URBAN WET-WEATHER FLOWS

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ABSTRACT/INTRODUCTION

This subject, Urban Wet-Weather Flows, was comprised of three basic subareas – combined-sewer overflows (CSOs), sanitary-sewer overflows (SSOs), and stormwater discharges. Major proceedings related to wet-weather flow (WWF) published during 2000 were the following: (1) ASCE EWRI Conference – Bridging the Gap: Meeting the World's Water and Environmental Resources Challenges (ASCE, 2001); (2) WEFTEC 2001, 74th Annual Conference and Exposition (WEF, 2001); (3) 5th International Conference: Diffuse/Nonpoint Pollution and Watershed Management (IWA, 2001); (4) Models and Applications to Urban Water Systems, Monograph 9 (CHI, 2001); (5) 2001 A Collection Systems Odyssey: Integrating O&M and Wet Weather Solutions (WEF, 2001); (6) 7th Annual Industrial Wastes Technical and Regulatory Conference (WEF, 2001); and (7) Proceedings of the Third International Conference on Watershed Management (ASCE, 2001).

STORMWATER CHARACTERIZATION

General

Fan et al. (2001b) reviewed the transport of toxic pollutants through multiple media and drainage systems in the urban watershed during wet-weather periods. Field studies have identified that a major portion of hazardous waste priority pollutants including benzene, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, and heavy metals (e.g., arsenic, cadmium, chromium, copper, lead, mercury, and zinc) contained in urban stormwater runoff are in particulate form or sorbed onto particles. Fatoki and Mathabatha (2001) investigated the distribution of heavy metals (zinc, cadmium, copper, iron, manganese and lead) in seawater and in sediment samples from the East London and Port Elizabeth harbors. The results indicate the contribution of heavy metal pollution from storm drains. Ship repair activities were also suspected to a source of elevated concentrations in the upper reaches of the harbor. Kayhanian et al. (2001b) analyzed the impact of 'non-detects' or 'NDs' on stormwater data because dissolved fractions of stormwater constituents often are not detected above laboratory reporting limits. Analysts and stormwater modelers have represented these NDs in stormwater data sets using a variety of methods. In the paper, different methods of data analysis were used to determine constituent mass concentrations from water quality datasets that include ND values. Depending on the number of NDs and the method of data analysis, differences ranging from 1 to 70 percent were in mean values, which would have significant impacts on estimations of constituent mass loading.

Rainfall Monitoring and Urban Hydrology

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. (2001a) reported on one technique for disaggregating long-term hourly rainfall records into subhourly increments that involved the use of artificial neural networks (ANNs). The research evaluated the influence on performance of several ANN model characteristics and training issues including data standardization, geographic location of training data, quantity of training data, number of training iterations, and the number of hidden neurons in the ANN. Results suggested that data from rainfall-gauging stations within several hundred kilometers of the station to be disaggregated would be adequate for training the ANN rainfall disaggregation model.

The L-THIA (Long-Term Hydrologic Impact Assessment) model can be used to assess how land-use changes affect annual average runoff (Bhaduri et al., 2001). Looking at runoff calculations, SWMM was compared with L-THIA. Applications of L-THIA and SWMM to two small watersheds in Chicago showed that L-THIA predicts annual average runoff between 1.1 and 23.7% higher than SWMM, and was easier and quicker to use than SWMM. Results suggested that L-THIA could be an appropriate tool for initially assessing the relative impacts of land-use change scenarios. The runoff coefficient (ratio of total streamflow volume to the total precipitation over a certain area and time) has been shown to play a fundamental role in the planning, design and operation of water resources in a catchment (Kadioglu and Sen, 2001). In this paper, monthly runoff coefficient changes within an annual period were represented through a simple polygon diagram concept obtained from monthly precipitation and runoff data. The application of the polygon method was presented for catchments around Istanbul, Turkey. Kojiri et al. (2001) reviewed the flood management system used for urban rivers in Japan. The system is composed of three subsystems: an on-line data collection subsystem for collecting rainfall and water level data; a flood prediction subsystem based on the previous 3-hour hydrologic data; and a results display subsystem. This system has been used for practical flood prediction. Semadeni-Davies et al. (2001) investigated the radiation balance of urbanized catchments as it relates to snowmelt. Snowpacks experience either enhanced or decreased irradiance depending on snowpack location and condition, and changes to localized irradiance (and melt rates) have implications for urban runoff generation. Net allwave radiation measurements over snow made in Lulea, Sweden during April 1997 and 1998 were presented. The results showed that urban structures significantly alter radiation over snow, and therefore, including snowmelt energetics within design and management techniques is needed.

Stormwater Quality

McPherson et al. (2001) compared the relative contributions of dry weather flow (DWF) and wet weather flow (WWF) from the highly urbanized Ballona Creek watershed (BCW) in Southern California using empirical and deterministic models. DWF contributed approximately 10 – 30% of the total annual flow discharged from Ballona Creek, a significant contribution. Yamada et al. (2001c) compared the pollutant load from runoff that were collected from storm sewer pipes in 7 cities. The contribution of land use, soil, amount of rainfall, rainfall intensity and antecedent dry period was quantified. Choe et al. (2001) analyzed surface runoff from selected residential and industrial zones. The event mean concentrations of COD, SS, TKN, and TP in the residential zone were 313 mg/L, 279 mg/L, 8.45 mg/L, 1.98 mg/L, and those in the industrial zone were 80 mg/L, 106 mg/L, 5.07 mg/L, and 1.93 mg/L, respectively. The degree of first-flushing effect was in the following order: TKN > COD > SS > TP > PO_4-P. The pollutant loads of the above constituents was highly correlated with SS. The report titled "The removal of urban litter from stormwater conduits and streams" (by Armitage et al.,) noted that little data was available on the nature and quantity of litter in stormwater drainage systems (Marais et al., 2001). The Council for Scientific and Industrial Research estimated in 1991 that 780 000 tonnes of waste a year entered the drainage systems of South Africa.

