeded during moderate or heavy rainfall. Colford et al. (1999) proposed and applied three analytic methods to evaluate the impact of such outflows on health of Lake Constance. They proposed a simple methodology to estimate the nutrient loads from CSO to the Lake, the results of which can be used to determine the cost-effectiveness of CSO improvement versus WWTP improvement.

Fish and macroinvertebrate sampling defined and prioritized the needs of CSO systems and assessed where other watershed pollutants caused more harm than CSO (Markowitz, 1998).

CE-QUAL-W2 was used to determine the impacts of CSO during a four-year study to mathematically model the water quality of Cheatham Lake on the Cumberland River below Nashville, Tenn. (Adams *et al.*, 1997).

Mulliss *et al.* (1996) found that several wet-weather flow (WWF) discharge parameters regularly pose a serious threat with regard to freshwater aquatic- life. Widera and Podraza (1996) investigated instream biological conditions and water

when combined with local hydrologic data, would be used to predict fate and transport of these microorganisms. Wakeham (1999) reported on the results of the investigation to determine why an $800 million investment program designed to improve swimming water quality in the northwest coast of England was not effective. They found that the problem of compliance with water quality criteria for human exposure to pathogens was more complex than originally believed and that current data analysis techniques and models by themselves could not completely described the complex environment.

Groundwater Impact

The effectiveness of microbial and chemical indicators to detect sewer leakage impacts on groundwater quality was evaluated by Cronin et al. (2006). The authors stated that the use of multiple parameters to predict groundwater quality impacts was better than the use of single parameters.

Bauer et al. (2004), using the integral groundwater investigation method, was able to identify source plumes of PCE and TCE contamination in an industrialize urban area in Austria. The data from the time-series approach was used to determine contaminant flow rates, mean concentrations and plume shapes.

Fischer et al. (2003) investigated the quality of the shallow groundwater beneath retention and detention basins used to treat stormwater runoff it

1999). The infiltration of dissolved herbicides and metabolites from a tributary stream can occur where the stream crosses a floodplain overlying an alluvial aquifer causing the contamination of shallow alluvial aquifers at rates that exceed in-field leaching by up to three orders of magnitude (Burkart et al., 1999).

Hatfield et al. (1999) examined a multi-disciplinary study on the effect of farming practices on subsurface drainage, surface runoff, stream discharge, groundwater, volatilization, and soil processes that influence water quality. Groundwater was vulnerable to contamination in karst areas where highway stormwater runoff may flow directly into karst aquifers with little or no natural attenuation and transport highway-derived contaminants rapidly from sinkholes to locations in the aquifer. Field testing sites were located in Knoxville, Tennessee and Frederick, Maryland. A pilot-scale stormwater runoff treatment system, in Knoxville (Tennessee) and Frederick (Maryland), has been designed using peat, sand, and rock to

Ammann et al. (2002) investigated where the infiltration of urban/industrial roof runoff into permeable subsurface material may adversely impact the groundwater quality and endanger drinking water resources. The pollution potential was found to be high and non-reactive tracers exhibited fast breakthrough and little sorption.

A water balance model was developed for a semiarid landscape of Spain (Bellot et al., 2001). The components were the soil water content, the actual evapotranspiration (Eta), and both the aquifer recharge (deep drainage) and runoff, which reflected water recharge, human use and soil erosion impacts. Combining the model predictions with the land cover vegetation units on the aquifer recharge area, the effects of some management policies on the deep drainage and runoff in five simulation scenarios were compared. Extreme precipitation during a wet year led to a higher erosion risk. Well clogging will impede the use of aquifer storage and recove

The impact of micro-topography on the failure of storm drainage inlets to capture their maximum flow was modeled by Aronica and Lanza (2005) using Saint Venant equations. The modeling confirmed that micro-topography effects can cause localized flooding. Vazquez et al. (2005) addressed the issues involved in one-dimensional and three-dimensional hydraulic modeling of CSOs. Both modeling approaches were validated by data collected on a small-scale model in France. Coonrod et al. (2005) reviewed the physical modeling done by the Albuquerque Metropolitan Arroyo Flood Control Authority to predict how diverting a portion of the storm flow into a constructed wetland would affect the hydraulics of the drainage system. The modeling included both a diversion baffle and a weir, as well as the debris removal system.

Jeon and Kim (2005) used artificial neural network rainfall-runoff models to predict streamflows in Korea. The results showed that the ensemble neural network outperformed the single neural network. Wu et al. (2005) demonstrated the application of an artificial neural network for watershed-runoff and streamflow forecasts. One important result of this research was the development of a methodology for input data organization, model performance evaluation and artificial neural network processing techniques. The paper by Di Pi are the most efficient and accurate paradigm among intelligent systems used to model rainfall-runoff. Sen and Altunkaynak (2004) presented a fuzzy systems approach in rainfall-runoff modeling in an effort to account explicitly for internal uncertainties.

climate model (RegCM2) with a hydrological model to simulate rainstorms and surface runoff. The linkage improved the modeling of moisture convergence, increased the moisture content in the atmosphere below 700 hPa, and enhanced precipitation in the basin.

Approaches to simulate snowmelt in urban areas are not developed as frequently as rainfall-runoff simulation approaches. Consequently, current urban snowmelt capabilities are not as advanced. Valeo and Ho (2004) provided a valuable contribution in this area by exploring current urban snowmelt models and proposing a new model that uses parameters developed specifically from urban snow studies. The Urban Snow Model (USM) was tested against flow data from a small residential community and compared with predictions made using a degree-day method for snowmelt and the SWMM model. The USM and a modified version faired well and based on the results were recommended over other approaches tested.

Updates to the U.S. EPA Storm Water Management Model (SWMM) continued as part of the SWMM redevelopment project. Rossman et al. (2004) reviewed the rewriting of SWMM's engine using an object-oriented approach and providing a rudimentary graphical user interface. Chan et al. (2004) presented a graphical user interface (GUI) to translate SWMM4 input files to SWMM5 input files. The translator was tested using over 200 input files and quality assurance tests indicated performance was acceptable. The source code for the translator will be made available on the Internet.

Burgess et al. (2004) discussed the considerations water resources engineers face when choosing between open source code versus proprietary software for an application. They stressed the important benefits of open source software from a broader perspective of the profession. There was an effort from seven European countries to develop an open modeling interface to link new and existing hydraulic models of sewers and rainfall-runoff models (Anonymous 2004). The objective was to provide a European-wide standard that will enable models to interface with one another and satisfy the integration requirements of a wide group of users.
Bhunya et al. (2003) presented a simplified two-parameter Gamma distribution for the derivation of a synthetic unit hydrograph. The revised version required approximate, but accurate empirical relationships for the parameters that affect t 0(e)s 0(eape8.1(ho)4.74f)-1.9(a)3.8e ndohp.444(e)6(C3.872.4(0(eap)12.98ea2.2(n)(A5.4(o24(0(e0444(e0444(e34(0(e))5.3(hoh)10

watershed geomorphology, leading to a parsimonious ANN modeling tool. This study reveals GANNs to be promising tools for estimating direct runoff.

Jordan et al. (2003) evaluated using dual polarization radar in rainfall-runoff modeling using a case study in Sydney, Australia. Dual polarization was compared to using calibration rain gauge networks for single polarization radar rainfall. Jain and Indurthy (2003) compared event-based rainfall-runoff modeling techniques (deterministic, statistical and ANN) for the Salado Creek in San Antonio and found that the ANN models consistently outperformed conventional models and provided a better representation of an event-based rainfall-runoff process, including better prediction of peak discharge and time to peak discharge. Brahm and Varas (2003) reduced the learning time of ANNs by selecting an adequate algorithm and by reducing the number of parameters. Principal Component Analysis (PCA) produced faster learning periods without diminishing fitness quality. The authors recommended the Levenberg-Marquardt algorithm for training feed-forward artificial neural networks and the use of PCA in models with a large number of correlated explanatory variables.

Mikhopadhyay et al. (2003) applied kinematic wave theory to predict flash flood hazards on coupled alluvial fan-piedmont plain landforms in New Mexico. The models suggest meterological data to develop in a downward approach a terrain-distributed model that could explain the flow in the subcatchments. Michel et al. (2003) proposed the use of an exponential store in conceptual, soil-moisture accounting rainfall-runoff models. The study showed that the common way of dealing with this store – without integration in time – is mathematically and physically flawed. This misuse could result in poorer reliability and efficiency of rainfall-runoff models that included such a store, especially when used for the simulation of flood events. Czachorski and Van Pelt (2003) reviewed a time-series methodology to extract the diurnal component of wet-weather flows in a sewer system. When attempting to analyze and model inflow and infiltration effects within a sanitary system, nuances in long-term infiltration dynamics and rapid peaking during large rain events can be lost or obscured if the diurnal is extracted improperly.

Kanso et al. (2003) reviewed a Bayesian approach for the calibration of models and applied it to an urban stormwater pollution model. Unlike traditional optimization approaches, the Metropolis algorithm identifies not only a "best parameter set", but a probability distribution of parameters according to measured data. The studied model includes classical formulations for the pollutant accumulation during dry weather period and their washoff during a rainfall event. Results indicate mathematical shortcomings in the pollutant accumulation formulation used.

Rainfall analyses

Pielke et al. (2006) provided an overview of the impacts of regional land use and cover on rainfall. Guo (2006c) promoted updating rainfall IDF relationships to improve urban drainage designs. The authors proposed that these updates are necessary in light of anticipated climate change impacts.

Spatial variability of rainfall was an issue addressed by many authors this year. Das et al. (2006) studied the influence of spatial variability in a distributed rainfall-runoff model.

Kavetski et al. (2006c) discussed inherent difficulties in calibrating conceptual hydrological models, including old strong indications that hydrological processes cannot be deterministicly chaotic. Further investigations showed that real-world hydrometeorological series did not contain chaos. Liu and Shao (2006) simulated rainfall runoff in urban districts in China. A model was established based on the St. Venant equation. Purcell (2006) presented the physical analog of the linear reservoir that is used to conceptually model the rainfall-runoff process. A laboratory-scale model of this physical analog was constructed and used to illustrate the concepts to students.

Fleurant et al. (2006) presented an analytical model for a geomorphological instantaneous unit hydrograph (GIUH). The model parameters are based on real geomorphological data and do not require calibration. Guo (2006b) theoretically

models. Chen and Adams (2006b) presented a methodology for developing analytical stormwater quality models using probability distribution theory for three processes – the rainfall-runoff transformation, pollutant buildup, and washoff. A case study showed that the analytical models were able to recreate the observed field data. Wang et al. (2006c) described a power function decay of hydraulic conductivity in the TOPMODEL-based infiltration routine. The advantages of the power function infiltration routine were replication of field-observed processes in urbanized areas and numerical consistency with power function decay of baseflow and topographic index distributions. Wong et al. (2006) modeled urban stormwater treatment using a first-order kinetic decay model in combination with a continuously-stirred tank reactor. Kanso et al. (2006) applied the MCMC-GSA model calibration method to runoff water quality modeling. The Metropolis algorithm was able to assess the uncertainties inherent in some parameters, as well as their interaction structure.

Garcia-Salas and Chocat (2006) assessed the uncertainties in modeling CSOs as a result of describing special structures in the model. Wride et al. (2006) used a system-wide computer model for the Greater Cincinnati Metropolitan Sewer District and calibrated using SWMM 4. The tool compared the up-to-date GIS data with current stormwater management data, documented differences, allowed for visualization of the difference locations in the system, provided a mechanism to methodically evaluate the differences, documented the decision making process, and created updated model data formatted for the model input files.

Sediment yield was simulated using a physiographic soil erosion-deposition (PSED) model. PSED was effective at water quality modeling integrated with urban stormwater modeling to assess impacts of stormwater discharges on ephemeral watercourses.

Faulkner and Lyon (2002) introduced a new screening model to predict the fate and transport of viruses in percolating water. The leaching fraction model has been implemented in the EPA VirMod computer program. The leaching fraction model can be integrated with GIS to easily incorporate spatial data layers and visualize model output. Schneiderman et

unified IDF relationships, spatial correction factors, a stochastic simulation model for spatial rainfall, and a methodology for improving the spatial correction factors in a case-specific way by performing simulations with the model.

individual rain cells need detailed descriptions. Data from a dense network of rain gauges at Antwerp were used for verification of the process. Cameron et al. (2001) successfully modeled extreme rainfalls using a generalized Pareto distribution to represent the rain depths of high intensity rain cells. Trefryl et al. (2001) used a partial duration series/ generalized Pareto regional index-flood procedure for updating rainfall intensity-duration-frequency estimates for the State of Michigan. Porras and Porras (2001) examined all series of extreme rainfall depths to produce less ambiguous depth-duration-frequency and intensity-duration-frequency curves for Venezuela. Cheng et al. (2001) used a simple scaling property of rainfall to guarantee

(Dolcine et al., 1999). A procedure to generate rainfall input for the EUROpean Soil Erosion Model was presented. To develop such a procedure, first of all the influence of rainfall event amount, rainfall event duration, and time to peak intensity of event rainfall on soil losses, calculated with EUROSE criteria, and in determining the influence of the number of gutters. The SWMM model was used by Kalaba et al. (2006) to predict the hydrology from composting sites in the United States. SWMM outperformed the rational method in predicting volume requirements for on-site detention facilities.

Kim et al. (2006c) combined rainfall-runoff outputs to improving streamflow prediction. Among the tested combining

Mourad et al. (2005a and c) evaluated the optimal size and characteristics of datasets that were used to calibrated and validate stormwater regression models. The results showed that models were most sensitive to calibration data and that more of the dataset should be used in the calibration activity.

The rainwater harvesting information system in Chennai City, India was outlined by Ravikumar et al. (2005). The methodology and analysis created an output from GIS overlay analysis that could be used as a utility map for rainwater harvesting.

Rodriguez et al. (2005a) compared three complementary methods for determining urban unit hydrographs from catchment morphology. All three methods showed a variability of the unit hydrographs with rainfall intensity, as should be expected.

The development and application of distributed hydrologic models continues to evolve as spatial data becomes more available and easier to process (Vieux 2004). Brath et al. (2004) analyzed several aspects of distributed model applications including calibration period required for efficient parameterization, spatial resolution of rainfall data for model calibration, and the reliability of model parameters for application to ungauged watersheds. Results suggest the need for at least three months of calibration data and sufficient rain gage network density to produce acceptable simulation results. The distributed model was also found to provide reliable simulations of ungauged internal river sections. Meselhe et al. (2004) compared the performance of a physically-based hydrologic model (MIKE SHE) and a lumped hydrologic model (HEC-HMS) in terms of ability to predict time and magnitude of peak discharges and runoff volume. Vieux and Bedient (2004) described the development of a new testbed network of radars to measure rainfall for real-time flood forecasting applications implementing physics-based distributed modeling.

data. An approach using groundwater can be used when the runoff in the basin is intermittent, a common case in the semi-arid regions, or perhaps in situations lacking river flow measurements. Although the study suggested that using groundwater data to calibrate a hydrologic model may be useful, the automated calibration approach was not successful. Yang et al. (2004) applied a fuzzy multiobjective function approach to calibrate single-event rainfall-runoff models using the time-to-peak, peak flow, and total runoff volume characteristics of the hydrograph.

Vieux and Bedient (2004) reviewed the use of event reconstruction to develop achievable model accuracy for urban flood prediction. The analysis indicated that once the radar data was gauge-corrected, remaining random error does not correlate strongly with the error in streamflow predictions, indicating that the random error measured by radar-gauge comparison is diminished when simulated runoff is compared to observed streamflow. Furthermore, bias adjustment of radar in real-time was noted as necessary to achieve acceptable accuracies.

Catchment scale water balance models have been the focus of recent work in Australia (Boughton 2004a). Using water balance models is a mature technology in Australia for agricultural and urban water supply, flood estimation, management of rural water resources, stormwater, and wastewater, and management of aquatic ecosystems. Nearly all water balance models in Australia are applied where streamflow data are available for calibration. Boughton (2004b) described the Australian water balance model and illustrated the application of the model using data from 19 catchments located across Australia.

Heineman (2004) introduced NetSTORM, a computer program that updates the HEC-STORM concepts to simulate rainfall-runoff and incorporate precipitation analysis routines. NetSTORM improves the STORM methodology by providing a modern interface and adding capability to simulate linked structures in a complex collection system, perform rainfall frequency analysis, and temporally disaggregate hourly and daily precipitation data.

Gautam et al. (2004) presented a study involving analysis of hydrogeological data and an artificial neural network model

Mosini et al. (2003) performed a sensitivity analysis for input parameters to the “CANOE” rainfall-runoff model on a Nantes area catchment basin. The results showed that the choice of runoff coefficient type exerted a significant impact on the results obtained. Sun et al. (2003) presented digital evaluation hydrological modeling for a small catchment in South Australia. Improved runoff predictions were obtained as a result of the improvement in spatial data input and spatial soil moisture representation.

Davidson et al. (2003) described a method for creating polynomial regression models and compared it with stepwise and symbolic regression models. The applications were rainfall-runoff modeling and approximating the Colebrook-White equation. Ducharne et al. (2003) developed a high-resolution runoff routing model RiTHM and its calibration and application to assess runoff. Blazejewski and Murat-Blazejewski (2003) presented analytical solutions for a routing of improvements at the lot scale would produce more than a 50% reduction in hydrograph peaks and volumes at the watershed outlet. At a larger scale, Schulte and Grace (2002) used SWMM to simulate runoff and storm drain hydraulics for a military base re-development project in San Diego. Overall, the drainage infrastructure was in poor condition and lacked hydraulic capacity to meet today's design standards. Additionally, the project required SWMM simulations to correlate closely with the Modified Rational Method. Several rules-of-thumb were developed to apply the Rational Method with SWMM.

Applying a calibrated SWMM model, Holder et al. (2002) simulated the catchment scale response of Harris Gully to Tropical Storm Allison. The simulation had to account for submerged conditions at the outlet into Brays Bayou that could reduce outflow capacity of the Harris Gully by 60-80%. The high water levels in Harris Gully for Tropical Storm Allison were successfully simulated with the model. A hydrodynamic model for the Nine Mile Run combined sewer App( ),sue e.5((l(t)3.i(t)3.nR)3.8gk(t)3.7(-4.8d)-1.76r the(t)3.s-4.9(Mil7(l)(S967(-4.8(d)]T78(co)16(o)-498(acc1eet to)7(ope)8((ac

Design of stormwater facilities based on time-integrated sediment-transport capacity may inadvertently result in channel instability and substrate changes unless the approach accounts for the frequency distribution of sub-bank-full flows, the capacity to transport heterogeneous bed and bank materials, and potential shifts in inflowing sediment loads.

Neither the index antecedent precipitation index and the Natural Resource Conservation Service's antecedent moisture condition triad consistently characterized the runoff consequence of watershed moisture preceding a rainfall event (Heggen 2001). A normalized antecedent precipitation index that modified the conventional index in three ways (inclusion of antecedent precipitation earlier in the day of the event, normalization to the station mean, and normalization direct estimation techniques were advisable for catchments with peculiar geomorphoclimatic properties.

One-dimensional floodplain models of the proposed modifications to William Cannon Drive in Austin, Texas, indicated no significant upstream impact during the 100-year flood (Buechter 2001). Given the limitations of traditional one-dimensional tools in this application TxDOT decided that to model this project using two-dimensional floodplain modeling techniques. The two-dimensional model better identified the potential impacts associated with the proposed highway reconstruction. Radar-rainfall data, remotely-sensed land-use and land-cover data, measured streamflows, and meteorological data were incorporated into the distributed flood forecasting model WATFLOOD to synthesize runoff hydrographs for three significant rainfall events that occurred in 1995 in the Duffins Creek drainage basin in southern Ontario (Cranmer et al., 2001). These results indicated that WATFLOOD could

Hydrologic losses were estimated on the basis of rainfall-runoff data recorded in 21 urban experimental catchments (Becciu and Paoletti 2000). From analysis of experimental data, the probability distribution function of the runoff coefficient was found to be approximately normal, and simple relationships for estimation of main moments were developed. The impact of grid-cell size on calibrated parameters and on the performance of a variable source area model intended for urbanizing catchments was examined by modifying TOPMODEL concepts to accommodate urban surfaces (Valeo and Moin 2000a). Results showed that in this integrated model of urban and rural areas, predicted processes based on calibrated parameters were dependent on grid resolution. The snow accumulation and melt routines of three drainage models that have been applied to urban settings were reviewed; two of these, MouseNAM and SWMM, were designed for urbanized catchments; the third, HBV, was a regional-scale model for rural catchments (Semádeni-Davies 2000). All contained a temperature index for melt – this method is shown to be theoretically unsound without modification for urban simulations. Literature on model development, validation, and application was found to be lacking.