Fifteen highway construction sites were monitored by the California Department of Transportation (Caltrans) to assess the runoff quality from the sites (Kayhanian et al., 2001a). The results indicated the following: (a) construction-site runoff constituent concentrations were less than typical Caltrans and non-Caltrans highway runoff constituent concentrations, with the exception of total chromium, total nickel, total phosphorus, total suspended solids (TSS), and turbidity. (b) The concentrations of TSS and turbidity likely resulted from soil disturbance. (c) The origins of the total chromium, total nickel, and total phosphorus concentrations are unknown. (d) A correlation was observed between TSS and particulate runoff concentrations of chromium, copper, and zinc, indicating that solids removal may reduce total metals concentrations. The Solids Transport and Deposition Study (STDS) characterized the rates and patterns of solids transfer to, and the collection within, storm water drain inlets located along Caltrans highway facilities (Quasebarth et al., 2001). The primary objective was to determine if certain distinguishable site characteristics controlled the transport and deposition of sediment, metals, vegetation, litter, and petroleum hydrocarbons to highway drain inlets. The ANOVA results indicated that the four primary factors (erosion control/sediment loading [vegetation factor], litter management [litter factor], toxic pollutant generation potential [adjacent land use factor], and roadway design [design factor]) likely had little overall control on solids accumulation or metals mass accumulation, although roadway design and litter management were possibly important in some cases. Smith (2001) presented a case study of stormwater and sediment analysis in flood control sumps in an urban watershed. The results suggested that: (1) first-flush samples may not reflect outfall concentrations of stormwater to the sump; (2) time-variable concentrations of pollutants in a sump can be related to the hydraulic characteristics of the basin; and, (3) post-event sediment analysis verified pollutant capture in the sumps. HEC-1 software was used to estimate the flow hydrograph for each outfall to a sump as part of the overall flow balance (Smith et al., 2001c). The results suggested that HEC-1 calculation provide a satisfactory estimate of the total runoff and its time-distribution to the sump. The hydraulic model was then used to estimate nonpoint loads of selected heavy metals to the sump and to the river

Atmospheric deposition of particulate matter, organic carbon and PAHs was measured at two stations in an urban area (Ozaki et al., 2001). The deposition fluxes of particulate matter and organic carbon were nearly constant over the sampling periods, while PAHs had seasonal variability. The first flush phenomenon was clearly observed during all the rainy periods. Although the PAHs in runoff agreed with that of atmospheric deposition, their fluxes were several times larger. Loading of dissolved organic carbon (DOC) from parking lot storm runoff was found to be a significant, yet relatively neglected, source of elevated DOC concentration in urban streams (Lee and Schwartz, 2001). This study investigated DOC transport and loading from an paved parking lot during rainstorm events in order to elucidate impacts of the stormwater runoff on the chemistry of an urban stream. DOC measurements from the parking lot showed that the interevent period between storms and the precipitation intensity controlled the maximum DOC concentration and the time required to reach the maximum DOC concentration, respectively.

The fate and transport of metallic pollutants through a watershed were related to the characteristics of the solid particles to which they are bound (Magnuson et al., 2001). Because the particles most often associated with metal pollution have nominal diameters of < 50 µm, split-flow thin-cell (SPLITT) fractionation was investigated as a means to study the metal loading as a function of particle settling rate. Sansalone et al. (2001) showed that urban storm water levels of Zn, Cu, Cd, Pb, Cr, and Ni can be significantly above ambient background levels, and for many urban and transportation land uses, often exceed surface water discharge criteria for both dissolved and particulate-bound fractions. The authors advocated a multiple-unit-operation approach to stormwater treatment.

Turer et al. (2001) investigated the accumulation of metals in roadside soils at a site for which extensive runoff data were also available. The results demonstrated that heavy metal contamination in the top 15 cm of the soil was very high compared to local background levels. The maximum measured amount for Pb was 1980 ppm (at 10-15 cm depth) and for Zn was 1430 ppm (at 0-1 cm depth). The correlation to organic C is stronger than the correlation to depth. Cluster analysis of the heavy metal data showed that Pb, Zn and Cu were closely associated to one another, but that Ni and Cr did not show an association with each other or with either organic C or depth. Mass balance calculations for Pb in soil showed that most of the Pb came from exhausts of vehicles when leaded gasoline was in use, with about 40% of the Pb retained in the soil. Zinc and other trace metal (V, Cr, Co, Ni, Cu, Cd, and Pb) concentrations were measured in the Atlanta metropolitan region and in relatively undeveloped watersheds within the Georgia Piedmont and Blue Ridge Provinces (Rose et al., 2001). Zinc concentrations in street runoff [median (Zn) = 905 µg/L] were significantly greater than zinc concentrations in Peachtree Creek storm runoff [median (Zn) = 60 µg/L], which were, in turn, greater than zinc concentrations contaminants within non-storm baseflow in Peachtree Creek [median (Zn) = 14 µg/L]. A two end member mass balance model suggested that a large proportion of the zinc present in the street runoff was adsorbed and transported by the suspended sediment.

Mosley and Peake (2001) characterized urban runoff from a catchment in Dunedin, New Zealand during base flows and storm flows from five rainfall events. Fe and Pb were found to be predominantly particle-associated (>0.4 µm) with concentrations increasing significantly at the beginning of storm run-off. In contrast, the majority of Cu and Zn was found in the <0.4 µm fraction prior to rain but a significant proportion was present in the > 0.4 µm fraction during the initial period of storm flows. The results indicate that Cu and Zn may be more bioavailable, and more difficult to remove by stormwater treatment, than Pb. The pH level and the concentration of major ions (Ca^{+2}, Na^{+}, Mg^{+2}, K^{+}), dissolved PO_4-P, and NO_3 generally decreased during storm flows due to rainwater dilution. Concentrations of total N and P often increased during the initial period of storm run-off, likely because of wash-off of particulate plant material. Significant amounts of non-point source runoff were shown to enter the Santa Monica Bay from the Ballona Creek Watershed during wet weather flow. Buffleben et al. (2001) monitored four storms in the watershed. The watershed is developed mostly with residential, commercial and light industrial land uses. They found that the suspended solids phase primarily transported the mass for five of the six metals studied: cadmium, chromium, copper, lead, and nickel. Arsenic was found primarily in the aqueous phase.

COMBINED SEWER/SANITARY SEWER OVERFLOW CHARACTERIZATION

Hannan et al. (2001) reviewed the ASCE study that developed a guidance manual for identifying Sanitary Sewer Overflows (SSOs). The project surveyed twelve medium-to-large utilities for their SSO-identification protocols, with protocols organized into three major categories: Hydraulic, Maintenance and Inspection, and Structural. King County (Washington) has been assessing inflow and infiltration (I/I) in the county's service area (Swarner et al., 2001a). The program included rainfall and flow monitoring, computer modeling, economic analyses, field investigations and pilot projects. The results will be used to determine the cost effectiveness of removing I/I from the system. This project has developed detailed information about the location of I/I sources and potential cost-effective improvements to remove or reduce critical sources of I/I. Inflow/infiltration values were estimated in the South Beaches regional wastewater collection system (Brevard County, FL) through re-examining pump flow data (Fernandez 2001). Operating station data was used in a custom-designed hydraulic model. Pump operating points were deduced through an interactive process of balancing flows from tributary pump stations.

Ahyerre et al. (2001a) investigated the solids composition of dry weather flow in the "Le Marais" combined sewer network in Paris after it was noted that there was an increase in the solids concentration in the lower part of the sewer's flow. The study results showed that the accumulation rate of the organic solids layer was 215 g/(m^2-day) with the particles heavily loaded with pollutants (VSS to TSS = 66 – 75%). Flushing experiments showed that this organic layer is 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 even at low shear stresses (0.5 N/m^2). Cigana et al. (2001) investigated the impacts of underflow baffles on the retention of floatables in a combined sewer system. The study showed that a critical horizontal velocity can develop in overflow chambers and when this critical velocity is exceeded, floatables that would normally rise to the surface and be skimmed off are kept in the flow and therefore are not intercepted.

Gromaire et al. (2001) documented the sources of pollutants (SS, VSS, COD, BOD_5, Cd, Cu, Pb, and Zn) in the Paris combined sewer area called the "Marais" catchment. The erosion of in-sewer pollutants was the main source of particles and organic matter in wet weather flows, whereas heavy metal loads mainly originated from runoff due to the corrosion of metallic roofs. A change of the chemical form of heavy metals was noted during sewer transport. It was hypothesized that a fraction of the dissolved metals from the runoff adsorbed onto sewer sediments. Griffin et al. (2001) reported on the CSO Control System Evaluation report for the City of Atlanta, Georgia. Based on the testing, the main pollutants of concern for meeting water quality standards were copper (Cu), zinc (Zn) and bacteria (fecal coliform). The two metals exceeded the baseline dissolved criteria frequently enough for remedial measures to be needed. Supplemental stormwater runoff sampling from parking lots and parks demonstrated high levels of metals (Cu and Zn) and bacteria. The frequency of exceedences for the stormwater runoff were similar to that of CSOs; thus, similar water quality compliance issues would remain even if the sewers were fully separated.

Sacramento County, California has completed a two-year project on the impact of grease accumulation in selected areas of the collection system (Hassey and Joyce 2001). Current grease handling policies of CSD-1 and local food producing facility wastewater flows result in heavy localized grease accumulation in the collection system that account for approximately seven percent of the annual grease related sewage overflows, and 36 percent of the flooded structure mitigation costs related to the overflows.

POLLUTION SOURCES

Atmospheric Sources

Ahn and James (2001) report that atmospheric deposition is a substantial source of phosphorus to the Florida Everglades. Phosphorus has been measured on a weekly basis since 1974, but the results were highly variable: the average mean and standard deviation of the calculated P deposition rates for 13 sites were 41± 33 mg P m^{-2} yr^{-1}. They found that the atmospheric P deposition load showed high spatial and temporal variability, with no consistent long-term trend. Because of the random nature of P deposition, the estimated P deposition loads have a significant amount of uncertainty, no matter what type of collection instrument is used, and replicate sampling is highly recommended. Atasi et al. (2001b) conducted source monitoring using specialized sampling equipment and ultra-clean analytical methodology to quantify the concentrations and fluxes of mercury, cadmium, and polychlorinated biphenyl in ambient air, precipitation, runoff, sanitary sewer, and wastewater treatment plant influent. The relationships between the atmospheric deposition and runoff on controlled surfaces were also examined. Atmospheric deposition was found to be the primary source of these pollutants in runoff. They concluded that wet weather flows, not atmospheric deposition, contributed the main portion of these pollutants to the Detroit Wastewater Treatment Plant. Atasi et al. (2001a) also pointed out that most water resources regulations (especially TMDL procedures) do not normally account for atmospheric deposition sources. Tsai et al. (2001) described their pilot study, conducted from August 1999 through August 2000, that estimated the loading of heavy metals from the atmosphere to San Francisco Bay. Dry deposition flux of copper, nickel, cadmium, and chromium was approximately 1100 +/- 73, 600 +/- 35, 22 +/- 15, and 1300 +/- 90 $\mu g/m^2$/year, respectively. The volume-weighted average concentrations of these trace metals in the rain water were 1.2, 0.4, 0.1, and 0.2 µg/L, respectively. Direct atmospheric deposition onto Bay waters, from both dry deposition and rainfall, contributed approximately 1900, 930, 93 and 1600 kg/yr of copper, nickel, cadmium and chromium, respectively. Stormwater runoff contributed approximately twice as much as the loading from direct atmospheric deposition. Direct atmospheric deposition was therefore found to be a minor contributor to the total load of these pollutants to the Bay.