In many cities of the world, urban cells may be hydraulically defined where built-up areas are highly subpartitioned into atsim27.00n(wi)4.6(t)aTf in9s.2515 -1.1437 T wa014.99 6.52 it0.0032 T-w[(ur)5(ba)ese,r4.6(1)-0.814(10.99-6.1H6(h)7)-0.814(ksatu)-

restoration of the hydrological-water cycle in the Azuma River and to set target values for the desired improvements. Becker et al. (1999) presented a few examples where detailed field studies described the essential elements of runoff generation and thus help to achieve a more realistic representation of the underlying mechanisms within process-oriented rainfall-runoff models.

An approach was developed for incorporating the uncertainty of parameters for estimating runoff in the design of polder systems in ungaged watersheds. Monte-Carlos simulation was used to derive a set of realizations of streamflow hydrographs for a given design rainstorm using the SCS unit hydrograph model. This approach was demonstrated for the Pluit Polder flood protection system for the City of Ja

Nania et al. (1999) designed and conducted experiments on flow patterns at street crossings and intersections. A

the assumption that extreme-rainfall time series are stationary and without trends. It was suggested that rainfall-frequency studies be updated on a regular basis for maximum usefulness because of observed changes in the annual maximum time series (Angel and Huff, 1997).

Hydrological studies of rainfall-runoff processes provided the basis for estimating design flows for urban-stormwater-drainage systems which control floods and the transport of sediments and pollutants. Oloughlin *et al.* (1997) summarized the theory of urban rainfall-runoff processes, the development of modeling practice, and the current use of computer models. Agbodo *et al.* (1997) reviewed HYDRA, HydroWorks, MOUSE, and XP-SWMM, which are widely used hydraulic-modeling tools utilized in determining optimum improvements of sanitary-sewer systems that have excessive I/I. Zhu and Schilling (1997) presented a method to predict errors of calculated mean-annual-overflow volume due to coarse temporal resolution of rainfall data that was used as input to rainfall-runoff models. Errors were quantified by comparison of overflow volumes based on rain-data series with different temporal resolution. The pattern of the temporal rainfall variation of the two data series were too different to derive error-prediction rules that were generally applicable for all rainfall regimes.

Hydraulic models

Grum et al. (2006) examined the effect of climate change on urban drainage using regional climate model simulations. The results showed that the modeled impacts greatly rely on the model's suitability in describing extremes at time scales relevant to urban drainage. Afshar (2006b) used adaptive refinement to improve the efficiency of ant algorithms in storm sewer design. The method was able to find an optimal or near-optimal solution, independent of the discretization level and size of the colony. Afshar et al. (2006a) used the TRANSPORT component of SWMM to implement the simulations and the results were compared with literature values. Frost (2006) presented updates to the parameters used to calculate minor loss coefficients in storm drains in the SWMM model.

Niemann et al. (2002) examined the pump station modeling capability of EPANET, XP-SWMM, MOUSE, and INFOWORKS and presented considerations necessary for models to represent actual conditions and their projected impacts on the public and environment. Despotivic et al. (2002) developed and calibrated detailed BEMUS and Visual OTTHYMO models for a catchment served by combined sewers in Belgrade. The calibrated models were used to assess catchment flooding for design flows at four locations in the catchment. Yeboah et al. (2002) presented work evaluating a 500-cfs pumping station to address flooding problems in the South End neighborhood in Boston. They conducted a comprehensive flow-monitoring campaign, developed pump head-capacity curves, and created a SWMM model of the station. The calibrated model was successfully used as a tool to evaluate the facility planning alternatives. Vallabhaneni et al. (2002a) used SWMM RUNOFF and EXTRAN to simulate infiltration and inflow to sanitary sewer lines and the impact on sewer hydraulics. Sharek et al. (2002) described their efforts constructing and analyzing hydraulic models coupled with continuous infiltration and inflow models and specifically highlighted their work evaluating the alternatives for improving the performance of the Western Lake Superior Sanitation District East Service Area collection system.

Rainfall-runoff quality models.

Behara and Adams (2006) presented the results of runoff quality analysis using probability density functions of rainfall characteristics, a runoff coefficient, and commonly-used pollutant buildup and washoff process representations. The verification results suggested that these analytical probabilistic models can be used during planning to assess runoff pollutant loads. Ahlman (2006) developed a modeling framework to analyze pollutant sources in urban stormwater runoff based on their origin (material corrosion, brake and tire wear, Sheng et al. (2006) used the unit pollutograph concept to estimate solids loadings to a stormwater runoff treatment unit. Relationships between solids mass and hydrologic volume were based on relationships that expressed either a first-order or zero-order relationship between solids mass and volumetric transport. Ostendorf et al. (2006) described calibrated models of deicing agent solids, pavement texture and specific conductivity for highway runoff. The models were applied in southern Massachusetts to determine if first flush exists in highway runoff.

Shi (2005) presented a solution for the Streeter-Phelps model of one-dimensional stormwater quality. Simulation results showed that the approach gave good estimates of BOD and DO in stormwater. Ahyerre et al. (2005) evaluated the efficiency of three stormwater quality models on three suspended solids data sets encompassing 34 rain events. When the results were compared to the simple hydraulic approach, the results were similar; the advantage was that the models were able to represent the shape of the pollutographs.

A novel modeling approach for estimating first flush metal mass loading was proposed by Kim et al. (2005b, c). The new washoff model was designed to predict event mean concentrations, accounting for first flush loadings as well. Model parameters included average daily traffic, antecedent dry period, rain intensity, rain volume and runoff coefficient. Deng et al. (2005) proposed a fractional kinetic model to describe the first flush of stormwater pollutants.

Load quantification models were proposed by Hochedlinger et al. (2005) as a means of estimating the overflow loads of combined sewers. One input for these models is rainfall, and the paper focused on the corrections required for rainfall measurements from tipping bucket rain gauges. Simulations of the runoff and associated pollutant load from a highway drainage system were undertaken by Aryal et al. (2005b). The runoff results showed that when the rainfall was not continuous, part of the depression storage and initial abstraction were recovered and affected the peak of the later runoff. Single-event simulations did not accurately reflect the suspended solids concentration in the pipe; continuous simulation that accounted for the initial sediment condition in the pipe was required. A diffuse nitrate modeling tool (DNMT) was proposed by Liu et al. (2005b) as a means of evaluation of pollutant loads in urban a5(red)-4.7(.)(redc-)-1.73Tc[(L)7.4nf tttn (e)2(t)3 development of a distributed red soil runoff model for the Okinawa region of Japan that uses radar data as an input parameter. The model was based on a kinematic wave flow m

Commonly measured fecal bacteria conna3tr

The spatial distribution of the water-quality equivalent of a snow cover on various landscapes were synthesized through log-normal distributions to predict snowmelt and runoff (Shook and Gray, 1997). When snow produces a significant portion of runoff, a smaller number of quality records could be more valuable for modeling than a much larger number of records of lower quality because the overall value of an operational-hydrometeorological network depends on the consistency and representativeness of average conditions of the collected records (Peck, 1997).

Collection system, CSO and SSO models.

Burgess et al. (2003) reviewed the application of design storms in the analysis of sewer system capacity. The paper addressed (1) the range of design storms to be applied; (2) the approach to accounting for spatial variability in those storms; and (3) the assumed conditions for antecedent soil moisture to be applied with those storms. Steiss (2003) reviewed the development of a basement flood relief plan for the Dumoulin Combined Sewer District in the City of Winnipeg. The authors described the SWMM model development, calibration and verification, assessment of existing levels of basement flood protection and relief alternatives to upgrade the combined sewer system, and the economic analysis of proposed relief works.

Chen et al. (2003) presented simulations for the interactions between storm sewer and overland flows using a dynamic model that simulated the complex hydraulic process in urban areas. The model was verified by the Typhoon Xangsane event in Nov. 2000, and applied for simulating the Typhoon Nari event in Sep. 2001. The dynamic urban inundation model was suitable for the flood simulation of an urban area under high intensity of rainfall. Dempsey et al. (2003) described an integrated modeling study that was designed to improve the performance of the urban wastewater system of Belfast, Northern Ireland. The overall study concluded that the proposed sewer upgrading scheme would achieve the long-term environmental objectives for both the Blackstaff and the Lagan.

Harwood (2003) reviewed the use of computational fluid dynamics to assess the performance of CSO chambers. The model could assess the performance of existing and proposed structures and the performance of remedial measures retrofitted to unsatisfactory CSO chambers. Schluetter and Mark (2003) compared several methods for calculating annual pollutant loads for a given CSO. The results were then used to demonstrate how the different methods could impact the regulatory decisions regarding maximum loads.

O'Leary et al. (2003) applied a statistical model for rainfall-derived I/I (RDII) to actual flow and rainfall data series from wastewater basins in Tuscaloosa, Alabama. RDII volumes estimated as functions of time weare compared to those calculated by traditional reading of hydrographs. The proposed methodology produced more stable estimates of RDII during rain events. Semadeni-Davies (2003) demonstrated the value of response surfaces for displaying multiple simulated responses to incremental changes in air temperature and precipitation using a case study of the Lycksele waste water treatment plant.

Harwood (2002) presented three strategies for the application of Computational Fluid Dynamics (CFD) to the modeling, design, and performance assessment of CSO chambers. Pollert and Stránský (2002) demonstrated the use of the one-dimensional MOUSE model and the three-dimensional FLUENT model for evaluation of separation efficiency of suspended solids in CSO. The 1D model simulated the runoff and pipe flow in the CSO catchment and the 3D model simulated the water flow and the dynamics of the suspended so

storms, high tides, or unusual flow diversions. The long term numerical modeling verified the suitability of rule sets for conditions which often cannot be anticipated.

Harwood and Saul (2001) reviewed some of the physical model studies which have been carried out in the UK to determine the performance of combined-sewer overflow chambers. The limitations of both physical modeling and computational fluid dynamics approaches were discussed, and it was concluded that the future of chamber modeling combine both approaches. The im flows, storage volume requirements, and project costs over a range of return periods.

A global mathematical model for simultaneously obtaining the optimal layout and design of urban drainage systems for foul sewage and stormwater was presented (Diogo et al. 2000). The global strategy adopted combined dynamic programming and metaheuristics to develop a sequence of optimal design and plan layout subproblems. A computational method for the optimal design of highway drainage inlets was formulated as a discrete-time optimal control problem (Nicklow and Hellman 2000). The example revealed that genetic algorithms and the discrete-time optimal control methodology comprised a comprehensive decision-making mechanism that could be used for cost-effective design of storm water inlets.

The FORTRAN source code in EXTRAN block of SWMM has been modified to take advantage of parallel processing for faster program execution (Burgess et al. 2000). Reductions in run times exceeding 30% were achieved. SWEHYDRO and MOUSE were combined to model both the collection and treatment system for Edmonton, Alberta (Ward et al. 2000). A detailed simulation of the treatment plant hydraulics was performed to optimize its operation during wet weather periods.

The pros and cons of design storm and continuous simulation techniques were compared for treatment plant and collection system design purposes (Dent et al. 2000). Examples were included from several municipal master-planning studies that illustrated how results can vary from one approach to another. The shear stress distribution over the sediment bed in a pipe with deposited sediments was quite uniform but larger than the mean shear stress in the cross section (Berlamont et al. 2000). Comparisons between numerical calculations and (unsteady) sediment transport measurements confirmed these results qualitatively.

Modeling and analysis of combined sewer systems received considerable attention. Milina et al. (1999) described the weather conditions. It includes: (1) Establishment of the site specific statutory requirements and environmental objectives, (2) Design of sewer system components with specific reference to influences on marine water quality, and (3) Development of monitoring programs (Alvarez et al., 1999).

about one hundred rainfall events allowed a large range of validation which can be considered of good quality. Zug et al.

wastewater system. The model was able to elucidate phenomena that related to the source and fate of these compounds. Dougherty et al. (2006a) modeled empirically the hydrologic and NPS pollutant flux in an urbanizing basin. Total soluble phosphorus flux was associated with mean impervious surface and urban and agricultural soil disturbance. Inamdar and Naumov (2006) reviewed the lessons learned from a project to assess sediment yields from a mixed-land use in the Great Lakes. They also addressed the accuracy of the SWAT modeling. Thomas and Tellam (2006) modeled the recharge and pollutant fluxes to urban groundwaters. This model, UGIf, predicted a similar average recharge rate for the aquifer as previous groundwater flow modeling studies, but with significantly more spatial detail.

A study procedure used to quantify urban pollutant loadings and provide accurate estimates of street and catchbasin cleaning practices was tested by Sutherland and Jelen (2002) for two case studies in Michigan. The procedure involves intensive monitoring of accumulation and both the physical and chemical characteristics of the contaminated sediment found on streets or parking lots and within catchbasins of a given land use. The accumulation data along with monitored rainfall is then used to calibrate SIMPTM, a continuous stormwater quality model. The procedure was applied to the two case studies and classical economic production theory and marginal cost analyses were used to identify the optimal mix of street and catchbasin cleaning practices. An enhanced version of SWMM was developed by Chen et al. (2002) and applied to the Castro Valley Creek watershed to simulate the process of diazinon application, decay, washoff, and transport. The model was calibrated and validated before simulating the diazinon dynamics in the watershed. Simulated diazinon concentrations in the creek matched observed data when monthly application rates were assumed proportional to the population within each subdivision of the watershed.
The level of uncertainty associated of stormwater quality model predictions generally limits the usefulness of the results for precise decision-making. Substantial calibration data is necessary to obtain reliable predictions. Calabrò and Maglionico (2002) compared the calibration and performance of SWMM, UPSIM (Urban Pollution SIMulator), and COSMOSS (Conceptual Simplified Model for Sewer System Simulation). Each model was calibrated and validated for two drainage catchments, one in Bologna and the other in Belgrade. The results of the study indicated that all calibrated models predicted the hydrographs and pollutographs well for both catchments. The simpler models (UPSIM and COSMOSS) required less effort because of their simplicity relative to SWMM. The authors identified several key parameters used for calibration of water quality routines in the three models.

Grum and Aalerink (2002) evaluated the potential of applying random coefficient modeling to describe pollutant concentrations in combined sewers during rainfall. The concept was tested by developing a random coefficient model for suspended chemical oxygen demand (COD) in a combined sewer and compares the model results to those predicted by an equivalent constant coefficient model. Ahlman and Svensson (2002a) applied the SEWSYS model to analyze the flow of substances within an urban catchment. The model keeps track of where each substance originates and where it finally ends up. SEWSYS was also applied by Ahlman and Svensson (2002b) to model substance flows in urban sewer systems. A simple conceptual-modeling approach was used by David (2002) to find a useful relationship between precipitation and total suspended solids loads at several monitored locations in a small urban watershed located in Lisbon. The paper by Pandit et al. (2002) demonstrated how the fully calibrated Continuous Annual Load Simulation model, CALSIM, was used to predict the annual total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP) loads, under wet-weather conditions, for the Briar Creek drainage basin, located in the town of Malabar on the east-central coast of Florida, during an average water year. CALSIM was used to predict the annual loads under historical (1943), current, and future conditions.

Models of controls.
Wu et al. (2006b) described a water-quality based approach for stormwater management strategies. This approach combined CE-QUAL-W2 and HSPF to link watershed and receiving waters.

Schneider and McCuen (2006) presented a methodology to assess the hydrologic performance of stormwaterror. Th1sQUAL.9(t4.6.45

of flooding and tidal variations in the drainage system using a case study in Taiwan. The detention basin simulation showed that the basin was able to provide effective control for floodwater drainage. Calabro and Viviani (2006) simulated the operation of detention tanks using COSMOSS. The model showed good removals of suspended solids in these tanks.

Hipp et al. (2006) optimized the implementation strategy for placing stormwater filters in an urban area to ensure that the area met TMDL requirements. The model used was a GIS-enabled model for estimating and mitigating pollutant emissions in watersheds.

Huber et al. (2006) performed continuous simulations using SWMM to evaluate regional differences around the United States in hydrologic and water-quality performance on stormwater controls. The stormwater controls were characterized as being limited by peak inflow rate or by storage capacity. Rohrer and Roesner (2006) used SWMM to examine the effectiveness of typical stormwater management practices in reducing the potential for stream erosion. An excess shear stress erosion potential index was used to evaluate changes in erosion between undeveloped conditions of a 10 hectare watershed and four variations of post-development stormwater control.

Wayllace and Likos (2006) numerically modeled artificial soil as an evapotranspirative cover using finite-difference based seepage modeling. Results indicated that the artificial soil acts as an effective ET cover system by restricting wetting front propagation and causing water to either evaporate or flow laterally.

Mike21 was used to model the effect of retrofitting an existing stormwater pond to improve pollutant removal efficiency and hydraulic performance (German et al. 2005). Baffles, culverts and island removal were studied as possible improvements; the results showed that baffle installation was the best alternative. A probabilistic model of a stormwater retention tank was presented by Kwietniewski and Lesniewski (2005). The model accounted for high rainfall and the stormwater balance in the tank.

Dussaillant et al. (2005a) developed a numerical model to describe the water flow through a rain garden. The water flow was broken into three layers – a root zone, a middle storage layer of high conductivity and a subsoil lower layer. Zhang and Mitsch (2005) modeled the hydrology of three created freshwater wetlands. Water budget predictions for a stormwater wetland provided useful data prior to its construction.

In order to perform a life-cycle analys

stormwater drainage systems. The study concluded that primitive chambers, for example, gully pots, were likely to be far

frequent runoff events. SLAMM evaluated several control practices including detention ponds, infiltration devices, porous pavements, grass swales, catchbasin cleaning, and street cleaning. A numerical model (sediment trap efficiency for small ponds-STEP) was developed to simulate sediment deposition in small ponds (less than or equal 1 ha) and to calculate the sediment trap efficiency (STE) (Verstraeten and Poesen 2001). Eight runs with an experimental pond in Belgium were used to test the model. The STEP model produced reasonable predictions of STE as well as the shape and magnitude of the effluent sediment concentration graph.

Huber (2001) summarized the ability of SWMM to simulate wet-weather controls favored in current practice, including those related to LID. The model simulated some practices well, such as storage, and other options not as well, such as wetlands and filtration. In designing a permeable pavement installation, surface infiltration capacity that allows an adequate volume of stormwater to be captured and treated by the facility must be provided and maintained (James et al., 2001). The paper detailed the underlying method and function of a free-ware program that uses SWMM for the design of permeable pavement installations.

The water balance model (Aquacycle) developed in this study represents water flows through the urban water supply, stormwater, and wastewater systems (Mitchell et al., 2001b). The daily time step provides temporal flow distributioD0 T3Tc-0.A-4.44(

A dynamic hydraulic model of the Baton Rouge, La. sanitary sewerage system was developed and calibrated against recorded flow and rainfall and a number of operational modifications and system augmentations were proposed to optimize the use of the tanks to reduce the frequency of SSO (Moody and Baldwin, 1998). Model construction included the development of Real Time Control (RTC) code to simulate the operation and performance of two major offline storage facilities during the recorded storm events. .00(6(ope(e)6RTCe)]TJ2-5.1567 0 TD-0.0021 Tc0.0036 Tw[sti)-57(im)9.3(u)-5.1l laminar flow model was used to simulate the horizontal movement of stormwater both through and over the wetland sediments, a 400-ha first-order headwater swamp located within the Teeswater River watershed in southern Ontario, Canada. An analysis revealed that the simulated wetland streamflows were sensitive to the antecedent saturation of the wetland sediments, the storage and flow transport characteristics of the wetland sediments, and the conveyance capabilities of the wetland channel system (McKillop et al., 1999).

According to Moustafa (1999), long-term data collected at Boney Marsh, Florida and the EPA wetland database were analyzed to develop a simple tool that can be used to predict and optimize phosphorus retention in wetland treatment systems. Wetland properties such as water loading rate, water depth, P-loading rate, and water retention time were examined for their influence on phosphorus retention. The relationship between wetland properties and phosphorus removal efficiency was reduced to a simple quantitative diagram (The Phosphorus Removal Efficiency Diagram) a simple management tool that predicted expected treatment range using controllable hydrologic conditions.