Roof Runoff

Wallinder and Laygraf (2001) studied the seasonal variations in the corrosion and runoff rates from copper roofs. Their experiments lasted for two years, at one urban and one rural location. Seasonal variations in corrosion rates were observed at the rural site, likely associated with variations in humidity, while no seasonal variations were observed at the urban site. The corrosion rates continually decreased with time. The yearly copper runoff rates ranged from 1.1 to 1.7 g $m^{-2}y^{-1}$ for the urban site, and from 0.6 to 1.0 g $m^{-2}y^{-1}$ for the rural site. The runoff rates were significantly lower than the measured corrosion rates as long as the adhering copper patina was increasing with exposure time. From 70 to 90% of the copper in the runoff (collected immediately after leaving the surface) was present in the most bioavailable form, the hydrated cupric ion, $Cu(H_2O)_6^{2+}$.

Highway and Road Runoff

Glenn et al. (2001a and 2001b) described their research at highway test sites in Cincinnati, Ohio investigating the effects 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, as compared to stormwater, due to longer residence times before melting, and the snow's porous matrix. Parameters such as residence time, solids loadings, alkalinity, hardness and pH influence the heavy metal partitioning in the snow. They found that Pb, Cu, Cd, Zn, Al, Mg, and Fe were mostly particulate bound, while Na and Ca were mostly dissolved. Partition coefficients for most heavy metals in snowmelt water ranged from 103 to 106 L/kg. Stenstrom et al. (2001) studied freeway runoff from three sites in the west Los Angeles area. Each site was sampled for 14 storms during the 1999-2000 rainy season. Samples were collected very early in the storm in order to compare water quality from the first runoff to water quality from the middle of the storm. A large range of water quality parameters and metals were analyzed. The data showed large first flushes in concentration and moderate first flushes in mass emission rates. Zhou et al. (2001) studied accumulations of heavy metals in roadside soils. Heavy metal accretion in the surficial soils was a function of depth, surface drainage patterns, distance from the pavement edge and soil indices. Rapid decreases in heavy metal accumulations were found as the distance from the pavement increased. Plasticity and organic matter content were important soil characteristics affecting the observed heavy metal concentrations.

Wastewater, CSOs and SSOs

The Massachusetts Water Resources Authority (MWRA) completed its Long-Term Control Plan for CSO control in 1997. The plan used a watershed approach to assess the impacts of CSOs in relation to other sources of pollution in the watershed, including stormwater and upstream flows. The EPA and the Massachusetts Department of Environmental Protection agreed to revise the water quality standards for certain waters within Boston Harbor. For the Charles River, a two-year water quality variance was granted to allow further study of the impacts of non-CSO sources of pollution, as well as for additional CSO control alternatives. Important current activities described by Walker et al. (2001) include an assessment of additional CSO storage; performance evaluations of the MWRA's Cottage Farm CSO facility; development of a more detailed stormwater runoff model for areas tributary to the Charles River; and upgrading the receiving water model for the Charles River.

Industrial Sources

Chang and Duke (2001b) summarized their research that examined stormwater quality from eight auto dismantling facilities in Los Angeles, CA, over a three year period. The majority of the samples had constituents exceeding stormwater discharge guidelines, but were highly variable. Talbot (2001) discussed some of the stormwater management challenges and solutions for power generation facilities.

Stormwater from a modern waste disposal site was characterized by Marques and Hogland (2001). They examined 22 different constituents and found that suspended solids, COD, BOD, total nitrogen and total phosphorus, exceeded discharge standards. Some of the runoff constituents were greater than found in the leachate from covered landfill sites. Copper, zinc and nickel were the most commonly detected heavy metals, being found in every sample. Surprisingly, the concentrations of zinc, nickel, cobalt, iron and cadmium found in runoff from composting areas were greater than the metal concentrations found in the runoff from areas having stored and exposed scrap metal. They concluded the presence of large amounts of organic compounds, plus site specific drainage pathways, were responsible for these findings.

Specific Pollutant Sources

Nonpoint sources of heavy metals (Hg, Cd, Cu, Zn, Pb, Ni) in the Rhine River watershed were investigated by Mohaupt et al. (2001). They found that urban stormwater was the most important source for these metals in the Dutch portion of the watershed. Erosion was of lesser importance, while atmospheric deposition onto open water was a much less important source. Anthropogenic nonpoint sources accounted for 40 to 80% of the total sources for some metals. They recommended further studies of urban nonpoint sources of heavy metals and on ways to improve urban stormwater management. A mass balance of all known sources and sinks for heavy metals (Ag, Cd, Cu, and Pb) in New Haven Harbor, CT, was conducted by Rozan and Benoit (2001). Sources included direct atmospheric deposition, rivers, treated sewage effluent, combined sewer overflows, and permitted industrial discharges. All of the fluxes were directly measured, and the uncertainties were quantified. River inputs accounted for most of the total yearly metal discharges, while the salt marshes removed about 20 to 30% of the metals from the rivers before reaching the harbor. Atmospheric deposition is of minor importance, and is comparable to sewage effluent discharges. Davis et al. (2001a) presented loading estimates of lead, copper, cadmium, and zinc in stormwater from different sources. They reviewed available data from the literature, and conducted controlled experiments and other sampling. Specific sources that they examined included building siding and roofs; automobile brakes, tires, and oil leakage; and wet and dry atmospheric deposition. The most important sources they identified were building siding for all four metals, vehicle brake emissions for copper, and tire wear for zinc. Atmospheric deposition was an important source for cadmium, copper, and lead.

Ellis and Chatfield (2001) reported that nonpoint discharges of oil and hydrocarbons to urban receiving waters constitutes a major pollution source, being responsible for up to 30% of all reported water pollution incidents in the UK. Commercial and industrial areas, along with heavily used highways, are the major sources of these pollutants, with about 20,000 to 24,000 tonnes of oil per year being discharged to urban receiving waters from these sources. Blanchard et al. (2001) investigated PAHs and PCBs in the combined urban flows to the Acheres wastewater treatment plant in Paris, France, under different meteorological conditions. The PAH concentrations were found to increase much more than the PCB concentrations during wet weather. They concluded that atmospheric wet deposition was the most important source for the PCBs, while urban stormwater was the most important source for the PAHs.

The suspected source of the bacterial contamination that has affected Lake Pontchartrain, New Orleans, LA, is urban stormwater that is collected and pumped to the lake. Barbe' et al. (2001) concluded that the stormwater may be contaminated by sanitary sewage. Five monitoring stations were selected for study that had varying distances to stormwater drainage canals. Fecal coliform concentrations was found to be wet weather-dependent at all stations, except for one. They found that the water is generally unsuitable for primary contact recreation, especially close to urban drainage canals, for at least two to three days following a storm event. The study period was characterized by unusually low rainfall and lower than typical fecal coliform observations. They suspected that the lower bacteria concentrations may have been due to the drought conditions, rather than from decreased contamination. Brion et al. (2001) addressed sources of bacteria indicators. They found that first flush discharges contained high levels of pathogens, originating from storm sewers, overflowing domestic sewers, and surface scour. They present some new analytical tools (bacterial ratio that varies with age) and modeling tools (neural network) to help identify the predominant bacteria sources in stormwater.

MONITORING AND SAMPLING

General

The Patrick Center for Environmental Research of The Academy of Natural Sciences in conjunction with the University of Delaware developed a method to assess streams based on geomorphic, habitat and riparian features (Cianfrani et al., 2001). An overall Stream Quality Index (SQI) was developed that could classify streams into four major categories: severely impaired, impaired, moderately impaired, and slightly or non-impaired. The SQI rating was used with other natural-resource inventory data in restoration planning and overall management of the Fairmount Park system.

Rainfall and Flow Measurement

The Tropical Rainfall Measuring Mission (TRMM) is a United States-Japan joint project to measure rainfall from space (Ohsaki 2001). In this paper, rain/no-rain discrimination for the TRMM was validated through simulation and theory for the no-rain condition and by comparison with the ground-based radar data for rain conditions. The precipitation radar (PR) aboard the TRMM demonstrated the feasibility of measuring rainfall from space (Sadowy et al., 2001). The Second Generation Precipitation Radar (PR-2) has been developed. The PR-2 will improve capabilities and substantially reduce system mass compared to the TRMM PR. This paper surveyed the technologies for the PR-2.

A combined Microwave/Infrared Rain Rate Algorithm (MIRRA) was presented by Miller et al. (2001). MIRRA combined the strengths of these two broad approaches to rain rate measurement from space. The algorithm was tested using data from the TOGA-COARE campaign, with shipboard radar rain rate estimates used as truth. Results indicate enhanced performance in bias, correlation and rms error for MIRRA. Calibrated radar rainfall systems, often called 'virtual rain gages,' have become popular due to the advantages they offer over conventional precipitation monitoring networks (Orie et al., 2001). The 3 Rivers (Allegheny County, Pennsylvania) Wet Weather Demonstration Program made virtual rain gauges available to the public by integrating the calibrated rainfall system with the Internet. A methodology was developed that matched coincident space-based radar (PR) and ground-based volume scanning weather radar observations in a parallel three-dimensional Cartesian grid (Anagnostou et al., 2001). The data matching was performed to minimize uncertainties associated with the type of weather seen by the radars, grid resolution, and differences in radar sensitivities, sampling volumes, viewing angles, and radar frequencies. The authors compared reflectivity observations from the PR and several U.S. weather surveillance Doppler radars (WSR-88D) as well as research radars from the TRMM field campaigns in Kwajalein Atoll and the Large Biosphere Atmospheric (LBA) Experiment. Correlation values above 0.8 were seen between PR and ground radar.