A new concept, transport detention time, was proposed in this paper to describe solute-transport processes. Using this concept, a new mathematical model was developed to describe BOD_5 removal in constructed wetlands. By treating a constructed wetland as a series of continuous stir tank reactors, an n^{th}-order ordinary differential equation was derived based on the principle of mass balance and convective-dispersive equation and by introducing transfer functions and Laplace transform (Chen et al., 1999).

Traver (1999) examined the calibration and performance of a hydrologic model in recreating recorded storm events from both the stormwater wetlands and the wetlands stream, and the nutrient removal effectiveness of the stormwater wetland basin.

Nnadi et al. (1999) compared the ability of various design storm distributions to simulate the actual rainfall pattern to the ia55.54 Tm0 5ca5cac

Urban stormwater quality can be protected by maximizing the infiltration of frequent micro storms that account for the majority of the precipitation in urban areas. A proposed criterion was that the pre-development initial abstraction of precipitation should not be decreased by development. Heaney et al. (1999) used a linear programming model, which in turn uses information from the GIS as input data, to find the mix of functional land use types that minimizes the cost of retaining the initial abstraction at its pre-development level. To assist local governments in their efforts to develop more effective stormwater management programs, Prince George’s County, Maryland Department of Environmental Resources in cooperation with the EPA developed a guidance manual for an innovative alternative comprehensive approach to stormwater management referred to as LID (Coffman et al., 1999).

Best management practices. A study of a physical model of the design of litter traps for urban storm sewers was carried out at the hydraulic laboratories at the Universities of Cape Town and Stellenbosch (Armitage and Rooseboom 2000). This study clearly showed why most designs fail and identified the use of declined screens as an approach that holds considerable promise. Low Impact Development (LID) is an innovative micro-scale runoff control strategy for WWF management issues based on the incorporation of distributed micro-scale Best Management Practices (BMP's) throughout the subcatchment (Wright et al. 2000). The potential and limitations of existing models to evaluate the effectiveness of this design approach were explored in this study. Numerical techniques for modeling overland flow from pavements were described (James and Wylie, 2000). The efficiencies of various approaches were reviewed and compared. The feasibility of a permeable pavement option in SWMM for long-tem continuous modeling was explored by Kipkie and James (2000). The results indicated that it would be feasible but further testing would be needed

A two-phase decision-making software, DELTANOE, was used for the choice of BMP in urban stormwater drainage (Barraud et al., 1999). Two phases were described: (1) an elimination phase - to exclude solutions which were identified as unworkable according to site considerations and (2) a decision phase - to compare and at least to choose a scenario with feasible solutions.

According to Murphy and Lokey (1999) a model was developed to assess urban BMP efficiency on the total pollutant load using a simple spreadsheet and Monte-Carlo style simulator. The model suggests that many BMP used to comply with the National Pollutant Discharge Elimination System (NPDES) requirements appear to have little impact on the annual load. It might be argued that many BMP need to be evaluated at the source, not the receiving stream.

A two-phase decision-making software, DELTANOE, was used for the choice of BMP in urban stormwater drainage (Barraud et al., 1999). Two phases: an elimination phase which permits the user to exclude solutions which were identified as unworkable according to site considerations and a decision phase which allows the decision makers to compare and at least to choose a scenario built up with feasible solutions.

Murphy and Lokey (1999) developed a model to assess urban BMP efficiency on the total pollutant load using a simple spreadsheet and Monte-Carlo style simulator. The model suggested that many BMP appeared to have little impact on the annual load. According to Moustafa (1999), long-term data collected at Boney Marsh, Florida, and the EPA wetland database were analyzed to develop a simple tool that can be used to predict and optimize phosphorus retention in wetland treatment systems. Wetland properties such as water loading rate, water depth, P-loading rate, and water retention time were examined for their influence on phosphorus retention. The relationship between wetland properties and phosphorus removal efficiency was reduced to a simple quantitative diagram.

A calibrated particulate transport model showed that high efficiency sweeping at weekly intervals combined with annual different models to improve real-time forecasts.

Fuzzy logic models were used to do real time flow prediction for an urban catchment near Brussels, Belgium (Debede and Bauwens, 2000). A general method to design fast and stable mathematical models for the computation of sewer system outflow hydrographs were shown to be essential for real-time control of urban storm drainage systems (Hermann and Eberl 2000). The unknown inflow-outflow function was developed into a power series resulting in a nonlinear model. The new model formulation was tested with several urban subcatchments of a larger storm drainage network.

A real-time sensor fault detection method applicable to sewer networks was used to aid in real time control applications during wet weather (Piatyszek et al. 2000). This method consisted of comparing the sensor response with a forecast of this response provided by a model in the form of a state estimator called a Kalman filter. The Philadelphia Water Department investigated the application of real time control (RTC) to maximize the utilization of its existing combined sewer network facilities in its Southwest Drainage District (Vitasovic et al. 2000). A version of the SWMM EXTRAN routing model was compiled as a Microsoft Window Dynamic Link Library and included as part of the SewerCAT modeling environment to meet RTC requirements and exploit existing EXTRAN models of the system.

Despite considerable modeling efforts in recent years, a tool was still lackin 0 99 Tw[t t of UNIX stations and the experiences from running them within an urban drainage real time control project. The main focus was not on what the models do but how they were put into action and made to run smoothly embedded in all the processes necessary in operational real time control.

A near real-time, stream-flow-simulation system utilizing continuous simulation rainfall-runoff generation with dynamic-wave routing is being developed by the U.S. Geological Survey (USGS) in cooperation with the Du Page County Department of Environmental Concerns for a 34-km reach of Salt Creek in Du Page County, Ill. (Ishii et al., 1998). The system is critical for more effective management of the Elmhurst Quarry Flood Control Facility, an offline stormwater diversion reservoir located along Salt Creek. A $1.5 million Capital Improvement Project in the Lake City drainage basin m4(g)4a TJ17.9odule si-11(m)10.al fo1 Pag bTD0.0065 Tc091 Tw8r Tw8t how 00652inre r6h0.0065(n how 00652itypw 0065i0 determine the optimal location of these stormwater treatment practices. The results indicated that the optimal location and number of stormwater treatment practices is a complex function of nutrient source locations, watershed network connectivity, land use, distance to channel and contributing area. Riverson et al. (2005) evaluated the functionality of a

Pleau et al. (1998) proposed a tool to

found that the model was no more accurate than discharge concentrations from a frequency distribution for that outfall site.

The application of the HSP-F to an arid, urbanized watershed (in Southern California) was evaluated by Ackerman et al.

parameters which define hydrologic response units on a watershed were evaluated (Gowda et al., 1999). Shanahan et al. (1998) found that QUAL2E was best suited for point-source discharges and was limited when examining

multipolarized radar and polarimetric SAR for soil moisture, snow, wetlands, and flooding hydrological applications.

One of the more common uses of remote sensing data in urban hydrologic modeling is to estimate land cover and impervious surfaces. Impervious surfaces are even being used as a surrogate for water quality. Reilly et al. (2004) presented a statistical planning model to estimate future impervious surface given minimal information about future growth. Correa et al. (2004) reviewed aerial photos and satellite imagery as options to estimate impervious surface cover for use in urban hydrologic models. The results suggested model results can be made more accurate using remote sensing data to classify impervious surfaces for different development patters, building densities, and varying amounts of vegetation.

Beduhn et al. (2003) reviewed a physically-based urban stormwater model for a Minnesota watershed with land-locked basins. Fitzpatrick et al. (2003) used mathematical models to evaluate strategies to meet water quality standards in a heavily urbanized tidal bay (Jamaica Bay, NY). The authors presented an overview of the anthropogenic changes in the bay, the field-monitoring efforts, the model's calibration and development, and the model's results from various management alternatives.

Christensen et al. (2003) modeled (using statistical and dynamic water quality models) fecal coliforms in Papillion Creek (NE) to determine the extent of fecal coliform pollution and the potential control stormwater treatment practices. Results indicated that fecal coliforms were dependent on sediment transport, urbanized areas contribute significantly to fecal coliform loads, and comprehensive stormwater treatment practices to control sediment, nutrients and bacteria would be needed. Garvey et al. (2003) discussed the parameters for evaluating and selecting models for TMDL development as applied to Steamboat Creek (NV). An approach to selecting appropriate watershed modeling tools, identifying important considerations and potential pitfalls of model selection, were presented.

Medina et al. (2003) presented the Low Impact Feasibility Model (LIFE™). This model was designed based on hydrologic principles in order to evaluate a wide range of LID-related applications, including site design, analysis and review, watershed planning and public education.

The responses of ADAPT, a daily water-table management simulation model, to variations in the principal input

Watershed Management and TMDLs

A Decision Support System for urban water management was developed and presented by Barros et al. (2005b). The system combines simulation models for hydrology, hydraulics and water quality. Baptista et al. (2005) proposed a design aid methodology (and associated software) for the evaluation and comparison of drainage scenarios using stormwater stormwater treatment practices. A review of the models currently in use in Australia for water balance calculations was reviewed by Boughton (2005). The delineation of the karst groundwater basin in Bowling Green, Kentucky was presented by Crawford (2005). This mapping was prepared to assist well as several other local case studies.

Baughman et al. (2003) reviewed the activities of the Metropolitan North Georgia Water Planning District in their development and implementation of their watershed management plan, which was designed to support TMDL implementation. A process for inter-jurisdictional cooperation was recommended in the Watershed Management Plan. Osidele et al. (2003) presented an uncertainty evaluation of sediment loading and transport in the Chattahoochee River in Atlanta, GA. Preliminary studies indicated that three uncertain factors influenced sediment behavior in the Chattahoochee

watershed in the Denver metropolitan area, Colorado. Laing/Village Homes developed the model to evaluate pollutant loadings from the development; Aurora determined the allowable pollutant loadings to the reservoir. A linked watershed and water quality model was applied to the Little River watershed, Georgia (Moskus et al., 2001). The model was a modified version of the Generalized Watershed Loading Function (GWLF) model that had been linked to a simplified transport model based on Water Quality Analysis Simulation Program (WASP). This model was to forecast water quality under future development conditions for flow, sediment, phosphorus, bacteria, and metals. Future scenario runs showed that water quality standards likely will be violated in the future. The WERF project 97-IRM-5E modeled the trading market in Maryland under various assumptions with the results used to design and implement a statewide trading program (Bacon et al., 2001). Credits could be created and sold by POTWs, as well as nonpoint sources such as urban, agricultural, and undeveloped land. This paper presents preliminary results from the first round of several trading scenarios. Water quality modeling was conducted to examine the effects of growth in the McDowell Creek Basin on the water quality in Mountain Island Lake (Quinlan et al., 2001). The water quality modeling included both a watershed and a lake model. This study investigated the effects of effluent discharges ranging from the existing 6 mgd up to 24 mgd due to basin development. Nonpoint source loadings were estimated at each level of development and were included. Results of the industrial (indirect discharge) sources. The objective of this project was to develop, implement, and assess specific performance measures designed to measure the environmental impact of the pretreatment program in a selected carried out in the framework of the EU Technology Validation Project. This pilot project was related to the combined urban drainage system of Genoa's historic center that consists of eight natural streams flowing in culverts under the urbanized area. The Venice, Italy study was one of the pilots of the “Integrated Wastewater Project under the EU sponsored Innovation Program (Pretner et al. 1999). The project aims to demonstrate that an integrated approach to the planning and management of wastewater facilities was feasible and cost-effective. The project focuses on the integrated modelling of the sewer network, wastewater treatment plant and the Venice lagoon. The model will aid in optimizing the planning and management of the wastewater structures by adopting innovative monitoring and control technologies.

Musiake et al. (1999) discussed the basic concept of improving the water cycle to better support sustainable urban systems in Japan. An investigative procedure was presented that explains how to set up the project goals and how to evaluate the water cycle. Tsunoyama et al. (1999) described efforts to restore the hydrologic cycle in the Ebi River, which flows through Funabashi City in Japan. Using a physically-based distribution model, the authors studied quantitative changes in the water circulation system over time, and deduced future changes.

Sustainability. From definitions of sustainability, Rijsberman and van de Ven (1999) derived five key elements, by which sustainable development can be described. The most important differences in the approaches can be reduced to the basic attitude towards (a) people in their environment and (b) norms and values. Combining these two components leaded to four basic approaches to sustainability. The suitable definition of spatial scales of investigated systems was one of the most important questions within the water management (Stransky et al. 1999). The approach of transfer of global principles to local scale allowed determining major problems in areas investigated and establishing linkages to their causes. The urban water management objectives of ecological sustainability, economic efficiency and urban amenity required the adaptation of an integrated approach to water management. Lawrence et al. (1999) reviewed developments in the application of total water cycle based management approaches across Australia, Canada, United Kingdom and United States. The authors concluded that the need for a more integrated approach to urban water management was now being widely recognized, with a growing adoption of total-water cycle-based management, and substantial investment in ongoing studies and research related to its further application.

Loke et al. (1999) presented a framework that attempts to give an overview of the scientific tools used in urban storm drainage to water-quality problems. It tried to clarify the structure and terminology of current engineering methods by using diagrams, namely the problem identification and management scheme, the decision-making process scheme and the actual methodology overview. stbase.78derJ1.8(a(st) u [(st) uuogy)sgciely red-23(4.1(ram1.81tho8(n)-4situtn)-a2.1ch-4.6(tal-wg9 rncl

over the next few years. The U.S. EPA released an updated version of its BASINS modeling system (Whittemore 1998). This software integrates database queries with environmental modeling and mapping and greatly reduces the time required to manually assemble and statistically summarize monitoring data from an array of spatial databases.

Wise and Palukiewicz (1997) presented a framework for implementing watershed approaches to protect water quality. Many communities were seeking to understand how future urban development could be used as a basis for developing long-term watershed management plans (Bhaduri *et al.*, 1997). According to Pelley (1997) nearly half of the United States have adopted watershed approaches to tackle recalcitrant water-quality problems. Leland *et al.* (1997) reported that the future health of the Willamette River would depend on actions taken today. Bae *et al.* (1997) showed local environmental authorities can extend the watershed monitoring capacity through the development of a stream monitoring and stewardship program involving a partnership between community organizations. Ten watershed management ppaiiiiiif a strea.8(a) for the development of urban drainage towards sustainability based on case studies of mature urban-drainage systems. CSO, receiving-water quality, and decreasing groundwater levels were considered. Sewerage system and centralized aerobic WWTP should not be considered as the only possible solution for wastewater disposal. Systems with source watershed delineation and hydrologic spatial data extraction. Abellera and Stenstrom (2005) reviewed the use of satellite imagery and GIS in stormwater modeling to improve the predictions of impervious cover in a watershed. These techniques, when combined with knowledge-based systems, have been evaluated as a method of reducing the need for expensive field surveys. Results showed that these new systems were comparable to the older field surveys. The use of GIS for stormwater management and land planning was reviewed by Johnson and Zelinsky (2005). The GIS mapping allows for various alternatives for stormwater management to be investigated, as well as indicates what the impact of future development is likely to be.

GIS have been used in various water resources and hydrologic modeling applications because of their ability to manage and process spatial data. The use of GIS has also increased as more spatial data has become available. The required resolution of the spatial data for a variety of applications remains uncertain and limited general guidance is available. Ikenberry et al. (2004) assessed the affect of data resolution on the values of SCS curve number, runoff depth, runoff volume, and peak discharge. The summary results provided general guidance on the need for relatively low or high resolution soils and elevation data.

Early applications of GIS in watershed modeling were as pre- and post-processors of watershed data and model results. Recently, models have been developed to function entirely or almost entirely within the GIS environment. Jain et al. (2004) developed a distributed rainfall-runoff model in GIS that uses Philip two-term infiltration model and diffusive wave for runoff and flow. Testing of the model for several catchments indicated the model can realistically simulate the runoff hydrograph at the watershed outlet. Developing the network topology is a major effort in developing a hydraulic model of an urban drainage network. Lhomme et al. (2004) introduced a method using geomorphological routing based on a DEM instead of physically-based routing methods. Tests of the method found the geomorphological model produced flood simulations that were similar to the physically-based routing model, yet avoided the tedious network topology creation.

GIS-based models used to predict stormwater runoff quality and receiving water quality are becoming more common. They have the advantage of spatial relationships being included in the analysis results to suggest sources, impacts, etc. Park and Stenstrom (2004) presented an approach using image processing of satellite imagery to classify land use and

GIS is being used for a wide array of other functions in wet-weather flow management. Zhan et al. (2004) presented a GIS extension for the ESRI ArcGIS software that produces spatially distributed curve number and runoff maps. Xu et al. (2004) demonstrated the use of GIS to aid in the simulation of snowmelt dynamics.

Al-Sabhan et al. (2003) reviewed the use of GIS and web-based systems for flood forecasting and hazard mitigation. The Web-based hydrological modeling system permitted integrated handling of real-time rainfall data from a wireless monitoring network. He (2003) reviewed the integration of a GIS and a simulation model for watershed management. The simulation results show that expansion of urban land would likely lead to an increase in runoff predictions were reasonably close to measured flow rates for the low flow part and the front peak discharge, but not for other flow rates later in the hydrograph. Nie et al. (2002b) applied a GIS-based hydrologic approach to incorporate buildings into urban watershed analyses and to evaluate the influence of grid cell size in distributed urban drainage modeling.

Hiramoto and Kariya (2002) presented a method to predict areas of inundation in cities even when rivers are not overflowing. The technique involves computing runoff flow paths using topography and other data in a GIS to derive the areas and depths of inundation. The technique was applied to a case study and found to provide fair predictions when compared to observed data. The model is concluded to be sufficient for production of forecast charts of inundation if human judgment and other model factors are incorporated into the analysis. Morita and Fukuda (2002) introduced a DSS for flood-control facility planning. The DSS is composed of a flood inundation prediction model and a flood damage estimation model. Analysis using the DSS yields damage reductions created by a flood-control facility. The DSS was demonstrated for a highly urbanized catchment located in the Tokyo Metropolis. Al-Sabhan et al. (2002) described a

increasing availability of digital and remotely sensed data such as land use, soil texture, and digital elevation models (DEMs), GIS has become indispensable in preprocessing data sets for watershed hydrologic modeling (Yu et al., 2001c). The transfer of inputs and outputs between the model and GIS can be greatly simplified by incorporating the model itself into the GIS environment. The authors incorporated a simple hydrologic model that used the curve number method of rainfall-runoff partitioning, a groundwater baseflow routine, and the Muskingum flow routing procedure, into the GIS model. Then the model was used to simulate the hydrologic response of the Upper West Branch of the Susquehanna to two different storms. The simulated hydrographs compared well with the observed hydrographs at the basin outlet.

Chester County, Pennsylvania municipalities have been working with Green Valleys Association to develop a "Sustainable Watershed Management Program" (Cahill et al., 2001). The heart of this program is a "Water Balance Model" that is interactively linked to a detailed GIS model. Municipalities can determine if the sustainable watershed goals are attainable or if changes are needed in municipal regulations. The visual component of the GIS allows the planners and municipal officials to quickly "see" the areas of concern, as well as the effects of regulatory changes. A comprehensive watershed approach to sewer separation planning stormwater systems were reviewed by Shamsi and Fletcher (2000). Popular AM watershed models. Several recent reservoir water supply projection studies were used to demonstrate a general framework for simulating changes in land use and resulting impacts on water quality. Butt et al. (1999) described a unified database for 14 Lake Tahoe Basin (Nevada) streams that included an inventory of riparian vegetation and stream morphology, using stream classification and riparian vegetation cover data sets. The authors provided detail on data collection and explain the development of the resultant database.

Calomino et al. (1999) described using GIS for large urban areas based on all the information needed for urban addition to stormwater and urban watershed modeling applications (Bryant et al., 1998). GIS tools were applied to the estimation and prediction of stormwater flows impacting a steel plant construction site. Data layers included USGS digital and scanned image maps, SCS soils maps and engineering drawings for the site (Lieberman et al., 1998).

Policy

Bradley et al. (2005) reviewed the US EPA's encouragement of having regulatory agencies issue watershed-based NPDES permits, rather than site-specific ones. The US EPA's water-quality trading policy for stormwater management and smart growth was reviewed by Trauth and Shin (2005). The issues that must be ironed out before trading can begin were identified, as well as potential solutions. Broviak (2005b) provided an overview of the US EPA's blending policy, where part of the sewer flow is fully treated and part is partially treated. The purpose of blending is to reduce the overall pollutant load in the effluent, but without sending destructive flows through the treatment plant.