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 autocovariance, and probability of zero rainfall. Application of the method in the upper Charles River watershed in eastern Massachusetts demonstrated that the method greatly improved the river flow simulation capability of the hydrologic model over alternate simulations using hourly rainfall from outside the watershed. An overview of weather radar-related developments in South Africa, as related to hydrological research and operations, was given by Terblanche et al. (2001). This program developed the necessary infrastructure, expertise and related hardware and software to collect and archive high-quality radar data. Shortcomings of weather radar data for hydrological applications were described and the ongoing research efforts to address these shortcomings were highlighted. Valeo and Tang (2001) developed a model for the second order process of rainfall in an area of southern Ontario. Hourly rainfall data collected from 17 gages over a period of five years were used to develop a correlation function for rainfall, with an exponential model for the correlation function being selected over a spherical and Gaussian model. A regional, index-storm approach based on L-moments was applied to estimate short duration (less than or equal 24 h) design rainfalls in South Africa (Smithers and Schulze 2001). The regionalization was performed using only site characteristics (latitude, longitude, altitude, concentration of precipitation, mean annual precipitation (MAP), rainfall seasonality and distance from sea). The index storm used was the mean of the annual maximum series and a relationship was derived between the index storm and MAP.

Rainfall simulation experiments were carried out on more than 40 1-m^2 plots to measure infiltration point-processes (Perrin et al., 2001b). The high density of measurement devices allowed identification of the origin and nature of the various contributions to runoff for the different physiographic units of the watershed: urban area, farmland, pasture, forested land, and paramo. Variations in the runoff coefficients were related first to the baseflow and second to the amount of rainfall in the previous 24 h. In the paper by Morin et al. (2001), high-resolution meteorological radar data are used for the determination of a characteristic temporal scale for the hydrological response of the basin – the 'response time scale' (T-s*). The identification of the response time scale was carried out by analysis of observations only and without assuming a specific rainfall-runoff model. For all analyzed basins a stable response time scale was identified with relatively short time scales found for the urban and arid basins (15-30 min) and longer time scales for the rural basins (90-180 min). Habib and Krajewski (2001) reported on the application of a computational fluid dynamics-based method to improve the aerodynamic design of rainfall measurement devices, including a two-dimensional video disdrometer that provides information about raindrop size distribution. The distorted wind field around and inside the instrument's body was simulated using a three-dimensional numerical model. Raindrop trajectories were simulated to investigate the wind effect on the catchment efficiency of the instrument.

The study by Kurz and Qualls (2001) evaluated the EPA's PCS (Permit Compliance Study) database and determined the various parameters that may be useful in developing I/I control and sewer rehabilitation strategies on a state and regional level. The study summarized DMRs (monthly NPDES Discharge Monitoring Reports) for 1999 from 790 systems in Region 4 categorized as "major." Maheepala et al. (2001) described the issues that need to be considered when conducting a successful and cost-effective hydrologic data monitoring program. It was found that that tipping bucket resolutions up to 0.5 mm would give reasonably accurate results in urban stormwater modeling, and two-minute data logging intervals were suitable for flow data monitoring. The results also suggested that combining low cost simple flow measurements and limited high cost sophisticated measurements could reduce the data acquisition cost without compromising the accuracy of flow hydrographs measured in stormwater conduits. Remote sensing was used as a source of data to address the spatial variability of hydrologic processes such as storm runoff (Melesse et al., 2001). Remote sensing provided quantitative land cover information of suitable spatial resolution for model inputs. The study area was the S-65A sub-basin of the Kissimmee River basin in south Florida, and results showed that the temporal and spatial variability of runoff volume resulting from changes in land cover could be determined from Landsat images.

The WERF research described by Schultz et al. (2001b) will assist municipal agencies to quantify and simulate rainfall-derived infiltration and inflow (RDII) that affects their sewer systems. Eight major categories of RDII analysis methods were tested in several diverse sewersheds and metrics suitable for objective comparison of the RDII analyses were identified. An accurate dye dilution testing protocol using Rhodamine WT was used to quantify flow meter accuracy in the Greater Detroit Regional Sewer System (Stonehouse et al., 2001). The seven technologies assessed were electromagnetic induction meters (magmeters); full-conduit, multiple-path, transit-time meters; full-conduit, open-channel, ultrasonic meters; flumes; and weirs. It was concluded that (i) there were observable accuracy differences between flow meter technologies, (ii) objective standards like dye dilution testing were critical, (iii) verifying installed accuracy was important, and (iv) the simplest technology that can be used often was the best. Swarner et al. (2001b) reported on the effort by King County determine the wet weather performance and geographic distribution of I/I through its entire service area; conduct several pilot rehabilitation projects to evaluation rehabilitation effectiveness; develop and calibrate an accurate hydraulic model of the system; and implement a Regional I/I Control Program. The paper discussed the political and administrative actions to achieve consensus among the local agencies and analyzed the I/I results as a function of basin size.

Toxicity Testing

Bdour et al. (2001) examined the relationships between Index of Fish Density (IFD) and man-made disturbances, watershed parameters, habitat parameters, water quality parameter, and climate parameters for the 61 HUCs (Hydrological Unit Code) for the South Fork Clearwater River basin in Idaho and 15-20 reaches for Red River and Newsome Creek within the South Fork Clearwater River Basin. The results showed that incorporating both fine and coarse scale parameters in any assessment model will improve the correlations. Biomonitoring using juvenile giant clams (*Tridacna maxima*) was conducted in conjunction with sediment and stormwater sampling at U.S. Army Kwajalein Atoll. Elevated levels of metals, PAHs, pesticides, and PCBs were detected in clams from the sampling locations. Trends in clam tissue, sediment and stormwater data suggested that both sediment and stormwater are significant sources of the pollutants detected in clams.

Testing for Chemical Pollution and Pollution Tracers

Automated samplers were used to collect urban runoff in Pecan Creek, Denton, Texas (Appel and Hudak 2001). The results showed that concentrations of some heavy metals (cadmium and arsenic), as well as pesticides (atrazine and diazinon), were within ranges typical for urban runoff and first flush samples were more concentrated than composite samples for most of the constituents. Automated samplers were seen to be an effective way to sample urban runoff in Pecan Creek. Ruban et al. (2001) studied the SS and COD concentrations in combined sewers using in-line ultraviolet and visible absorbances. The optical measurement of SS and COD could then be used to determine average or long term pollution loads, for example the yearly impact of urban stormwater discharges. Continuous and on-line measurements would allow agencies to react with short delay to unexpected phenomena. A portable, field rugged, sampling and analysis system was developed for the rapid screening of aqueous samples during scoping and remediation studies (Beals et al., 2001). The equipment uses ion selective solid phase extraction (SPE) disks and counted for the radionuclide of interest in the field using portable detectors. The Savannah River Site H-area tank farm storm water runoff system was analyzed for Sr-90 and Cs-137.

The investigation by Moustafa and Havens (2001) determined the effect of sampling frequency and sampling type on estimates of monthly nutrient loads and flow-weighted nutrient concentrations in a constructed wetland. The results showed that bi-weekly composite sampling could be used to monitor nutrient concentrations and loads discharged from larger-scale Everglades Stormwater Treatment Areas (STAs) now under construction. Compounds including coprostanol, epicoprostanol, cholesterol and dihydrocholesterol were quantified in CSO waters and their relative ratios calculated to investigate their potential application as source tracers (Marvin et al., 2001). A mean coprostanol:epicoprostanol ratio of approximately 70 was calculated for CSOs. When combined with physical measurements (e.g., current velocities) and meteorological data, these ratios may assist in determining the influence of shore-based activities, including sewage treatment and livestock operations, on aquatic systems. Indicators for assessing pathogen contamination and for distinguishing human origin and animal origin were investigated (Sankararamakrishnan and Guo (2001) with samples being taken from storm sewer outfalls to a coastal lake during wet weather as well as from the lake during the dry weather. The FC-to-FS ratio indicated the contribution of both human and animal wastes, with the presence of human wastes confirmed by increased concentrations of caffeine, fluorescence whitening agent, fluoride and anionic surfactant during wet weather.

Biological and Microbiological Testing

Elevated bacteria levels indicated significant impairment to surface water quality in many urban areas within the Great Lakes watershed (Murray et al., 2001a). CSO outfalls were assumed to be the major source of bacteria to streams in many of these urban areas, including the Rouge River of southeastern Michigan. The data depicted a strong influence of upstream water and rural runoff on the water quality of the Rouge River, and FC to FS ratios suggested the primary source of bacteria throughout the watershed was from domesticated animals and wildlife and not from CSOs. Sources of the indicator bacteria total coliform, fecal coliform, and enterococcus were investigated in stormwater flows discharging to Mission Bay in San Diego, California (Schiff and Kinney 2001). Stormwater flows were targeted because long-term monitoring had indicated that wet weather discharges were the predominant source of bacterial contamination. Upstream tracking during multiple storm events on two watersheds showed that bacterial sources were diffuse and widespread. Two case studies were used to demonstrate how WERF's ecological risk assessment methods, Aquatic Ecological Risk Assessment: A Multi-Tiered Approach, could be used to improve the ecological- and cost-effectiveness of water quality management (WERF 2001b). The two cases (Salado Creek in the City of San Antonio, Texas, and the Jordan River in Utah) were explored in detail, including direct and indirect effects of changes in flow on fish and invertebrate aquatic life.

SURFACE WATER IMPACTS

Flow Regime Impacts

Rose and Peters (2001) reported an investigation that examined streamflow characteristics that changed during the period from 1958 to 1996, in a highly urbanized watershed (Peachtree Creek) compared to less-urbanized watersheds and non-urbanized watersheds, in the vicinity of Atlanta, GA. Data were obtained from seven US Geological Survey stream gauges, 17 National Weather Service rain gauges, and five USGS monitoring wells. The fraction of the rainfall occurring as runoff in the urban watershed was not significantly greater than for the less-urbanized watersheds, but this ratio did decrease from the higher elevation and higher relief watersheds to the lower elevation and lower relief watersheds. For the 25 largest stormflows, the peak flows for the urban creek were 30% to 100% greater than the peak flows in the streams located in the less developed areas. The streamflow also decreased more rapidly after storms in the urban stream than for the other streams. The low flow in the urban creek was from 25 to 35% less than for the less developed streams, likely caused by decreased infiltration due to the more efficient routing of stormwater and the paving of groundwater recharge areas.

Weng (2001) describes how GIS was used in conjunction with distributed hydrological modeling. GIS was able to document the changing spatial patterns of urban growth in the Zhujiang Delta of southern China. Extensive urban growth over the past two decades has created severe problems in water resources management, indicated by an increase in annual runoff depth during the 1989-1997 period. The urbanization lowered potential maximum storage, and increased runoff.

Erosion, Channel Stability, and Sediment

An emerging concept in channel design uses sediment transport as the basis for quantifying channel stability. Byars and Kelly (2001) examined channel stability in the Austin, TX, area. They concluded that a channel that is not undergoing excessive erosion or sedimentation has a function and form similar to a natural stream and should be the goal of good channel design. This approach, however, requires a more comprehensive understanding of the local climate, geology, hydrology, and stream mechanics than historically utilized.