Collaborative education and outreach activities are promoted by Aston (2005) as a means of producing effective nonpoint source pollution control. Pines (2005) outlined us() ou)t ues ialtedus irem0.1(r)en4.4(u)tss a mpueattin4.4(u)g6(se)tu4.4(u)d4.4(u)e05(

EPA water quality criteria.

Gregory and McLamarrah (2003) reviewed Houston's business plan for Continuous Improvement for Collection Systems. The outcome of this work is anticipated to be a reduction in

The Department of Natural Resources in Queensland, Australia conducted the Queensland Water Recycling Strategy (QWRS) to determine future Government directions in water recycling (Gibson and Apostolidis 2001). This strategy considered the beneficial use of all waste streams such as domestic sewage, industrial and agricultural wastes, as well as urban stormwater. The Urban Development Corporation (UDC) in Japan developed a new system, a “Rainwater Recycle Sewer System” (Matsushita et al., 2001). This system is supported by “Rainwater Storage and Infiltration Technology (RSIT)” for new town creation and urban renewal. The new system consisted of two elements: RSIT components based on Public-Private Partnership (PPP) and a stormwater drainage system. The private sector is responsible for the main part of RSIT, and the public sector is responsible for th

implementation of the Section 319 non-point source program, development and implementation of Watershed Restoration Action Strategies envisioned under the Clean Water Action Plan, implementation of monitoring programs and for addressing the requirements of the TMDL program. McDonald et al. (2000a) presented the preliminary findings, conclusions, and recommendations for the development of a pollutant load trading program and the modification of the existing nutrient (nitrogen and phosphorous) and TDS TMDLs and WLAs on the Truckee River, Nevada. As a result of the TMDL process, the Truckee Meadows Water Reclamation Facility had WLAs incorporated into their NPDES permit, resulting in potential restrictions on planned growth. In order to accommodate for planned growth and to meet water quality objectives, a pollutant load trading program to develop “watershed offsets” was beginning implementation. McDonald et al. (2000b) described a multiyear project to develop revised TMDLs and a pollutant-load trading program for the Truckee River.

Additional papers examined community and political issues related to WWF control programs. Lindsey et al. (2000) explore five programs led by EPA’s Office of Water that address today’s environmental issues in wastewater management. Many of the programs are voluntary but regulatory programs continue to play a role in wastewater management. Through humor, Jones (2000) focused upon constraints that now inhibit a watershed solution to environmental, multi-media problems, and proposed potential remedies. The Tollgate Drainage District (Ingham County, Weather Demonstration Project. Also described were the consensus building strategies that were used to engage numerous stakeholders, provide them opportunities to influence decisions, and participate in the Rouge River restoration.

beach-water quality was urban runoff and Surfrider activists stenciled signs on street gutters to educate people that all street gutters were connected directly to the beach (Labedz, 1998).

After 100 years of industrial development, the Emscher area in Ger. has been presented with the need for environmental restoration and social changes (Geiger and Becker, 1998). Special attention has been paid for the choice of the future drainage system linking source control by infiltration of stormwater with collection and treatment of polluted runoff and currently a large number of pilot projects are underway which show the need for public participation to accept new technologies. Geldof (1998) reviewed urban water management in the Neth. over the last few years and provided some suggestions to cope with emissions from sewer systems, peak discharges, high ground water levels and dehydration of soil in agricultural areas and nature reserves. The solution for urban runoff and water quality management in the Birkeland basin Sandsli, Bergen, Nor. is based on urban hydrological planning and the new blue-green concept in the homegrown Scottish BMP to deal with poor water conditions as a result of urban runoff. Lawrence (1998) outlined the national approach to stormwater management in Aust. including implementation practices by both state and local government powers.

Lee (1997) discussed issues and regulatory requirements related to the privatization of water and wastewater services in Latin America. Lyon (1997) examined privatization law as it applies to water management in Europe and in the United States and classified it into three categories: institutional, management, and product law. In addition, Corssmit and Brunsdon (1997) discussed the transition of the Fairbanks Municipal Uilities System to private ownership, including water, wastewater, electric, steam heat, and telephone utility in and around greater Fairbanks, Alaska.

The degree of compliance in th

The review of existing stormwater recycling systems focused primarily on the recycling of general urban runoff (runoff generated from all urban surfaces) for non-potable purposes. Chanan and Woods (2006) reviewed total water cycle management activities in Sydney, including a complete review of current water management strategies. Marks et al. (2006) described a South Australia development that integrates

pollutants correlated to watershed impervious area and aquatic biology indices. Wieske and Penna (2002) reviewed the stormwater strategy of Laguna Beach, California. The papers reviewed the methodology that engineers have used to manage the urban runoff problems plaguing the city. Zimmerman and Thomas (2002) presented the Clayton County Watershed Management Team's approach to watershed management plan implementation. Plan implementation relies heavily on teamwork and enhancing existing water quality programs versus creating new mechanisms to protect Clayton County waterbodies. Gassman and Lee (2002) discussed the planning needed for Broward's Countywide Integrated R(d)- i watershed protection; preserving the unique ecology of the watershed; fostering informed public opinion; involving the public in watershed protection planning and implementation; and working with existing organization to create an ongoing program. Miller et al. (2002a) reviewed alternative wet weather permitting strategies that recognize real-time conditions in the Indiana systems. The City of Indianapolis considered several strategies (mass, seasonal and tiered limit strategies) used in other places, as well as a 'flow-proportional limit' strategy.

Tuomari and Thompson (2002) reviewed the success of Wayne County's IDEP Training Program. The key goals of the training program are sharing our expertise with other local units of government involved in stormwater management and collaborating efforts in reducing improper discharges to surface water. The modules of the training program are: Overview, Basic Investigations, Advanced Investigations, Construction Related Illicit Discharges, Combined Basic/Advanced Investigations, and two (2) specialty training sessions.

British Columbia's Stormwater Management Guidebook was reviewed by Stephens et al. (2002). The Guidebook describes the adverse impacts of past stormwater management practices and walks its audience through stormwater management planning, including: how to develop goals, objectives and priorities; how to undertake public consultation; how to assess watershed health; how to select, implement and monitor best management practices (stormwater treatment practices); and how to finance the long-term implementation of a stormwater management program. The Stormwater 'Source Control' Handbook for Australian practice was presented by Argue (20020. The Handbook attempts to provide and Wilber (2001) reviewed TMDLs in several states. The reviews indicated that TMDLs, and the resulting Load Allocations (LAs) and Wasteload Allocations (WLAs), often were based on limited data, unsound modeling and poor

reviewed. Although watershed studies require a significant investment in data collection and in public involvement, the resulting solutions were typically more cost-effective and accepted by the public. Waterific, an interactive science program about water, was created to educate the public about water-related issues (Ziegler et al., 2001). The focus of Waterific was to enhance environmental awareness, education and celebration. In addition, the program is a fun, hands-on activity that meets the core content required by the Kentucky Department of Education for sixth-grade science. By pooling talent from various water quality agencies, the school students saw first-hand how all the agencies work together and independently to maintain the water quality in Northern Kentucky.

According to the U.S. EPA's Index of Watershed Indicators, at least 21% of watersheds have serious problems, 36% have some problems, 16% have good water quality and 28% lack sufficient information to analyze (Hun, 1998). Managers for the Joshua's Creek, a 21 km^2 watershed in southern Ont., Can. used a three stage process to sustain water resources in the face of rapid urban development. The process included a macro-scale watershed plan, detailed subwatershed plans, and specific stormwater management plans (Bishop, 1998). The Tualatin River Basin in northwest Oreg. experienced rapid urbanization bringing changes in land uses, increased pollutant loads to the river and its tributaries from the WPCP and urban runoff (Jackson, 1998). Requirements defined by the Clean Water Act such as NH_3 and P load limitations were implemented in 1988 and temperature allocations were scheduled for 1997.

Municipalities are required to implement multiple regulations resources, and stormwater management regulations for a study reach within the context of existing and future development conditions throughout the watershed of Tyler Creek, Elgin, Ill.

As part of N. J.'s watershed management approach, water-resource programs, e.g., stormwater management, wastewater management, source-water protection and CSO control, will be coordinated and implemented through a statewide watershed-management process (Cohen, 1998). N. J. has maintained a federally approved coastal-zone management program for 18 years and used the Coastal Management Act to implement the State Development and Redevelopment Plan (SDRP) and the Statewide Watershed Management Plan (Frizzera 1998). The Rock River Watershed Partnership was established to conduct a full watershed study of the Wisc. portion of the Rock River as a result of stricter P restrictions imposed in 1996 (Schroedel et al., 1998). The Partnership is a cooperation of communities that line the Rock River Watershed area and efforts have been made to share information. Rudolph et al. (1998) gave an overview of the

BMP manual development in the Kansas City metropolitan area, a bi-state effort, was reviewed by Jacobs and Henson (2004). The rationale underlying the new approach of multi-municipal cooperation included substantial long-term savings in the development and maintenance of public infrastructure, better natural resource protection, and compliance with new federal water quality regulations. Geomorphic engineering was introduced into standard stormwater designs in the Kansas City metropolitan area (Prager et al. 2004). The purpose of incorporating geomorphic engineering was to better understand and model the effects of channel energy on natural stream features. Nutrient criteria were established in the Santa Margarita River watershed with the unintended consequence of eliminating reclaimed water discharges in the watershed (Rowan et al. 2004). Because of this, governmental agencies are reviewing instead the use of riparian wetlands to reduce the nutrient loads in runoff during storm events.

The stormwater management plans for St. Charles were discussed by Martin et al. (2004). GIS was used to determine locations of outfalls and locate illicit connections and discharges. Peterson and Kacvinsky (2004) reviewed the multi-nonpoint sources by capturing favorable economics. Thurston et al. (2003) hypothesized that a well-designed, tradable runoff allowance system could create economic incentives for landowners to employ low-cost runoff management practices to reduce excess stormwater flow to more ecologically sound levels. Attributes such as percent impervious surface, soil type, and so on, determined a given land parcel's runoff potential and management alternatives and, by extension, its allowance requirements.

Bloom (2002) provided a national review of known proposed or issued TMDLs or TMDL implementation plans that call for the imposition of numeric effluent limitations in MS4 permits as a means to achieve TMDL-derived load reductions. The paper also highlighted some of the policy implications of this emerging trend. Dors and Tsatsaros (2002) reviewed the determination of a margin of safety for TMDLs for water bodies that are determined to be water quality limited. Freedman et al. (2002) discussed the results of the WERF-funded research project on navigating and improving the TMDL process. The objective of this research was to investigate issues and concerns with the TMDL program, and to develop and identify ways to improve the TMDL process. Clark (2002) used the Cascade Reservoir TMDL Implementation Plan as an example for the development and application of a database project tracking tool. The tracking system serves as a master summary of all projects and stormwater treatment practices constructed for the purpose of reducing the phosphorus load to the Reservoir, and is used to assess phosphorus load reduction, to analyze cost-effectiveness and to assess the performance of each BMP individually or as a whole.

Bhimani et al. (2002b) presented the findings, conclusion and recommendations for the implementation of a water-quality presented a case study of stakeholder involvement in the development of TMDLs in the Sacramento River watershed. This presentation focused on the benefits and drawbacks of the stakeholder process as a forum for problem solving, the approach taken to foster collaboration and connection between stakeholder activities and the TMDL development process, the work products developed by the stakeholder groups, and the lessons learned from the process.

Effluent trading to maintain water quality on a watershed has gained momentum recently, however the method is complex. Kerns and Stephenson (1996) addressed the key elements for a successful trading operation. The EPA (1996d) acknowledged the benefits of pollutant trading among the various sources within a watershed as a means of reducing costs, and a framework for watershed-based trading was drafted (EPA, 1996e). Imbe *et al.* (1996) did a water budget to determine the impact of urbanization on the hydrological cycle of a new development near Tokyo, Japan. A cost-program in California and Kansas. The study found that fiscal resources, a well-educated public, positive perceptions of the federal policy, and co-operative planning efforts lead to better compliance with the mandate and a higher quality response. Stidger (2006b) reviewed current and projected stormwater regulations, including low-impact development strategies for highways.

Mark and Parkinson (2005) advocated an integrated approach as the future of stormwater management. The goal was to propose alternative approaches for controlling development in flood-management land. Rauch et al. (2005) reviewed the state-of-the-art and current implementation of integrated approaches in urban storm drainage. Intregration was being implemented at two conceptual levels: (1) integrating the storm drainage system with the receiving environment, and (2) considering the interaction and influence of stakeholder participation on the performance and development of the storm drainage system.

Lee and Stenstrom (2005) compared three stormwater permit programs to determine their effectiveness in assisting agencies in meeting their NPDES permits. The land-use monitoring program appeared to be more successful than the beach-water-quality program or the industrial monitoring program. Urbonas and Doerfer (2005) advocated master planning for stream protection in urban watersheds. The paper suggested several general principles that can be used to deal with these emergent problems. Zhou

Implementation Guidance has been developed and the paper focused on the complex issues raised during the public comment period for the Guidance. Bradley et al. (2004) reviewed the holistic strategy to wet-weather events under development by the US EPA. The purpose of the new strategy is to provide required flexibility for stormwater, CSO and SSO discharges covered by NPDES et Tw[(is to provr3(l)44((har)5thar)5.ere)8.5 -1.1T* p3e2eti3ei3e2=4(=44)4.754)svip3e p3e u=4.e

Phase II programs. Bateman (2002) reviewed the outsourcing of the bulk of Florida's NPDES program activities. Private contractors write and monitor permits, and inspect construction, industrial and municipal permittees.

Schrameck (2002) presented Michigan's General Storm Water Permit and Phase II Stormwater regulations and the innovative approach for the Rouge River. The permit incorporated some of the better aspects of the Phase I Federal Storm Water program, such as the Illicit Discharge Elimination Program and the Public Education program, without the onerous aspects of the intense sampling found under that program. The permit also mandated that the communities/agencies within the various subwatersheds of the Rouge cooperate together to format a plan for public involvement in the restoration process and, most uniquely, required that the various parties within the subwatersheds develop a comprehensive watershed management plan for their separate areas that will be linked together to form a basin wide Remedial Action program for the Rouge River.

Harrison (2002) reviewed the municipal perspective on zero-impact policy issues and the concerns that it raises. While the inventory of stormwater quality management measures to reduce pollutant discharges is growing, they do not achieve the zero-discharge mandate and do not reduce the vulnerability to statutory enforcement action.

Under Phase I of the NPDES permit requirement, permits were required for stormwater discharges associated with industrial activity (Daniel 2001). Typically these discharges were material handling and storage areas at certain industries. Authorized dischargers were required to develop and implement stormwater pollution prevention plans to prevent the discharge of pollutants in runoff. Pollution prevention has been the key for stormwater discharges associated with

EPA Phase II stormwater regulations become effective (Cowles, 1998). The Wis. Department of Natural Resources recognized that a comprehensive urban stormwater permitting program was needed for the Milwaukee River Basin as water quality in area streams and the near-shore area of Lake Michigan did not meet state standards. Aggressive voluntary efforts to control sources of rural and urban NPS pollution did not achieve desired results (D'Antuono, 1998a and 1998b). Wayne County's Rouge River National Wet Weather Demonstration Project (Rouge Project) is a comprehensive program to restore the water quality and beneficial uses of the Rouge River, a tributary to the Detroit River in southeast Mich. with significant sources of pollution from industrial and municipal point sources, stormwater runoff, and CSO (Murray, 1998). One of the Rouge Project's key findings was that major barriers to effective pollution control and water resources management are often institutional, not technical. The Rouge Project supplemented the existing regulatory program with a

Present worth is often used to select among alternatives in the public works arena (Bate et al., 2001). This is adequate if the options are technically equal and operations and maintenance costs are controlling, but it overlooks are intangible criterion such as social impacts, meeting the design criteria, construction, traffic and utility impacts, constructability, as well as service life and reliability. “Paired comparisons” allow comparisons of intangible criterion that impact the project. Case histories illustrated the use of the “paired comparison” process. Booth et al. (2001) reviewed a survey of residents in the Oak Creek and Menomonee River watersheds, both located in Milwaukee County, Wisconsin to determine the willingness to support ecological restoration of urban streams. One purpose of the project was to assess the willingness to pay (WTP) of urban watershed residents for urban stream restoration and to identify the underlying economic, psychological, and social motivations for WTP. The basic hypothesis tested here was that psychological variables, environmental attitudes, and ethical values are more important than strictly economic phenomenon.

In the future, systematic and ongoing asset management programs are expected to influence evaluations by bond rating agencies, budget allocations, decisions by enforcement authorities, and acceptance of rate increases (Morgan and Wagner 2001). This approach incorporates life-cycle analysis, longer planning horizons and more intensive tracking of asset conditions. Of the nine primary program components in the CMOM/SSO guidance, most are related directly or indirectly to asset management activities. The privatized operation of the Milwaukee Wisconsin, sewerage facilities has lowered costs of operation ($14 million per year) and increased service performance (Tobel and Jankowski 2001). Additional benefits include increased asset and pe

Fund program and discusses potential uses of the funds for nonpoint source water quality projects. The Minnesota Legislature commissioned a six-month study to investigate the framework for a cost-benefit model to analyze water quality standards through a watershed-based approach that evaluates both point and nonpoint pollution sources (Laws of Minnesota 1998, Chapter 401, Section 59). Although watershed management has been practiced in Minnesota for decades to protect and restore water quality, this study was undertaken because of the growing understanding of the complex and often conflicting choices facing those who live in, use, and manage watersheds if watershed integrity is to be maintained over the long term (Ward 2000).

The costs for controlling sanitary sewer overflows (SSO) and combined sewer overflows (CSO) have also been examined. A problem common to many SSO equalization facilities was that the planning level cost estimates were significantly less than the final implementation costs. Keller et al. (2000) presented guidance for developing the costs of SSO equalization facilities so that their cost-effectiveness can be properly evaluated during the planning phase. New regulations governing discharge of untreated combined sewage (defined as wastewater consisting of both sanitary and storm flows during rain events) to the nation's receiving streams have challenged the traditional methods for determining cost responsibility and sewer rates for municipal wastewater utilities for the City of Detroit and Southeastern Michigan (Foster and Fujita 2000). A number of asset management tools and techniques that have been used in utilities, including wastewater utilities, were discussed by Morgan and Wagner (2000). The authors outlined a new approach for integrating these tools called Infrastructure Capital Assets Management (ICAM). The approach included modeling tools, decision support tools, and rational methodology to provide decision-makers the tools needed to develop strategies and justify retaining revenues as part of informed management of their assets (Morgan and Wagner 2000). Spartanburg Sanitary Sewer District (SSSD) in

Singapore with the use of a dual-mode system (DMS) which uses collected roofwater for nonpotable uses. This amounts to 12.4% the current average monthly expenditure on water (Appan, 1998).

In Columbus, Ohio, (El-Hosseiny et al., 1998a) uncertainty of model results increased as model complexity decreased for small and medium storms (25—50 mm/d), however system performance was unpredictable for high hourly intensity, e.g., 100 mm/h. In determining the optimal complexity level, there was no difference between using total cost of an alternative versus design costs plus uncertainty costs. The city of Indianapolis, Indiana performed traditional sewer system evaluation surveys to eliminate I/I, costing between $8.20 and $9.80/m ($2.50 and $3.00/ft). An alternative approach addressed wet weather collection system overflows in two phases costing $2.80 and $1.50/m ($0.85 and $0.45/ft), respectively (Westropp and Bellucci, 1998). A Nashville, Tenn. study indicated that an I/I removal of approximately 14 700 m^3/yr /100 m of lining may be expected from rehabilitating deteriorated sewers (Kurz et al., 1998).

The U.S. EPA (1997g) published a catalog of Federal funding sources for supporting local governments to implement watershed projects. Financial capability, along with other factors listed, may be used to negotiate reasonable compliance schedules for implementation of CSO controls (U.S. EPA, 1997h). Austin, Tex. implemented a trenchless-sewer technology, the installation of U-liners. Along with a new maintenance agreement, this will permit the city to repair approximately 35,000 ft/yr and reduce its per foot sewerline-rehabilitation cost by 44% (Water Eng. Manage., 1997a).

A general Benders'-decomposition model, which deals with solving mixed-variable problems, was developed to optimize the repair and replacement strategy for a sewer network. The model determines the least-cost solution by minimizing combined-wastewater treatment and repair associated with I/I (deMonsabert and Thorton, 1997).

Sarnia, Can. planned to upgrade its WWTP, to install four CSO-storage tanks, and to intercept stormwater runoff to upgrade, restore, and protect water quality in the St. Clair River . The first CSO tank has been installed with a cost-effective-cleaning system (Parente and Stevens, 1997). Underflow baffles were identified as a potentially cost-effective alternative for controlling CSO floatables at relatively inactive CSO outfalls by the Massachusetts Water Resources Authority. A study indicated that underflow baffles could provide up to 70% capture of floatables under a wide range of flow conditions (Walker *et al.*, 1997).

Battenfield *et al.* (1997) revealed some of the lessons learned in the development and implementation of a cost-effective solution to control the excess WWF of the Houston, Tex. sanitary system. Ahyerre *et al.* (1997) summarized three main difficulties of sewer-quality models, i.e., doubtful mathematical formulation, uncertainties on input and calibration data,

systems (Benson, 1996; Reese, 1996). Roesner *et al.* (1996) described a stormwater-master plan that formulates an integrated way to finance necessary stormwater infrastructure for a new development near Orlando, FL. The EPA's Environmental Financial Advisory Board (EFAB) and Environmental Financing Information Network (EFIN) are
/ T T 6 n e t

The paper by Shaver and Ridley (2002) discussed a number of tools that were recently developed to reduce stormwater-related impacts. These tools could include low impact design approaches from an individual and comprehensive catchment perspective, recognition of urban stream values, offsetting mitigation approaches when adverse impacts are unavoidable, and the establishment of regional criteria for stormwater discharges.

Growing demands on drainage still challenge designers with respect to runoff quantity and quality; landscape aesthetics, ecology and beneficial uses; and operation of existing urban wastewater systems (Chocat et al., 2001). Integrated approaches, optimal operation of the existing infrastructure, advanced pollution and runoff source controls, improved resilience of receiving waters, and adaptive water management can achieve further advances in water quality protection. Specific research needs include new technologies and strategies for stormwater management, advanced treatment of urban wet-weather effluents, and tools for analysis and operation of drainage systems. Smith et al. (2001a) investigated a range of process technologies to assess their suitability for the treatment of different water sources for non-potable reuse. For (9(6) (w(6w r t s sihthis study, a large scale suitabil9n-0.0015cg19-6.5(n8o)-4.3(nr06.5ud)-4.vg0.0029 0.0015 7onr06.5udoo94 Tc0.0027 Tw[(can)-4.2(ach

results to date were presented in the paper.

Clark (2004) reviewed the use of a flood-alert system which combines real-time NEXRAD radar with hydrologic models. The goal was to improve the prediction of flooding flows – when they occur and where they will affect – in addition to predicting the effects of new development on flooding potential.

Nehrke and Roesner (2004) evaluated the effects of flood control design and stormwater treatment practices on the flow-frequency curve. Comparisons were made between pre- and post-development flows assuming that peak-shaving techniques, a common requirement in urban drainage design, are used. In addition, the use of detention ponds was examined for their impact on the curves. Peak-flow reduction targets based on habitat and geomorphic (median grain size mobilization potential) was examined by Dierks et al. (2004). It was proposed that in sand and gravel bed streams, peak flow targets based on that mobilization threshold could serve as a surrogate for maintaining intact benthic and macroinvertebrate habitats, even in urban streams.

Rahman and Weber (2003) reported on the use of a holistic context in Brisbane City to address stormwater management. One key initiative included facilitating Water Sensitive Urban Design (WSUD) components within an Integrated Water Management Strategy that looks at policy formation, planning strategies, design option, community marketing and acceptance, maintenance programs and finally evaluation of various WSUD approaches.
Rowe et al. (2003) advocated using water quality criteria as the basis for hydraulically sizing conveyance systems under the proposed SSO rule. The fundamental problem that most municipalities' struggle with was how much capacity would be sufficient. Turner-Gillespie et al. (2003) studied the regional flood response in the Charlotte, NC metropolitan area. The regional flood response strongly reflected urbanization effects – increased flood peaks and decreased response times – and geologically controlled attenuating reaches, which decrease flood peaks and increase lag times. Roy et al. (2003) reviewed the solutions used by Littleton, MA and that were based on LID techniques to reduce the effects of stormwater runoff on the highly developed watershed of Long Lake. These solutions included grass and vegetated swales, constructed wetlands, bioretention cells, landscaping features that encourage the on-site infiltration of stormwater, the redesign of the boat ramp and parking area, and controls on private residential lots within the watershed.

Funayama et al. (2002) reported on the approach of the Tokyo region for using storage pipes and interconnecting network pipes to provide storage and prevent flooding, with the result being that this approach was cost-effective.
Woods et al. (2002) reviewed the balancing of the water budget in the Ipswich River (Massachusetts) watershed. The

guidelines for appropriate sewer design criteria were developed. Due to the complex hydraulics in the vicinity of the Jackson Pike WWTP and as part of the West Columbus (Ohio) Local Protection Project (WCLPP), a detailed dynamic model was developed to assess the sewer system performance under different operating conditions (El-Hosseiny et al., 2001). The model used the sewershed approach to maximize system storage without affecting the current services and to satisfy the regulations. The sewershed approach and the developed model allowed the determination of the optimum projects as a credit for I/I estimated to be eliminated by structural rehabilitation. Because of the inherent variability of I/I, response in sewer systems flow reductions due to rehabilitation generally cannot be definitively quantified and at best, a range in reduction can be established (Samson et al., 1998). A slipline pipe was installed on the NORSD Westerly Interceptor project (Dell'Andrea, 1998) to relieve I/I and exfiltration at a cost significantly less than a total replacement would have been. A slightly smaller diameter pipe section is inserted inside the existing sewer and the annular space between the two is filled with grout. Montgomery, Ala. monitored the rehabilitation of manholes in a sanitary sewer system and found that a cementitious mortar, in places covered with a coal-tar epoxy liner effectively sealed out I/I from the system (Holmberg and Rowe 1998). Their experience also indicated that proper surface preparation is vital to ensure adhesion between the mortar and substrate for lasting benefits of the work. The NORSD assessed the condition of the interceptors and CSO (Duke and Knott, 1998). Guidelines for manhole and pipeline defect classification were established and procedures for condition assessment were also developed. Anderson and Curtis (1998) discussed how a hydraulic model can be developed that will ensure the level of accuracy that should be required as part of any hydraulic evaluation mulching/cutting heads (Thacker and Gonzales, 1998).

Grace (1997) described four case studies of marine-outfall rehabilitation and maintenance where obstructions had caused serious problems in wet-weather- and wastewater-effluent drainage. Larsen *et al.* (1997b) reported that after construction costs of 6.8 million dollars for regional-sewer rehabilitation in the Broward County, Fla. Southern Regional Wastewater Collection System, I/I is still a problem. The repair project eliminated 5.64 million gallons per day (mgd) of extraneous flow but an estimated 10.5 mgd still enters the system. An evaluation of eight basins in Seoul, Korea revealed that every five meters the sewer systems needed repair and this was made worse by I/I, resulting in poor operation of the WWTP. Trenchless-rehabilitation technology was recommended as a solution (Parks, 1997). Guajardo and Gogers (1997) developed a roadway drainage plan with improvements on existing discharge flows to the receiving stream in the Houston, Tex. Pazwash and Boswell (1997) presented specific methods to collect and use roof runoff for lawn and landscape watering, car washing, and deck and driveway cleaning.

Bhaskar *et al.* (1997) used a physically-based-rainfall-runoff-estimation method. The geomorphological-instantaneous-unit hydrograph (GIUH) estimated flooding from wet weather and obtained results comparable to observed events. Bonta (1997) derived frequency distributions as an alternative method for determining watershed curve numbers from measured data, treating rainfall and flowrate data as separate frequency distributions.

Over 7,900 ft of 24 in. — 54 in. diameter failing sewer pipe was repaired using sliplining and cured-in-place-lining d o b7n63 stor

prevent increases in flow associated w

concerns (Brzozowski 2004). The goal is to restore the natural hydrology and reduce the impacts of urbanization on streams and flooding potential. Vellidis and Lowrance (2004) evaluated the effectiveness of riparian forest buffers as a way to reduce nonpoint source pollution. These riparian systems were found to reduce the concentrations of solids in surface runoff and nitrates in shallow groundwater.

Rowan University was charged by EPA to assess two creeks in New Jersey in relation to watershed characterization, water quality, modeling and outreach (Jahan et al. 2004). The deliverables include an interactive website and a CD-ROM for local government planners, environmental specialists, developers, and citizens.

Oost (2004) examined the Rainstore3, Grasspave2 and Gravelpave2 systems. The systems were developed to better address problems of poor stormwater management. In order to improve water quality in the Alna watercourse (Oslo, Sweden), a study was carried out to rank subcatchment areas for their existing and potential degradation, as well as to assess possible corrective measures (Nordeidet et al. 2004). The highest 15 ranked catchment areas accounted for 70% of the total load of heavy metals; all were strongly influenced by three major highways. It was estimated that wet ponds could remove a substantial portion of the total solids and around half (or more) of the heavy metals. Inner city (Malmo, Sweden) control of stormwater was achieved through the use of combinations of structural stormwater treatment practices (Villareal et al. 2004). It was found that the green-roofs are effective at lowering the total runoff from Augustenborg and that the ponds should successfully attenuate storm peak flows for even the 10-year rainfall.

Figola (2004) examined the use of Storm Water Quality (SWQ) unit to treat runoff from an old gas station. Settling of grit, sediment toxins and heavy oils was the primary treatment mechanism. A Continuous Deflective Separation (CDS) unit was used to treat urban runoff in Florida (Rushton 2004). The CDS unit was effective at removing litter, trash and larger sediments. A treatmentatiol-0.000-6(011on).000hD- 7(eatgu]TJT*l welyet al e)6.6(x503.9(g)]TJ16.6186 0 TD0.0016 , trae)-1t T for conducting detailed spatial analysis, long-term precipitation data analysis, an explicit runoff routing model, and a prototype optimization model for functional land development strategies were included.

Gardiner et al. (2003) presented the idea of regional stormwater stormwater treatment practices as a solution to meeting future TMDL allocations in southern California. The authors argued that regional BMP facilities, such as detention and/or infiltration basins or wetlands, could provide higher levels of treatment more reliably and were easier to construct and maintain when compared on a cost per acre basis. O’Connor et al. (2003) reviewed current municipal practices to implement low-cost stormwater treatment practices to address stormw effectiveness database. The national stormwater BMP data clearinghouse continues to screen and post new BMP data to the database, as well as respond to inquiries from the public. An overview of both of the database software and results of the data evaluation were provided in this paper.

Strecker et al. (2002) presented the Urban Stormwater BMP Performance Monitoring Manual that was developed by integrating field experience of ASCE's Urban Water Resource Research Council and the development of the ASCE/EPA National Stormwater Best Management Practices Database. The Manual was intended to help achieve stormwater BMP monitoring project goals through the collection of more useful and representative rainfall, flow, and water quality

USDA, was used for BMP placement analysis, and the relative effectiveness of stormwater treatment practices at three different spatial placement levels, i.e., on-site, sub-regional and regional levels, were compared. Based on the model simulation results, a BMP placement optimization approach was developed to determine a most cost-effective BMP placement strategy at the watershed scale.

Development projects in the high-altitude mountain environment of the Rocky Mountains such as Colorado often require innovative best management practices (stormwater treatment practices) due to challenging runoff conditions, the relatively short growing season, vegetation and wildlife habitat considerations, and the high level of water quality of receiving waters (Earles and Jones 2001a). This paper described a variety of stormwater treatment practices and stormwater/dewatering discharge management strategies that have been successfully employed on development projects. Case studies were presented for addressing runoff from snowmelt; shallow groundwater; soil erodibility, mobilization atormw and suspension; water chemistry; and regulatory requirements related to water quality and wetlands protection, and included examples of structural stormw benefits of two different erosion control mulches; blown straw and a manufactured biodegradable erosion control blanket. Sprinkler-type simulators were used to create rainfalls having intensities of 2, 4, and 6 in/hr. The collected data indicated that some surface cover treatments consistently reduced soil losses, while others can actually increase soil losses under some test conditions. They concluded that the Revised Universal Soil Loss Equation can be used to estimate the benefits of mulches at construction sites. Shammaa and Zhu (2001) presented a state-of-the-art review of TSS removal techniques. Three main techniques were reviewed: infiltration, filtration and detention. Infiltration trenches, infiltration basins and porous pavements were the common infiltration practices. Filtration systems included filter strips, grassed swales and media filters. Wet and dry detention ponds (including polymer-assisted ponds) and constructed wetlands were the most common detention practices. The function, performance and suitability of each technique were discussed, and a comprehensive review was provided to guide the selectionouln(g)4.3dolhnuie WLeve r 0 TDprsys4.3(us)3.7(h)p h physical structures had to be designed as retrofits of existing facilities in the developed watershed or integrated into the existing land uses. Baseline, construction, and post construction monitoring, using EPA stream habitat assessment protocols, ambient water quality monitoring, fish and benthic macroinvertebrate surveys, and channel cross section monitoring, have been and continue to be used to collect data to justify implementation of successful practices (Baker et al. 2000). In Portage, Michigan, a storm water treatment system currently under design will significantly increase the quality of life for city residents while meeting and exceeding regulatory requirements. This new regional facility is to be linked to a recreational trail way system, provide treatment for runoff from 1.9 km^2 (463 acres) within the highly developed urban core targeting 80% pollutant removal rates, and double the length of existing trail ways in the city (Jacobson et al. 2000). Mattson et al. (2000) presented a study of urban stormwater impacts in the Severn Sound Area of Ontario, Canada. The study objectives were (1) characterization of dry weather and runoff quantity and quality; (2) monitoring effects of stormwater runoff on the bacterial concentrations at an urban bathing area; and (3) development of pollution control plans for the participating urban municipalities in the Severn Sound watershed with an overall goal of a 20% reduction of stormwater phosphorus loads.

The City of Rockledge, Florida developed and implemented a Stormwater Management Program using a watershed-wide management approach, which included stormwater facility inventory maps along with necessary hydrologic, hydraulic, and water quality data (Schmidt et al. 2000a). The Stormwater Master Plan for Miami International Airport (Florida) included comprehensive evaluations of hydrology, hydraulics, water quality, stormwater treatment practices, and facility planning in phases to allow cost-effective implementation of the plan while aircraft operations continued and increased. A variety of constraints were identified, including the protection of aircraft passenger safety (no fog or bird attractants) and the environment (water quality, manatees, and hazardous material cleanups) (Schmidt et al. 2000b). Lake Macatawa , near Holland, Michigan, was listed by the Michigan Department of Environmental Quality’s 303(d) nonattainment list; high phosphorus concentrations from nonpoint sources and excessive turbidity were found to be the main contributors to poor water quality. A list of 44 stormwater treatment practices were considered as controls for reduction of the nonpoint phosphorus load. An objective and quantitative procedure, based on economic production theory and marginal cost analysis, was developed to assign the proposed level of effort and subarea watershed locations for each BMP (Scholl 2000). In order to comply with the County's MS4 Stormwater NPDES permit, the Anne Arundel County (Maryland) Department of Public Works (DPW) had to field locate all storm drain outfalls and stormwater management ponds, assess their structural condition, perform a general assessment of stability of downstream channel conditions, and identify stormwater management retrofit opportunities for implementation as County capital improvement projects. A relational database has been developed for data management and analysis, with a direct link to GIS coverages (Smith et al. 2000b). Templeton (2000) presented an overview of the Nutrient Management Strategy for point source dischargers to North Carolina's Neuse River and the State’s experience in implementing the Strategy thus far. Whitman et al (2000) described two efforts to test new stormwater retention technologies in the Los Angeles, California watershed. These efforts were designed to better manage stormwater and to address the impacts of urbanization and imperviousness. The efforts

Urban streams are often badly degraded from their pre-development, natural state. Restoration of these streams is becoming a widespread practice, and is often done in conjunction with WWF control efforts. Athanasakes et al. (2000) described the holistic stream restoration program which was developed by the Louisville and Jefferson County, Kentucky, Metropolitan Sewer District. Their discussion focused on issues involved in developing and managing a streambank stabilization/stream restoration program, such as getting a program started, a brief overview of stream restoration techniques, items to consider during construction and a summary of items learned throughout the development of the program. Stormwater management in an urbanized basin near Dallas, Texas included channelization of a creek which was eroding private property (Amick 2000). Since the watershed was nearly fully developed, areas where mitigation could be accomplished were limited. Mitigation was required - leading to some restoration of another urban stream that had previously been channelized. The creeks in the Kelowna, British Columbia, Canada area, like those throughout North America, have been impacted by human development. The City of Kelowna initiated the Lower Mill Creek Watershed Program in 1997. Objectives of the program included (1) improvement of Mill Creek water quality by preventing streambank erosion and creating riparian areas; (2) restoration and enhancement of instream and streamside habitat; and (3) education of the public, private landowners and developers on the importance of Mill Creek (Gow and Kam 2000). The U.S. EPA has allowed local governments to establish natural vegetative buffers (greenways) along stream corridors in lieu of incurring other EPA enforcement actions associated with violations of the Clean Water Act. Kleckley and Kung'u (2000) identified the role of greenways in protecting water quality and aquatic and stream corridor habitats, and described an on-going greenways project in Jefferson County, Alabama. Rodriguez at al. (2000b) presented a pool-riffle design for straight urban streams where existing infrastructure has prevented channel planform re-alignment. The proposed structures fulfilled four main requirements: (1) increased flow variability during low and moderate flows; (2)

Stovin and Saul (2000) described an extensive laboratory and computational fluid dynamics study into the hydraulic performance and sediment retention efficiency of tanks. The results showed that (1) using computational fluid dynamics, it was possible to predict the flow field that was measured in the laboratory, and (2) a critical bed shear stress could be used to determine the extent of sediment deposition. The study also showed that the length to breadth ratio of the chamber was the most important parameter to influence sediment deposition, and that changes to the benching and longitudinal gradient of the tank had minimal effect. Intensity/duration/frequency (IDF)-relationships of extreme precipitation have been widely used for design of stormwater facilities. Because the properties of extreme precipitation may be very different for different storm types and different seasons, IDF-relationships which permit decomposition into different components and scaling properties were established by Willems (2000). Hydrologically functional landscapes integrated principles of maximizing infiltration, contouring the land

Wisconsin before and after BMP installation from 1993 to 1999 to examine the responses of stream quality to watershed-scale BMP implementation. Results clearly demonstrated characteristics, sponsoring and testing agencies, watershed characteristics, BMP design and cost data, monitoring then, if required, adding detention BMP to maintain the runoff volume and peak runoff rate, (Coffman et al., 1998a, 1998b, and 1998c) LID creates a "functional landscape" that incorporates design features that mimics pre-development, natural watershed hydrologic functions. Runoff may be reduced and controlled at the site by minimizing impacts to the extent practicable by reducing imperviousness, conserving natural resources, recreating detention and retention storage, maintaining pre-development Tc by strategically routing flows to maintain travel time, and implementing effective public education programs that encourage property owners to use pollution prevention measures. Net results for LID stormwater treatment and management mimic the water balance between runoff, infiltration, storage, groundwater recharge, and evapotranspiration (Dep. Environ. Resour., Prince George's County Md., 1997). LID techniques integrate stormwater controls in small discrete units throughout the site. Distributed BMP reduce the need for a centralized BMP facility. Micro-management of stormwater, which has been used successfully in several communities, stores water temporarily at many locations on and off the street and below the surface and as close as possible to the precipitation source prior to entry into a combined, sanitary or storm sewer system (Carr and Walesh, 1998). Bioretention uses plants and soil to filter runoff from developed areas. Laboratory and field tests showed good removal of metals, P, and NH_3 with little or negative removal of nitrate. A significant mulch layer was found to be important for metals removal (Davis et al., 1998b).

Within the 16.2 ha (40 acre) festival grounds in downtown Milwaukee, Wis. a flow splitter diverted the first flush stormwater from a 1.2 ha (3 acre) area to a constructed landscaped island with a layer of peat over a layer of fine sand and at a hospital in Green Bay, Wis., a pressurized two stage filter system was designed to reduce pollution from a 2.6 ha (6.5 acre) parking lot (Bachhuber, 1998). A swale-infiltration trench system that combined three engineering techniques (infiltration, storage and throttled drainage) to manage rainfall runoff can be applied to new developments or as a retrofit (Sieker, 1998). Urban stormwater was treated by a combination of engineered and natural treatment systems comprised of a wetland perimeter swale and a berm which directed collected surface water runoff to a 30 m wide forested wetland filter strip (Berg, 1998). A sand-filter system and two grassy medians located on highways near Austin, Tex. were evaluated (Barrett et al., 1998c). The grassy areas reduced SS by 85% while the sand filter reduced pollutants by 90%, but was plagued with maintenance problems and detention times exceeded the 48 hour design. The capability of vegetated highway medians for treating stormwater runoff in the Austin, Tex. area was studied by examining pollutant removal efficiencies of two medians on major highways. Removal efficiencies at the two sites were remarkably similar despite being designed solely for stormwater conveyance and differed in slope and vegetation type and were comparable with those observed in structural controls such as sedimentation/filtration systems (Barrett et al., 1998d).

Washington, D.C. required that BMP be required for new and re-development projects to control urban-stormwater-runoff pollution. Dee (1997) retrofitted an existing drainage basin with a sand-filtration system that controlled the 2-yr and 15-yr rainfall events. An innovative BMP system for a recreational farm in Taiwan was evaluated by Wen and Yu (1997). The BMP system included a grassed strip, a swale, wetland vegetation, two check dams, a shallow lotus pond, and two wet-detention ponds. The results indicated that BMP put in series could provide high pollutant removal, especially for particulates. According to Pechacek *et al.* (1997), key components of BMP include good-housekeeping procedures; preventive-inspection and maintenance schedules; management strategies to prevent contamination of stormwater runoff; facilities that manage runoff to prevent contact between pollutants and runoff; and facilities that reduce pollutants in the

Braune and Wood (1999) described how South Africa currently has one of the highest rates of urbanization in the world, causing a significant increase in surface water runoff and attendant increases in flooding and significant decreases in water quality. They presented a method of how the existing problem areas can be identified and ranked, and how the use of BMP can be used to reduce the impacts associated with urbanization. Cutler and Eastman (1999) described two projects in Christchurch Cith, New Zealand. The first, Regents Park, was an urban subdivision in an area with springs, open drains and a high water table. The City Council worked with the developer to naturalize and enhance the open waterways so that they added value to the landscape, ecology, drainage, and value of the subdivision. The second area, the Tranz Rail transfer yards, was a multi-million dollar development involving extensive areas of roofing and paved

structural stormwater treatment practices can be effective in water quality treatment of stormwater pollution "hot-spots" or in "ultra-urban" settings. The most promise appeared to be

Pyke et al. (2002) used a loosely-coupled watershed-water treatment plant modeling technique to provide a screening-level assessment of (1) the impacts of major point and nonpoint source pollutant loads on treatment plant operating costs; (2) the potential of agricultural and urban stormwater treatment practices and best available technologies (BATs) to mitigate these impacts; and (3) the cost-effectiveness of stormwater treatment practices an design. Calculations showed that almost all the runoff was retained on site. Basins paved with porous pavement had the best percent removal of pollution loads with many removal rates for metals greater than 75 percent in the basin with a smaller garden area and greater than 90 percent with larger gardens. More phosphorus loads were discharged from basins with vegetated swales than from basins with no swales. Metal and nutrient pollutants in the sediments were not found to be migrating to the deeper strata.

Roesner and Brashear (1999) reported that over the last ten years, a number of BMP manuals have been developed to address the control of urban runoff for receiving water quality protection. They concluded that there was a lot of ignorance in the scientific community about what constitutes a properly designed BMP and what it really achieves, with respect to environmental protection. They therefore recommend a design criteria development approa4.4(er7.9(oa4.4.4.d a o)-4.9(p)a)8 program for preserving hydrologic cycle characteristics in urban areas. Tada et al. (1999) investigated three alternative storage methods that can be used to assist stormwater reuse. The best method (Type-1) uses a small tank to separate “first-flush” runoff nonpoint pollution loads from the remaining discharges. Type-2 has an overflow weir to separate polluted runoff stormwater, while type-3 has an orifice to separate un-polluted stormwater into the utilization tank. Pratt (1999) described the use of storage reservoirs under permeable pavements for stormwater treatment and reuse. Permeable surfaces for roads and footpaths have been used as a means of disposal of stormwater in developed urban areas and undersealing them to enable them to retain stormwater for reuse for non-potable uses was feasible. However, the stormwater may be degraded where the pavement was used for car parking. Tredoux et al. (1999) described the Atlantis Water Resource Management Scheme that uses artificial recharge of urban stormwater and treated wastewater to augment natural groundwater. The important element was the separation of the stormwater into components of distinctly different quality. Residential and industrial urban runoff was separated into baseflow and stormwater components and utilized for various appropriate purposes.

Public education.

Mashiah et al. (1999) found that raising community awareness of stormwater impacts was a critical component of an effective stormwater management program. The campaign included television advertising, newspaper and radio advertisements, displays, free environmental audits for local businesses, and a stormwater ambassador program for local schoolchildren. Heremaia (1999) described the public stormwater education program used as part of the Christchurch (New Zealand) integrated environmental planning program. The successful pilot program included the development of a web site, audio conferences, a competition, and a drama production. Young and Collier (1999) described the research-practices based on an average rainfall year. Results from two watersheds in Michigan show that annual catch-basin cleaning and street sweeping every 15-30 days could reduce annual total suspended solids loadings by 80 percent.

A management study for the Bell Branch and Tarabusi Creek subwatershed of the Rouge River was presented by Sutherland et al. (2002). The goal of the study was to help public agencies develop appropriate management practices. The advisory group for the project recommended stormwater management practices that reduce or eliminate pollutants at their source, such as leaf collection, catchbasin cleaning and street sweeping.

O'Loughlin and Stack (2002) compared four algorithms for pit pressure changes and head losses in stormwater drainage frequent flow bypass required more maintenance than antic good removal of pollutants. A NYC study indicated street litter is a major contributor of floatables to N.Y. Harbor (Grey and Oliveri, 1998). Hooded catchbasins were 80—90% effective in retaining floatables and a city-wide program to inspect, map and hood all catchbasins was reviewed. Based upon a detailed examination of 18 facilities in Ger., Can., and U.S., Pisano et al. (1998) reported the performance of two widely used sewer and tank flushing technologies, i.e., the tipping flusher and the flushing gate.

Infiltration and Biofiltration, including Grass Swales and Grass Filter Strips

Rain gardens and their design requirements were also reviewed in 2006 (Anonymous 2006b). Heasom et al. (2006) presented hydrologic modeling for a bioinfiltration traffic island in Pennsylvania. Seasonal-variability of the model parameters were used, and the results showed that the model could reflect what was seen in the field.

Hunt et al. (2006c) evaluated the hydrology and associated nutrient removal in three bioretention sites in North Carolina. The results showed that the fill media selection was critical for total phosphorus removal. Davis et al. (2006) investigated whether transport of nitrogen and phosphorus through bioretention media improved water quality. The results showed that the best control of nutrients in bioretention facilities would result from carefully managing the growth and harvesting of vegetation. Dietz and Clausen (2006) reported on creating saturation conditions in a rain garden to improve pollution retention. Saturation enhanced the removal ability of the rain garden for total nitrogen.

Maeda et al. (2006) evaluated the spatial distribution of soil structure in a suburban forest catchment and its effects on soil moisture and runoff fluctuations. The authors presented a simple, physical-contour-based model that can describe topography and spatially heterogeneous distributions, and uses the model to clarify how spatial heterogeneous variability influences long-term rainfall runoff processes.

Low Impact Development

Gregory et al. (2006b) evaluated the impacts of imperviousness in large, developing watersheds. The paper presented methods for estimating the increase in impervious cover and quantifying the resulting impacts of various developments on impervious cover.

Lefers et al. (2005) reviewed how the known information regarding the relationship between downstream flooding, upstream landuse and runoff flows was used to determine the delay in peak time and the need for infiltration at a new development in Madison, Wisconsin.

Traver and Ermilio (2005) presented the continuous monitoring of a bioinfiltration traffic island stormwater treatment practice. Traver et al. (2005) reported on the performance of an infiltration trench designed to capture and treat runoff from a parking garage. Birch et al. (2005) monitored the ability of a stormwater infiltration to remove contaminants from the influent runoff. Removal efficiencies were characterized for total suspended solids, nutrient, trace metals, organochlorine pesticides and fecal coliforms. Stanford and Yu (2005) evaluated the performance of urban and ultra-urban bioretention units. The two units were monitored for their effectiveness in removing nitrogen, phosphorus and TSS. The monitoring conformed to the requirements of the Technology Acceptance Reciprocity Protocol.

as well as with a Principal Component Analysis (Barraud et al. 2005). Pollutant concentrations were found to decrease rapidly with depth in the soil profile; the statistical analysis showed how pollution affected each sampling depth. Deschesne et al. (2005) investigated the long-term performance of four stormwater infiltration basins in Lyon, France. Pollution migration was seen to a depth of approximately 30 cm, but below that depth, concentrations were less than levels of concern. No relationship was seen between age, hydraulic resistance and pollution. The metals concentration in soil and seepage water in an infiltration device from roof runoff was simulated using long-term numerical modeling (Zimmerman et al. 2005). Concentration increases in the infiltration device were seen for three roof types, but limited movement below the device was seen for all soils except the low-adsorbing one. The hydrologic and water quality performance of four bioretention cells in central North Carolina was investigated by Sharkey and Hunt (2005). Non-agricultural fill soils in the cells resulted in reductions in total phosphorus and total nitrogen. Evapotranspiration was a substantial factor in water removal in the bioretention cell.

Hsieh and Davis (2005a and b) examined the removal ability of several media mixtures suggested for use in bioretention systems. Two media designs were proposed as providing the best removal efficiencies for suspended solids, nitrate, ammonium and heavy metals. They found that the runoff quality was improved after passing through the bioretention column and that the top mulch layer was most effective at removing the TSS. Dietz and Clausen (2005) performed a field study on rain garden flow and pollutant treatment. Total nitrogen and ammonia were the only two pollutants where reduction was seen although substantial water removal was achieved in the system without an underdrain.

Kirby et al. (2005) investigated the hydraulic resistance in grass swales under low flow conditions. The resultant “small-flow” curves extend the Stillwater n-VR curves by approximately one order of magnitude (to smaller values of VR). Munoz-Carpena and Parsons (2005) developed design nomographs for vegetative filter strips. These nomographs were based on the mechanistic hydrology and sediment transport modeling for representative soil types, disturbed area sediment properties, design storm classes and vegetation characteristics.

Lassabatere et al. (2005) showed that geotextiles can affect the movement of heavy metals in stormwater as it passes through an infiltration structure. The factors that caused the greatest effect were the geotextile type, geotextile water content, flow rates, and the number installed. The geotextiles impact is typically through modifying the flow regime. Compost amending of soils to improve infiltration and reduce runoff was advocated by Cogger (2005). A secondary benefit of these amendments is the restoration of organic content and nutrients to the amended soil layer. The use of

Center for Green Roof Research. Hoffman (2006) focused on the use of green roofs to combat CSOs through calculation years because of the low metal concentrations expected in runoff.

Groffman and Crawford (2003) measured the denitrification potential in urban riparian zones and a suite of related microbial parameters (microbial biomass carbon [C] and N content, potential net N mineralization and nitrification, soil inorganic N pools) in four rural and four urban riparian zones in the Baltimore, MD metropolitan area. There were few differences between urban and rural and between herbaceous and forest riparian zones, but variability was much higher in urban than rural sites. There were strong positive relationships between soil moisture and organic matter content and denitrification potential. Herath et al. (2003) performed a simulation study of the impact of an infiltration facility on the hydrologic cycle of an urban catchment. Infiltration improve system. He summarized the range of pollutant removal efficiencies achieved by vegetative BMP and reviewed available design procedures for grass-lined swales and constructed wetlands for the United Kingdom. Gharabaghi et al. (1999) described how rolled erosion control products have proven to be successful in reinforcing vegetative channel lining systems and improving their performance in erosion and sediment control. Mendez et al. (1999) summarized the results from an 18-month field experiment that was conducted to evaluate the effectiveness of grass filter strips in removing sediment and various nitrogen species from runoff. They found that the grass filters reduced contaminate yields from 42 to 90% and concentrations from 20 to 83%, depending on length and nutrient specie. Boubakari and Morgan (1999) tested the effectiveness of growing *Festuca ovina* and *Poa pratensis* on contour grass strips for erodible sandy loam soil on steep slopes. The *Poa pratensis* was less rigid and became flattened under submergence in the later part of the storms and was therefore not very effective in controlling erosion on the steepest slope tested (29%).

The effectiveness of grass strips in controlling highway-runoff contaminants was studied by Newberry and Yonge (1996). The largest portion of metals was found to be retained within the first 1 m of grass strip and 10 mm of depth, with 84% of the applied Zn, 93% of Pb, and >99% of Cd and Cu being retained by the grass strip. Pratt (1996) described recent research into design approaches for sizing of infiltration areas, illustrated the seasonal variability and difficulties in evapotranspiration have a significant impact on moisture movement in soils, and that models must include these near-surface processes. Pitt and Lantrip (2000) examined the effects of urbanization on soil compaction and resulting infiltration capacity through a series of double-ring infiltrometer tests. They found that sand was mostly affected by compaction, with little change due to soil-water content levels. However, the clay sites were affected by a strong interaction of compaction and soil-water content. The fit of the data to the Horton equation was inconclusive, indicating

Given the characteristics of urban surfaces, and notably the amounts of the different pollutants that stormwater was likely to contain, an experiment was carried out in Valence (France) on two infiltration facilities, in order to assess the impact of intentional stormwater infiltration systems on the soil, and on groundwater. Stormwater from impervious urban areas can adversely impact water quality and quantity. The PET was a control device designed to moderate both the quality and quantity of urban runoff (Li et al., 1999). Urban stormwater often contains high levels of traffic-generated metal elements and particulates. These constituents were transported by stormwater runoff to surficial soils, drainage systems and

methodologies for determining the design parameters based on local conditions, technologies for soil-clogging

Grass Swales

Deletic and Fletcher (2006) examined grass filters for stormwater treatment using both field testing and models. The selected model, TRAVA, was able to reproduce within the desired range the removal of sediment in the grass filter. Nara and Pitt (2006) investigated sediment transport in grass swales. Depth of flow and swale lengt performance of a Swedish urban stormwater pond. A seasonal comparison of the removal efficiencies showed that removal of Cd and Cu was about the same for summer and winter-spring, but removal of Pb, Zn and TSS dropped from the summer to the winter.

Pyatt and Li (2006) monitored the performance of a constructed sediment pond in Ontario, Canada. The pond removed suspended solids to a large degree, but some events did have high concentrations leaving the sediment pond.

variations in rainfall and evaporation were considered. Soil characteristics (hydraulic conductivity, texture, pH, and cation exchange capacity), the infiltrated volume, and the infiltrated area were used to calculate the movement of the most mobile heavy metal, Zn, in the soil below the basin. In Dubai, United Arab Emirates, high groundwater levels restrict the amount of infiltration that is permissible and influence the design of the ponds (wet versus dry) (Darnell et al., 2001b). Design criteria specific to Dubai were established to maximize the efficiency of systems that incorporate the use of detention ponds. The criteria included minimum storage pond volumes, clear times, pond geometry, water depth, the use of linings, and alternative land uses. The first pond constructed using the design criteria is now in operation collecting runoff and excess groundwater flows.

For more than a decade, the Queen's University/National Water Research Institute Stormwater Quality Enhancement Group studied stormwater ponds with a fully instrumented on-line system in Kingston, Ontario, Canada as a representative field installation (Anderson et al., 2001). The Group concluded that a number of identifiable factors will significantly influence the success, failure and sustainability of these ponds. These factors included initial design, operation and maintenance, performance and adaptive design. Guo and Hughes (2001) presented a risk-based approach for designing infiltration basins with design parameters of basin storage volume, drain time, and overflow risk. The risk-based approach provided an algorithm to calculate the long-term runoff capture percentage for a basin size. The diminishing return on runoff capture percentage would serve as a basis to select the proper basin storage volume at the site.

Cosgrove and Bergstrom (2001) reviewed the new policies and proposed regulations in New Jersey that require that no increase in stormwater pollutant loads from proposed residential and commercial developments. The authors reviewed the water quality management facilities. The resulting design curves should lead to a reduction of non-point source pollution to Guam's receiving waters. Marsalek et al. (2000) examined the hydrodynamics of a frozen in-stream stormwater management pond located in Kingston, Ontario, Canada. Measurements of the velocity field under the ice cover agreed well with that simulated by a CFD model (PHOENICS(TM)). During a snowmelt event, the near-bottom velocities reached up to 0.05 m-s(-1), but were not sufficient to scour the bottom sediment. Van Buren et al. (2000b) studied the thermal balance of an on-stream stormwater pond in Kingston, Ontario, Canada. During dry-weather periods, pond temperature increased as a result of solar heating, and thermal energy input exceeded output. Conversely, during wet-weather periods, pond temperature decreased as a result of limited solar radiation and replacement of warm pond water by cool inflow water from the upstream catchment, and thermal energy output exceeded input.

Newman et al. (2000b) described the application of the Storage-Treatment (S-T) Block of the EPA Storm Water Management Model (SWMM) to design and/or analyze extended-detention ponds (EDPs). The importance of this refined method for EDP design was emphasized with examples of how the use of rules-of-thumb or BMP-manual guidelines could result in unexpectedly poor EDP performance. Proctor et al. (2000) reported on Kentucky's Sanitation District No. 1 working with a local elementary school to convert a badly eroding stormwater detention basin into an outdoor learning center for the school. The results were that the sewer district gained a corrected detention basin, the public gained an education in stormwater management, the students learned about water pollution, and the school gained an educational resource in the Outdoor Learning Center. Dewey et al. (2000) adapted a two-dimensional, vertically averaged hydrodynamic model to compute the circulation and sedimentation patterns in stormwater detention ponds or other water impoundment facilities. The Circulation and Water Quality Model (CWQM) identified areas in the pond where short-circuiting and dead zones occurred. Sedimentation, based on first-order decay, also could be predicted. Field testing verified that the predicted suspended solids (SS) concentra quality, especially in areas like the Coastal Plain of southern New Jersey, where the soil was sandy and the water table shallow, and contaminants may not have a chance to degrade or sorb onto soil particles before reaching the saturated zone. Ground water from monitoring wells installed in basins in Camden and Gloucester Counties, New Jersey, was sampled and analyzed for volatile organic compounds (VOC), pesticides, nutrients, and major ions (Fischer, 1999). Crunkilton and Kron (1999) measured the toxicity of stormwater runoff before and after it had been allowed to flow through a pilot-scale wet-detention basin. Selected heavy metals and PAH compounds were measured in incoming and

Pond sizing.
Bertrand-Krajewski and Chebbo (2002) compared two types of stormwater treatment facilities – storage-settling tanks and on-line settlers) for event, annual and inter-annual time scales. Storage-settling tanks with specific volumes of 100 m^3/active ha intercept approximately 80 % of the annual TSS pollutant load, and on-line settlers designed for 8L/s/active ha can intercept 82 to 85 % of this load. Differences exist between combined and separate systems but are usually less than 10-15 %.

Bertrand-Krajewski and Bardin (2002) evaluated how the uncertainties in urban hydrology contribution to calculating storage/settling tanks volumes and pollutant loads. The example presented was a calculation of the uncertainties in some quantities describing the behavior of the Venissieux (France) storage and settling tank during one rainfall event. The quantities were the flow rates and the volumes entering into the tank, the inflow and outflow mean concentrations and masses of TSS (Total Suspended Solids), and the TSS removal rate. The results led to the following relative uncertainties 8% for the total volume, 30% for the inflow concentration, 38% for the outflow concentration, 31% for the inflow mass, 39% for the outflow mass and 138% for the removal rate.

Guo (1999) described a simple method to size stormwater detention basins using a volume-based method such as provided by the Federal Aviation Administration that was applicable to small urban catchments. The average outflow presented a new model to predict the transport characteristics of suspended sediment for an on-stream stormwater management pond. Simulated suspended concentrations vs. time and the size distribution of the flocculated sediment, produced with the calibrated model, agreed well with flume measurements.

Hollingwork et al. (1999) also presented an analytical probabilistic model (MTOPOND) that used probability distribution functions of rainfall characteristics in order to develop closed form expressions for the long term pollutant removal efficiency of stormwater ponds. Operational management practices for detention facilities to limit flooding risks simultaneously with reduced pollutant discharges was possible by optimizing the settling process, as described by Jacopin et al. (1999a). They found that proper descriptions of the particle sizes were critical and that the particle size distribution in the surface sediments were close to those of the suspended solids in the stormwater. Jacopin et al. (1999b) further described the optimization process where the detention facilities were empty most of the time, offering a large safety margin to protect against flooding. The detention facilities store all of the runoff from light and medium rainfall events, consuming about half of the detention capacity. The probability of exceeding the tank capacity was small, even for the larger storms. Adamsson et al. (1999) found that computational fluid dynamics (CFD) was a good tool for studying the hydraulic properties of detention basins in urban drainage systems.

According to Greb and Bannerman (1997), the influent particle-size distribution affected the efficiency of an urban residential area stormwater wet pond’s performance on sediment and associated pollutant removal. Karounarenier and Sparling (1997) studied toxicity of stormwater-treatment-pond sediments. Guo (1997) measured the amount of heavy-ponds within the city of Edmonton were selected to evaluate their TSS removal. Pettersson (2002) investigated the characteristics of suspended particles in a small stormwater pond. The results showed the particle volume in the stormwater (particle volume per stormwater volume) predominately consisted of very fine particles and that the smallest particles comprised most of the surface area. The stormwater pollutants exhibit strong correlation with particle characteristics. Scholz (2002) presented an overview of the pilot plant that will assist in developing design and management guidelines for operating stormwater pond systems. Sustainability analyses were also performed.

Konrad and Burges (2001) used a three-year rainfall record from a site in the Puget lowland, Washington in a mass-

ethylbenzene and xylene. The system treated gasoline-contaminated groundwater and stormwater runoff. Heyvaert et al. (2006) investigated the ability of a constructed surface flow wetland to tr hydraulic performance of a constructed wetland treatment system at Heathrow Airport designed to treat de-icing and stormwater discharges.

Proakis (2003) investigated pathogen removal in wetlands constructed for stormwater treatment in Huntington Beach, CA. With mussel predation and based on laboratory experiments, enterococcus concentration was expected to be reduced highlighted by the distribution of sediment throughout the wetland.

In the study by Kao and Wu (2001), a mountainous wetland located in McDowell County, North Carolina was selected to demonstrate the natural filtration and restoration system for maintaining surface water quality. Analytical results from the summer of 1997 indicated that this wetland removed a significant amount of NPS pollutants [more than 80% N removal, 91% total suspended solid removal, 59% total phosphorus removal, and 66% COD removal]. In Taiwan, research on constructed wetlands was conducted as part of a project supported by National Science Council (Yang 2001). Different waters, including contaminated river water, aquaculturing pond water, sewage, industrial wastewater, and storm water, were tested by using microcosm or macrocosm constructed wetland systems. The results of this project showed that the wetlands' effluents had a high potential for water reuse. Shutes (2001) illustrated the role of plants for treating water pollution in man-made wetlands in tropical and temperate climates. The design of the Putrajaya Lake and Wetland system in Malaysia was compared with an urban-runoff-treatment constructed wetland in a new residential development in the UK.

The ability of a wetland to mitigate highway-runoff pollutants, particularly metals, was investigated by Mitchell et al. (2001a). Fifty-seven rainfall-runoff events were monitored. Data collection included rainfall volume and frequency, conduit flow rate, and temperature, conductivity, pH and dissolved oxygen in the runoff. Metal concentrations were reduced via flow through the grassy median and then the wetland system. Average heavy metals removals were zinc (67%) and iron (67%), followed by lead (54%) and then nickel (45%). Metals were reduced some even during winter months and low temperatures. Wetland sediment analysis indicated a broad range of concentrations of metals. Rodgers et al. (2001) reported on the A-01 effluent outfall, which collected both normal daily process flow and stormwater runoff from a industrial park area and did not meet its South Carolina NPDES permit limits for metals, toxicity, and total residual chlorine at the outfall sampling point. Installation of a constructed wetland system including a basin to manage stormwater surges reduced the problematic constituent concentrations to below the NPDES permit limits before the sampling point. The constructed treatment wetland system proved its ability to treat industrial wastewaters containing metals with low O&M costs. With an anticipated life of over 50 years, the wetland system will be cost-effective.

The Greater Toronto Airports Authority (GTAA) constructed the first full-scale vertical-flow treatment wetland in Canada for reduction of ethylene glycol in stormwater (Flindall and Basran 2001). The two-cell treatment wetland was preceded by a sedimentation forebay. The wetland facility collected water discharged from terminal aprons, taxiways, and runways where aircraft receive de-icing compounds particularly glycol, are applied. The facility provided 24 to 48 h of retention to attenuate storm flows and remove suspended sediment. The selected vegetation was *Phragmites australis* reeds. This emergent hydrophyte should be able to withstand the periodic flooding conditions characteristic of a stormwater management system. The reeds will provide very little habitat benefit for gulls and waterfowl and will therefore not attract birds that may cause hazards for aircraft.

Constructed wetlands have been used to capture, detain, and treat stormwater runoff from urban areas because they have the potential to treat a variety of pollutants. Knight and Kadlec (2000) presented an overview of constructed wetlands used for water pollution control. Bachand and Horne (2000) examined the effect of vegetation type on nitrogen removal rate in wetlands used to treat wastewater, including urban runoff. Based on the study and a literature review, in organic carbon-limited free-surface wetlands, a mixture of labile (submergent, floating) and more recalcitrant (emergent, grasses) vegetation would be recommended for improving denitrification rates. Carleton et al. (2000) examined the pollutant removal performance of constructed wetlands treating stormwater runoff from a residential townhome complex in northern Virginia. Median load removals of all constituents were greater for a subset of storms that had inflow volumes less than the maximum volume of the marsh. Estimated removals were positive for most constituents and consistent with expectations based on the relative ratios of wetland area to drainage area at the two sites. Zhu and Ehrenfeld (2000) compared the ability of sediments from Atlantic cedar wetlands in suburban and undisturbed watersheds to remove added inorganic N in laboratory incubations. Results suggested that wetlands in suburban drainages may have limited ability to retain frequent, pulsed N inputs from runoff, and high intrinsic N mineralization in N-saturated sediments can become a cause of water quality degradation. Graham and Lei (2000) evaluated the effective long-term operation of stormwater management ponds/wetlands, including removal, methods of removal and disposal of removed sediments.

Davies and Bavor (2000) compared the performances of a constructed wetland and a water pollution control pond in terms of their abilities to reduce stormwater bacterial loads to recreational waters. Bacterial removal was significantly less effective in the water pollution control pond than in the constructed wetland. Quintero-Betancourt and Rose (2000) assessed the microbial quality of stormwater and/or reclaimed water in terms of bacterial indicators, coliphages, Cryptosporidium and Giardia in order to determine its suitability for use in recharging stressed wetlands overlying a public water supply wellfield. Preliminary data demonstrated that the level of bacterial indicators such as fecal coliforms and total coliforms in three of the lakes sampled were above the water quality standard established by the Florida Department of Environmental Protection for ambient waters, and other pathogens and indicators were detected.

Wetlands have been chosen for retrofitting existing developm reduction in native graminoid and herbaceous perennial abundance.

One often cited advantage of wetlands for stormwater treatment is the associated development of wildlife habitats. A study by Bishop et al. (2000a) of 15 stormwater pond wetlands and one natural wetland varying in age from 3 to 22 years in the Guelph and the Greater Toronto Area (GTA) in Ontario, Canada, showed that wildlife made use of the ponds, but species richness at almost all sites was low to moderate, indicating that the ponds did not provide high quality habitat for wildlife. Due to concerns that wildlife would be attracted to stormwater detention ponds and be exposed to contaminants accumulating in these ponds, contaminant levels in ponds, sediments, and wildlife were also investigated (Bishop et al. 2000b). A variety of impacts detected in wildlife species including fish, songbirds, and amphibians led the authors to conclude that stormwater ponds did not offer clean ecosystems for wildlife and the monitoring of contamination and its effects within stormwater ponds was necessary. The Lake County Sanitation District has developed a program to recycle treated wastewater in Lake County, California. The plan included constructed wetlands to improve water quality, enhance wildlife habitat, offer evapotranspiration of excess water, and provide public benefits by creating settings for passive recreation and wildlife study. Kimmelshue et al. (2000) presented a paper which included results from a wetlands screening study, a preliminary design effort and the design and construction of an initial wetland.

According to Koob et al. (1999), the successful design of constructed wetlands required a continuous supply of water or individual plant species under various stormwater-pollutant loadings and detention times. The plant species being evaluated are: cattails (*Typha latifolia*), reeds (*Phragmites sp.*), and bulrushes (*Scirpus sp.*) (O'Shea et al., 1999). The design and pollutant removal performance of seven wetland mitigation sites and two detention basins with emergent vegetation in Virginia were examined over a three-year period to assess the effectiveness of mitigated wetlands for the control of NPS pollution and the influence of design on wetland performance as a stormwater treatment practice, in a study sponsored by the Federal Highway Administration and the Virginia Department of Conservation and Recreation (Shaw et al., 1999). The Tollgate District Sewer Separation Project involved the separation of a combined sewer system, and the creation of a wetland detention basin. In addition to its stormwater detention uses, the wetland serves as a wildlife refuge, learning center, and a local point of public outreach to bring the community together (Lindemann, 1999).

The Virginia Stormwater Wetland Simulation Model (VASWETS) was developed on the basis of a double-layer (water column and substratum) box approach to model the fate of pollutant transport in bucket wetlands (Liao et al., 1998a and 1998c) and has the ability to predict and optimize performance and to compare design criteria of stormwater-wetland systems. The Harris County Flood Control District implemented a wetland mitigation bank project northeast of Houston, Tex. that included highway runoff. The project includes 89 ha (220 acres) of stormwater-polishing wetlands as part of the overall 607 ha (1 500 acres) Greens Bayou Wetland Mitigation Bank (Knight and Koros, 1998). The Tollgate Drain project of Ingham County, Miss. created a wetland to act as a na possible but also provide adequate wetland storage capacity for the next storm event. This study concentrated on three outlet configurations for draining wetlands: an orifice, riser, and siphon. Each outlet type was evaluated for its ability to maintain the hydraulic effectiveness and hydrologic regime of the wetland.

Existing wetlands located in the future Rocky Ridge subdivision of Calgary, AB, Canada will be retained and incorporated into an integrated-stormwater-management system for the subdivision. Van Duin *et al*. (1996) discussed measures taken to protect the integrity of these wetlands during and after construction of the subdivision including a

Dennett and Spurkland (2002) investigated the performance of a constructed wetland along Steamboat Creek, a tributary to the Truckee River. Monitoring of the wetland for one year showed that total nitrogen was reduced by an average of 42 percent, and the inorganic forms of nitrogen were removed more efficiently. The stormwater management system, including wetlands, at Intel's Ronler Acres Campus in Hillsboro, Oregon was described by Whitaker et al. (2002). The project uses extended dry detention basins, spreader bars at the outlets, and pervious, vegetated spillways to maximize stormwater infiltration. Also, bio-retention planting strips are incorporated in the parking lot landscaping to encourage infiltration of stormwater flows and reduce the use of irrigation water. Integration of the stormwater facilities with the mitigated wetland benefits local wildlife by creating a larger habitat block. Nietch et al. (2002) compared ponds and constructed wetlands for stormwater treatment. Compared to wet ponds, wetlands tended to have higher constituent concentrations in an effluent, inefficient nitrogen removal and preferential retention of phosphorus. The reuse of stormwater collected in retention ponds by nurseries was investigated by Norman et al. (2002) because of the potential for concentrating plant pathogens. *Erwinia* that natural wetlands remain threatened by anthropogenic activities. They also found that the use of constructed wetlands is not as widespread as in the U.S. and that more research is needed before the technology will gain widespread acceptance (cold weather performance, more monitoring, design adaptation, and effects of constructed wetlands on wildlife).

Traver (2002) compared routing techniques in a stormwater-wetlands and found that the traditional storage-indication routing likely is not appropriate for stormwater wetlands, especially for smaller, water-quality storms. This concern was media would be the surface formation of iron oxides. Sansalone media-to-sand ratios and ranged from 68 to 94%. Brown et al. (2001) assessed the use of kudzu (

technologies.

Alper (2003) investigated the removals of oils and organics from wastewaters, including stormwater, using MYCELX

stormwater. Asphalt pavement had increased petroleum products (e.g, phenols) possibly due to the interaction of acid rain with the asphalt pavement (James and Shahin,1998). Laboratory experiments conducted over the past three years showed that activated carbon, peat moss, zeolite, and compost were efficient at removing toxicants such as organics and metals from the stormwater runoff and retaining them during subsequent flushings with distilled water (Clark et al., 1998a). Sand was found to effectively remove toxicants from runoff, but then released them in subsequent flushings. Field experiments evaluated several filtration media for stormwater infiltration and treatment potential (Clark et al., 1998b). An activated carbon and sand mixture showed the best overall removal, though a recommendation for settling of runoff prior to filtration is given. A two dimensional model was developed to assist in the design of infiltratioe d

was performed by Cigana and Couture (2005). Permanent capture decreased with an increase in the horizontal flow

The paper by Siddique (2002) described the District of Columbia Water and Sewer Authority's proposed approach for

O'Neill (2002) discussed the Topeka, Kansas best management practices for reducing CSOs. The recommendations from a workshop were sewer separation and diversion of stormwater into a construction wetlands system. Frehmann et al. (2002a) investigated stormwater management in an urban catchment through simulation of the system. It was shown that the management measures, especially source control measures, could significantly reduce the CSO volume and pollutant discharge load, resulting in a positive impact on receiving water quality. Pond et al. (2002) presented the use of stormwater micromanagement systems (temporarily storing stormwater in many varied locations on the surface and, as needed below the land surface, near to where it falls as a method of preventing persistent basement flooding. The goal is not to prevent the volume from entering the system but to delay the entry of the runoff to the hydraulic capacity of the sewer system.

Hollenbeck (2002) reviewed 100 projects performed by RJN Group, Inc., throughout the U.S. in the last 25 years, for lessons learned in terms of investigating sewer systems and determining rehabilitation needs. The key variables in these distributed CSO storage and operation of such systems in real time. The City

Kok et al. (2000) reviewed the work of Canada's Great Lakes 2000 Cleanup Fund, which is administered by Environment Canada, in supporting the development and implementation of cleanup technologies to control municipal pollution sources, to clean up contaminated sediments, and to rehabilitate fish and wildlife habitats. The Urban Drainage Program has been instrumental in advancing the state of the art in CSO and stormwater management in Ontario (Kok et al. 2000). The Philadelphia Water Department’s (PWD’s) CSO program goal is to improve and preserve the water environment in the Philadelphia area and to fulfill PWD’s obligations by implementing technically viable, cost-effective improvements. The PWD’s strategy to attain these goals has three primary phases (currently being implemented): (1) continued implementation of a Nine Minimum Controls comprehensive program; (2) planning, design, and construction of 17 capital projects to reduce CSO volume and frequency; and (3) a commitment to complete comprehensive watershed-based planning and analyses to identify the actions needed to further improve water quality and quantity dynamics in local water bodies (Marengo 2000). In 1998 the City of Rockland, Maine, began a major capital improvement program of its wastewater collection and treatment system and included provisions for high-rate treatment of CSO flows (Freedman et al. 2000). Clifforde (2000) reviewed efforts by the English and Welsh water industry to solve urban CSO pollution problems and to develop guidance for integrated stormwater management. The Northeast Ohio Regional Sewer District has undertaken the lead role in CSO management in the metropolitan Cleveland area and has recommended a CSO control plan. This plan includes several technologies that will maximize use of the existing system, as well as new facilities for CSO control (Matthews et al. 2000). Various public utilities in Broward County, Florida have implemented sanitary sewer rehabilitation programs which are expected to include a minimum of at least 7,796 repairs (Larsen and Garcia-Marquez 2000). Seigle et al. (2000) reported on the negotiated long-term CSO control plan for Manchester, NH. An inventory and structural evaluation of CSOs in towns (greater than 30,000 inhabitants) in Slovakia was carried out during a three-year joint research project of the Water Research Institute and the Department of Sanitary Engineering of the Slovak Technical University in Bratislava (Sztruhar et al. 2000).

Riverine litter occupies a spatial and temporal position in any systematic analysis of river systems and was a problem that was increasing in scale. Quantifiable source factors of litter in the river Taff, South Wales, United Kingdom, system were found to be mainly two - sewage inputs through CSO and fly tipping Whilst sewage-derived material constituted approximately 23% of all items on the river Taff, large quantities of waste, especially plastic sheeting, originated from fly tipping sites (Williams and Simmons, 1999). If the storage in the rain water tanks can be used to flatten the rain water runoff, rain water tanks can have an additional benefit. The effect of rain water tanks on the CSO emissions was therefore investigated with a reservoir model. Compared with storage in the combined sewer system or at the overflow, storage in rain water tanks will be more efficient in reducing the overflow emissions (Vaes and Berlamont, 1999). Milina et al. (1999) described the results of an integrated model development and its application to the Hovringen wastewater system in Trondheim, Norway. Major model development needs concern the integration of sewage production, transport and treatment simulation, the interface with existing databases and the possibility of simulating processes that were controlled in real time. The developed integrated model has been used to design the treatment process as well as static and dynamic measures in both the catchment and the sewer system.

The use of sand and other media filters was gaining acceptance in the held of urban stormwater structural best management practice. Much work has been done to develop local design guidance, such as in the State of Delaware and

Based on 91 sewersheds worldwide the average reported I/I reductions were 49% of peak I/I rate with a standard deviation of 25%. Twelve projects reported reductions greater than 75% (Keefe, 1998). Racine, Wis. (Marman et al., 1998) constructed diversion facilities with storage and partial treatment. The facilities prevented a cumulative SSO discharge volume of 3 million m^3 (783 MG) between 1993 and 1998 and actual SSO discharge was limited to 0.05 million m^3 (14 MG). A study to set up a long-term wet-weather control plan by the NORSD in the Westerly District of Cleveland, Ohio discovered problems with manhole invert plates, system blockages, and located sources of dry-weather

Andoh (2004) described the monitoring results of satellite

means was presented by Rowe *et al.* (1997). In Lower Paxton Township, Pa., > 60% of the I/I was identified as coming from private sources (Elliot *et al.*, 1997). Besides rehabilitation of public sewers, where necessary, the town developed an ongoing plan to seek out and correct I/I from private sources. The Miami-Dade Water and Sewer Department of Florida developed a very comprehensive Infiltration/Exfiltration/Inflow-reduction program that is one of the largest and most successful in the country (Aguiar, 1997).

Sanitary-sewer flows and wastewater-treatment-cost effectiveness were compared five years before a downspout-diversion program and 15 months after the program. The diversion program yielded a 25% reduction in mean-flow volumes and a significant reduction in wastewater-treatment costs (Kaufman and Wurtz, 1997).

Innovative WWF control strategies include using rainwater and runoff for potable uses and controlling gaseous emissions from combined sewer systems. Herrmann et al. (1999) reported on a four-story apartment building which was renovated using an innovative water concept. Roof runoff used stored for use in flushing toilet, and excess runoff was infiltrated, allowing the building to be completely unconnected from the stormwater sewer. The authors showed that independent from the soil and the available space it was possible to restore the natural water balance again by combination of rainwater use and subsurface infiltration. Lausten et al. (1999) described the use of a biofilter to capture and control hydrocarbon odors including VOCs from a combined sewer and an interceptor sewer in Philadelphia, Pennsylvania. The biofilter has proven to be a successful process application for treating VOC compounds from the air stream. Pae it b-9(po)]srazf

outlined the remediation process followed by the City and included I/I investigations, pilot I/I remediation, sanitary sewer system modeling, and implementation of CMOM initiatives. Carter and Hassell (2003) reviewed the City of Gladstone, MO's collection system study and identified and quantified I/I entering the collection system. Hannan (2003) presented the results of investigations into why sewers overflow and backup, steps management can implement to mitigate SSOs, and examples of successful solutions to particular overflow problems. Reported causes and rates of overflow available in the public domain would be documented and effective measures utilities have adopted would be reported. Rabbaig et al. (2003) investigated 'unaccounted-for' flows during dry weather conditions through an organized plan to located dry weather I/I (DWI/I). This paper described the key challenges of performing the DWI/I evaluation in Detroit's large urban combined sewer system, and presented the key project task methodologies utilized to meet these challenges.

Dent et al. (2003a) compared rehabilitation of deteriorated pipelines and laterals as part of an SSO abatement program to other methods (conveyance improvements, storage, and treatment). The authors presented a new method for identifying where I/I is occurring and how cost-effective rehabilitation is when compared to other alternatives. Dutt (2003) presented the pipeline rehabilitation program developed for Richland, CA. The program focused on isolating the worst inflow and infiltration (I&I) problem areas and then using a holistic basin rehabilitation approach to effectively rehabilitate the pipelines in the basin. Edwards et al. (2003) reviewed the advantages and challenges of trenchless rehabilitation of a sewer pipe on a vacuum sewer system in Portsmouth, VA. McCormack et al. (2003) demonstrated the effectiveness of eco-friendly, lightweight Weholite pipes for upgrading the sewerage network and avoiding CSOs in times of heavy rainfall. Ellis and Barnas (2003) reported on the four methods of rehabilitation selected for a 110-year-old brick intercepting sewer in Milwaukee, WI.

Kimbrough et al. (2003) compared sewer flow meter performance and advocated for the Environmental Technology Verification (ETV) Program. The ultimate goal of the ETV Program, according to the authors, is for consumers to require third-party verification reports as a necessary reference in awarding flow monitor procurements. Jurgens and Kelso (2003) presented the results of where the City of Fayetteville, AR returned to an area that was rehabilitated ten years earlier to determine what worked, what failed, and what events occurred in that time period to cause additional failures in the collection system. Few few defects were found on pipe segments that had been repaired in the earlier rehabilitation project.

Weiss et al. (2002) performed a long-term analysis of infiltration and inflow in 34 combined sewer systems in Germany. The results showed that significant control of pollution can occur by reducing I/I. Schultz et al. (2002) presented an overview of the provisions and programs that the Milwaukee MSD has developed to more effectively control infiltration and inflow into the interceptors and community sewers. The presentation emphasized those provisions where the rules, standards specifications and design documents have been improved by incorporating feedback from field observation of construction practice. The contribution of foundation drains connected to the sanitary sewer system in Elmira, Ontario, Canada was investigated by Waite et al. (2002). The connections were found to be the primary source of I/I flow. Wilson (2002) reviewed the cost effectiveness of I/I rehabilitation in Enumclaw, Washington after 25 years of smoke testing, sewers. The research addressed (1) state-of-the-art problem assessment; (2) pressure sewer systems; (3) polymers to increase sewer carrying capacity; (4) sealing methods and materials for sewer rehabilitation; (5) demonstration and evaluation of Insituform; (6) trenchless sewer installation by "plowing in;" (7) house lateral rehabilitation; and (8) impregnated concrete pipe to increase corrosion resistance and strength. This review was designed to assist communities that will be implementing the soon-to-be-issued SSO Rule. Moisio and Barton (2001) reviewed the design standards for sewers used by the Metropolitan Sewer District of Greater Cincinnati (MSDGC). The MSDGC maintenance program was designed to avoid SSOs due to poor maintenance. What had been documented was that replacement pipes were designed to the standard of new sewers and therefore I/I for the older sewer system was not accounted for in the calculations. The new revisions to the design standards will incorporate I/I contributions for older areas, thus allowing the installation of replacement pipes that can carry the flows from older areas. O'Sullivan et al. (2001) reviewed the implementation of a private sanitary sewer lateral replacement program (SSLRP) in Mobile, Alabama. The SSLRP performed in two distinct processes that used separate contractors – the testing and identification of defective private sanitary sewer laterals (PSSLs) and the replacement of defective PSSLs essentially at the cost of the property owner. A detailed program methodology, consistent penalty system, and close coordination between Water and Sewer System, the engineer, and the contractors were the keys to the program's success.

Hilderhoff and Wendle (2001) recommended a mini-basin or mini-watershed approach to sewer rehabilitation, as was used by Susquehanna and Lower Paxton Townships. Total rehabilitation by mini-basin means that all sewer system components including mainline, manholes, service laterals and building sewers located in one mini-basin were repaired to meet the same acceptance testing standards as new sewers. This work was completed at the expense of each Authority and not the property owner. Blakley and Summers (2001) reviewed the approach taken by the McCandless (Pennsylvania) Township Sanitary Authority for I/I control and recommended this synergistic approach to other communities. The approach combined strengths of five different strategies (dye testing, line replacement, pipe relining, line grouting and manhole rehabilitation), creating a synergistic effect, that balanced cost with gain. Field and O'Connor (2001) recommended communities develop a strategy for SSO pollution abatement because extensive sanitary sewer rehabilitation without planning is (1) relatively costly, (2) time-consuming, and (3) extremely disruptive to traffic, property owners, etc. I/I control studies have demonstrated that just correcting I/I in street sewers will not necessarily correct the problem because building connections contribute as much as 60% of the infiltration load. Building connection rehabilitation may be unfeasible economically. Inflow elimination or reduction, cost-effective sewer rehabilitation, and collection system inspection with associated clean out and repair must be performed in all cases, and must be part of an integrated economic and feasibility analysis.

Lukas et al. (2001) reviewed the WERF project to identify and develop Predictive Methodologies for Determining Peak Flows after Sanitary Sewer Rehabilitation Projects. The first result of the municipal surveys was the lack of documentation on rehabilitation projects and particularly, their effectiveness. The paper by Watts and Forbes (2001) analyzed the procedures used to rate I/I defects located during the recent Sanitary Sewer Evaluation Studies (SSES) conducted in Carolina and Luquillo, Puerto Rico. The methods used to prioritize appropriate rehabilitation methods were presented. Kurz et al. (2001) reviewed the City of Chattanooga's permanent network of flow meters for monitoring sewer flows as part of their billing. In addition, the flow meter data assisted the city in its CMOM program by locating capacity problems. Nashville's flow metering system identified over 10 million m^3 of I/I removal after rehabilitation. Jackson, Tennessee's flow meters demonstrated that I/I rehabilitation solved what appeared to be a capacity problem in a major trunk line. Hollenbeck and Rieger (2001) outlined the Rock River Water Reclamation District program that was designed to mitigate basement backups in the District. This program identified and rehabilitated both public and private sources of infiltration in the study area. Post rehabilitation flow monitoring confirmed that 10-year storm protection from overflows and basement backups was achieved.

The condition of a combined or sanitary sewer influences overflows from the system, and sewer inspection and prioritization of repair efforts are important parts of overflow control. Continual improvement and streamlining of an inspection and evaluation program for the condition of a system of interceptor sewers and CSO facilities in the Cleveland utilities prioritize inspection of sanitary sewers to overcome problems/limits of available data and the limited ability to inspect and repair or replace sewer infrastructure. In validation exercises using case studies supplied by the experts, the tool was shown to outperform a group of experts in quantifying the need to inspect (Merrill et al. 2000b). In 1995, the Washington Suburban Sanitary Commission, which is located in Montgomery County and Prince George's County, Maryland launched a 4.5-year, multimillion-dollar I/I analysis and sewer system evaluation survey. The paper by Nguyen et al. (2000b) summarized the results of the Rock Creek I/I Analysis project, described the tools developed to analyze the voluminous amount of data, and discussed the method used to prioritize the repairs of the identified defective manholes rmt was qused tofhouo

tio)-4.8(n)-4.8(capn)-48((te)6.6al cio)-4.8srts inthne, selection of a monitoring tool for benchmarking their progress.

White (2001) reviewed the joint agency program of King County and the City of Seattle (in conjunction with the Seattle-conditions encountered during design of near-surface CSO facilities in Providence, RI. It also reviewed the geotechnical-related construction issues and geotechnical instrumentation program implemented to mitigate the potential for damage of constructed facilities. Jones and Robinson (2002) reviewed the Chattahoochee Tunnel installed in suburban Atlanta to increase conveyance and reduce the number of SSOs into the Chattahoochee River. The five key features in the tunnel design included ideal tunneling rock; the lack of a need for tunnel supports in most of the length; fractured rock supports included rock bolts or steel ribs; low groundwater flow; and linings of cast-in-place concrete only in areas of fractured rock or significant groundwater flow.

Larsen and Garcia-Marquez (2002) reviewed trenchless technology application failures. After a review of failures experienced in South Florida, they proposed that the most common defects and failures are due to: sanitary sewer problem misdiagnosis, inadequate technology selection, poor design and inadequate specifications, improper installation, and/or inadequate inspection.

Gibbons et al. (2002) reviewed a case study of the Grant Street Pump Station flood mitigation in a West Allis, Wisconsin neighborhood. The paper presented the process for alternatives identification, stakeholder involvement, evaluation, and remedy selection and a description of the selected alternative for mitigation of localized flooding in the city of West Allis, Wisconsin. The constraints of the urban setting, and the need to consider environmentally sound remedies that will not degrade the existing watercourse, required a new look for an approach to meeting the objective.

operator has rendered this component of the collection system seemingly non-existent (Huerkamp et al. 2000). Street storage refers to the temporarily storing stormwater in urban areas on the surface (off-street and on-street) and, as needed, below the surface close to the source. A case study approach, based on two largely implemented street storage systems, was used to explain the concept of construction and operation of street storage systems (Walesh 2000). Huisman et al. (2000) studied the propagation of surface waves on the operation of a urine separation system. The authors showed that

is not generated by the first flush of pollution input and that regression curves are not very reliable for prediction of the first flush load of pollution input into drainage systems (Deletic, 1998).

Real-time control (RTC).
Ocampo-Martinez et al. (2006) discussed the application of fault-tolerant optimal controls of sewer networks in Barcelona, Spain. The main aim of this project was to protect against CSOs.

Cheung et al (2004) provided a review of current RTC issues and industry needs, available tools, and comparison of the RTC modules of current computer models, and experience in applying RTC for pre-design analyses and evaluation of security of the cables during natural disasters. These in-sewer fiber-optic cables were also used for the Storm Drainage Information System, which can provide the Headquarters with real-time information about the operation status of each stormwater pump.

Nielsen and Nielsen (2002) evaluated the integrated real-time control system for the wastewater treatment plant and sewer system. The system was capable of adjusting the plant's hydraulic capacity based on loads as monitored by the real-time control system. The effects of real time control of sewer systems were evaluated by Frehmann et al. (2002b) using an integrated model with four submodels (surface runoff, sewer flow, wastewater treatment plant, and receiving water). The results showed that the effect of a control measure may be ambivalent in an existing system but that drainage system can be optimized toward environmental protection using real time control on the catchment scale. Klepiszewski and Schmitt (2002) compared a conventional, rule-based control of a combined sewer with a fuzzy-logic control through the use of hydrodynamic simulation of optimizing storage capacities of four combined sewer overflow tanks. The results indicated that both control systems were able to reach the objective and the use of the fuzzy-logic-based system provided no additional benefits, in spite of its additional costs. Sugita et al. (2002) performed a feasibility study on the real-time control of pumps for the reduction of CSOs. The use of RTC control made it possible to reduce CSO by roughly 50% for small rainfalls (total precipitation of < 20mm) by storing rainwa1.14(9e-22.62280)6(reapip()-3.9(v((9e-2Sug)-4.9 a4(9e-2dalls)0 TD.e of RTC application to the Roma Cecchignola CSS through the use of an advanced hydraulic model. Comparison of the results obtained with the tested strategies showed that a global control strategy reduced overflows considerably more than a local control strategy. Charron et al. (2000) presented the results of a study of RTC to reduce CSO in and around Louisville, Kentucky, which showed a global RTC strategy would enable a more efficient use of the existing system capacity and reduce the overall cost of the CSO control. Cigana (2000b) introduced the use of linear overflow devices to help municipal managers achieve increased retention of sewage in a sewer while protecting against flooding. Cigana's examples demonstrated that the required water head was reduced by 50% for the same overflow rate. Jain (2000) summarized the hydraulic characteristics of a two-ramp drop structure used for diverting flows from near-surface storm-sewer systems to underground storage tunnels. The construction of this structure may be more suitable in urban areas where an open-cut construction is not feasible. Lavallée et al. (2000) reviewed the RTC system installed for the Quebec Urban Community (QUC), Canada. The results showed that a Global Predictive Real Time Control (GP-RTC) strategy on the Westerly Sewer Network was successful in terms of proven efficiency. GP-RTC meant that only 4 storage facilities would be required instead of the 7 needed without GP-RTC, a 22% savings (Pleau et al. 2000). Pollution-based RTC, or PBRTC, is designed to reduce the potential pollutant load on receiving waters during wet weather without expansion of transport or storage capacity. In branched interceptor systems PBRTC reduced CSO pollutant loads by more than 20% compared to volume-based RTC (Risholt 2000). Stinson et al. (2000) presented results of two case studies of RTC on portions of sewerage systems near Paris, France and in Quebec City, Canada. Villeneuve et al. (2000) compared three RTC strategies used in a collection system in terms of optimization of the use of the system capacity and the cost of long-term CSO control. The Philadelphia Water Department used the SWMM EXTRAN and SewerCAT models investigate RTC in its Southwest Drainage District (Vitasovic et al. 2000). Schutze et al. (2000) reviewed RTC for an integrated system that included the collection system, the treatment plant and the river. The results of their work was the development of an algorithm for the complete urban wastewater system and the methodology for parameter optimization.

(1999) presented an approach to joint operation of an urban drainage system and the corresponding sewage treatment plant. This operation was based on real-time flood forecasts, which were computed with the aid of radar rainfall measurements to minimize the combined negative effects of the hydraulic load (water quantity) and the pollution load (water quality) in the receiving waters during floods. Schmitt et al. (1999a) developed a new management strategy of the City of Nancy's sewage system (Lorraine, France) in order to reduce rainwater pollution overflows using a model which simulated flows in interceptors, transport of dissolved and solid pollutants, and precipitation, flocculation and

weather flows. The results showed that wet startup provided better performance than dry startup and that it took two hydraulic residence time periods to achieve the targeted level of performance.

Bendick et al (2004) and Neufeld (2004) evaluated cross-flow microfiltration, with and without backpulsing, for the treatment of dilute primary sewage effluent, representing CS equipment has 4-mm openings that will not only trap floatables but also provide CSO treatment by acting as a barrier to solids. Takasou et al. (2002a) performed a study on the control of CSOs by a fine CSO screen. This review included investigating their performance, structure, application, installation, maintenance, head loss coefficient and filtration rate.

Takasou et al. (2002b) researched the potential use of a high-speed, space-saving fiber filter to reduce the discharge load of CSOs in Japan and evaluated its practical performance and applicability. The results showed that a high-speed fiber filter can be used to decrease the amount of primary treatment wastewater overflow on rainy days.

An evaluation of the effectiveness of UV disinfection of CSO processed through Continuous Deflective Separation (CDS) devices was reported on by Akridge et al. (2002). The combination of treatments was found to provide a three-log reduction of fecal coliforms in a preliminary study. Boner et al. (2002) evaluated the use of bromine disinfection for wet-weather flows at the Uptown Park CSO facility in Columbus, Georgia. Disinfection capabilities of BCDMH (1-bromo, 3-chloro, 5,5-dimethylhydantoin), in a suspension form manufactured by BioLab, Inc were examined on a bench-scale level along side of other chemical disinfectants to quantify disinfection performance at different CSO strengths. BCDMH dosing system set-up, tests and calibrations were performed.

Turner et al. (2002) reviewed the steady-state bacteria delisting approach in Georgia. Study conclusions and recommendations called for a full-scale demonstration to provide embankment stabilization, peak flow attenuation, flushed pollutant removal and disinfection. Stormwater tr

Carrette et al. (2001). The concept was that higher hydraulic loadings could be treated within the biological treatment area if additional secondary clarifier volume was supplied. This operation scenario was successful and the overall pollutant discharge was significantly reduced. Chen and Beck (2001) also reported on using practical controllers to maximize the flow through the biological treatment system of a WWTP, with the result being the minimization of bypass flows. The results of the tests illustrated that the tested controllers regional Treatment Facility in Syracuse, N.Y. demonstrated and tested vortex and storage abatement strategies with high-rate disinfection. The estimated construction cost for the 1.84 m^3/s (65 ft^3/s) CSO facility is $3.5 million or about $1.9 million/$m^3$ s ($50 000/$ft^3$

systems, with averages of 2.2 mg/L BOD_5, 3.0 mg/L TSS, 1.25 mg/L NH_4-N and 12.2 mg/L TON. Luyckx et al. (1999) compared the separating efficiency of an improved high-side weir overflow and a hydrodynamic Storm King separator.

Company for treatment of WWF. The Densadeg separator accomplishes optimized flocculation with the contact mass and effective lamellar settling. It is compact, flexible, and efficient and can be used either alone or in connection with a storage basin.

Averill *et al.*(1996) discussed interim results of a Canadian multi-agency initiative to test technologies for the treatment of CSO under realistic field conditions. A modular, automated pilot plant, composed of an elevated tank, interchangeable CSO treatment technologies, and a conventional clarifier, is located in the City of Scarborough, near Toronto, ON, Canada. The Storm King®, a vortex separator, has been the first CSO technology tested and has shown promising results to date. The data collected in this study will add to the knowledge of vortex field performance that is otherwise limited but necessary for a design of a full-scale facility.

Pfister (1996) discussed a laboratory study on the use of Fenton's Reagent, which is hydrogen peroxide coupled with divalent iron salts, for treatment of CSO in existing overflow tanks. Addition of the Fenton's Reagent to the CSO tank combines physico-chemical processes w

Wojtenko and Stinson (2000) provided a state-of-the-art review of the performance and effectiveness of ultraviolet (UV) light disinfection for CSO applications, and concluded that UV irradiation has potential for use in high-rate processes. As part of the expansion of 100-MGD WWTP in Wayne County, Michigan, a UV disinfection system design was provided - the largest of its type in the US. The UV system was designed to disinfect (measured using fecal coliforms) the "blended flow" from the primary and secondary treatment processes, and would be expected to provide disinfection that meets permit requirements for wet weather flows up to 175 MGD (Christeson and Fath-Azam 2000). Safety concerns and more stringent regulations regarding gaseous chlorine use have forced reconsideration of disinfection practices, with UV seen as an attractive alternative. However, varying flows pose a challenge for UV systems. Faisst et al. (2000) reported on the implementation of UV disinfection at two coastal communities carried out in response to these challenges. Wojtenko et al. (2000) presented a state-of-the-art review of chlorine dioxide (ClO_2) for high-rate CSO disinfection. In general, ClO_2 appeared to be effective for high-rate disinfection and a suitable Cl_2 replacement. The New Orleans Sewerage and Water Board has attempted to control the odor and disinfection problems common to SSOs through the use of Nok-Out, a blend of oxidative chlorine compounds and non-charged amines. Since its inception, the use of this blend has effectively controlled both odor and disinfection problems (Austin et al. 2000). The City of Atlanta's four westside, high-rate CSO facilities used coarse and fine screening followed by sodium hypochlorite disinfection. Disinfection optimization studies found that the CSOs exhibit a first flush, that the water quality varies throughout an event and between events, and that the CSOs are currently contact-time limited during the first flush in regards to disinfection (Richards and Gurney 2000).

One concern with using the standard methods for measuring microbial indicator concentrations in sewage before and after disinfection is that they fail to measure particle-associated microorganisms, thus underestimating the total concentrations present. A related concern is that particles and other matter in the water interfere with a disinfectant's ability to contact and, therefore, inactivate microbes. EPA researchers presented the results of two projects which examine the effects of particle association on measurements of microbial indicator concentrations in CSOs, and determine the effectiveness of

Coagulation and Ballasted Flocculation. Annadurai et al. (2003) examined the floc characteristics and removal of turbidity and humic acid from high-turbidity stormwater. Loose flocs were promoted by an acidic suspension and technical issues. The choice between providing relief sewers or implementing I/I reduction programs is not always clear, according to Mamid et al (2004). The master plan for McDowell Creek Basin, Charlotte-Mecklenburg, NC, is described. Hydraulic analysis of this system used dynamic hydraulic modeling. A cost-benefit analysis of 13 comparable projects revealed that I/I reduction programs could provide cost savings of up to $1.6M.

Nelson (2004) discussed various aspects of the new Capacity, Management, Operations, and Maintenance (CMOM) regulations. The main objective of CMOM is to ensure that agencies responsible for the sanitary sewer systems have the appropriate legal authority, staffing, budget, and tools to properly manage the collection systems and prevent overflows. Robertson et al (2004) described a CMOM Lite Tool Kit and gave an example used for a central Florida utility.

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