Hunt and Grow (2001) describe a field study conducted to determine the qualitative and quantitative impact to a stream from a poorly controlled construction site. They used fish electroshocking, Qualitative Habitat Evaluation Index, and zigzag pebble count studies. The 33 acre construction site consisted of severely eroded silt and clay loam subsoil and was located within the Turkey Creek drainage, Scioto County, OH. The number of fish species declined (26 to 19) and the number of fish found (525 to 230) decreased significantly when comparing upstream unimpacted reaches to areas below the heavily eroding site. The Index of Biotic Integrity and the Modified Index of Well-Being, common fisheries indexes for stream quality, were therefore reduced from 46 to 32 and 8.3 to 6.3, respectively. Upstream of the area of impact, Turkey Creek had the highest water quality designation available (Exceptional Warm Water Habitat); but fell to the 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.

Biological Impacts

Horwitz et al. (2001) examined the different fish communities in paired reaches of streams having forested vs. unforested riparian zones. The streams traversed land uses ranging from rural to highly urban. Their preliminary results found that the type of buffer had little effect on the fish communities in the rural reaches. However, the fish community patterns were much more variable in the urban reaches, being affected by the effects of urbanization on channel morphology, habitat, hydrology, and water quality. Sonneman et al. (2001) studied the effects of urbanization on the benthic diatom communities in streams near Melbourne, Australia. The subcatchments had imperviousness levels ranging from 0 to 51%. They found that the differences observed were best explained by variations in nutrient concentrations (phosphorus, ammonia, and total nitrogen). The level of urbanization, along with the presence of small sewage treatment plants at a few sites, influenced the nutrient concentrations found. They observed that diatoms were better indicators of nutrient enrichment, while macroinvertebrates were better indicators of catchment disturbance. Walsh et al. (2001) reported the effects of macroinvertebrates at the same Melbourne area locations as reported by Sonnenman et al.,(2001). Responses were more obvious in the eastern areas (having a wide range of development) and were associated with conductivity, while the western areas (having little development) had little observed variations. The metropolitan areas were all severely degraded, having high abundances of a few tolerant taxa. Extensive development of urban drainage systems, even in areas having low urban densities, increased the observed degradation.

Fifty et al. (2001) investigated the impact of wastewater and stormwater discharges on the coastal receiving waters on a coral atoll in the middle of the Pacific Ocean (Kwajalein Atoll), a pristine marine environment. They used *Tridacna maxima*, a giant clam species, as an indicator organism. Juvenile clams were deployed for a 3-month period in the vicinity of pollutant sources and reference sites, and then analyzed for metals, PAHs, pesticides, and PCBs. The clams were a successful bioindicator, with tissue samples from sites near pollutant sources (contaminated sediment and stormwater) containing higher concentrations of chemicals than at the reference sites.

Grant et al. (2001) reported frequent elevated levels of enterococci bacteria in the surf zone at Huntington Beach in southern California. They studied the sources of these indicators and found high levels in urban runoff, bird feces, marsh sediments, and on marine vegetation. They concluded that urban runoff had relatively little impact on these elevated surf zone bacteria levels because of the long travel time needed for the urban runoff to travel from the source areas to the ocean. They found that marsh sources were more likely responsible for the high surf zone bacteria levels. Jiang et al. (2001) used a nested-PCR analytical method to detect viruses in coastal waters at 12 beach locations in Southern California. The sampling locations were all impacted by urban runoff sources. The sampling locations were all located at the mouths of major rivers and creeks. Human adenoviruses were detected in 4 of the 12 samples (880 to 7,500 per L), coliphages were found in all 12 samples (5.3 to 3330 PFU/L), and F-specific coliphages were found in 5 of the 12 samples (5.5 to 300 PFU/L). The bacterial indicator levels (total coliforms, fecal coliforms, and enterococci) all exceeded the California recreational water quality limits, but the bacteria levels found did not correlate well with the observed human adenovirus levels. They concluded that the standards that rely on bacteria observations to indicate viral quality of recreational waters be re-evaluated, and that more routine monitoring of human viruses be conducted on a regular basis.

Mahin (2001) reviewed recently completed epidemiological studies conducted after the publication of the 1986 EPA bacteria guidance. The Massachusetts Dept. of Environmental Protection were concerned about the risk level that is 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.

Chemical Impacts

Diamond et al. (2001) found that the effects of toxicants depended on a combination of both chemical and flow characteristics. Conventional laboratory testing of toxicants with constant exposure concentrations are not very applicable to wet weather flow conditions. They surveyed more than 30 toxicological investigations that have used time-dose or pulsed/intermittent exposure, 15 contaminants, and 10 different species. They concluded that it is possible to predict the chronic effects of fluctuating exposures of fast-acting contaminants (such as ammonia or sodium chloride) using available acute toxicological models. Wong et al. (2001) developed a monitoring method using the green alga *Selenastrum capricornutum* to predict levels of heavy metals in water. When exposed to stormwater samples, the specific activity of the peroxidase in the cell extract was directly related to the copper and lead concentrations. The peroxidase responses were also correlated with the 96 hr biomass toxicity assay of *S. capricornutum*. They concluded that the use of this peroxidase can be used as a marker for testing heavy metal toxicity in the water.

Habitat Management and Restoration

The purpose of the EPA-funded Arid West Water Quality Research Project is to conduct scientific research to develop appropriate water quality criteria and improve the scientific basis for regulating wastewater and stormwater discharges in the arid and semi-arid West. Meyerhoff et al. (2001) described a study where historical and site reconnaissance level data were gathered on ten effluent dependent waters. They found that while the aquatic community may be limited, significant benefits occurred in the terrestrial communities that developed in response to the created aquatic environment. Based on the concerns raised during this research, the EPA's Region IX published a "net ecological benefit" guidance document that provided an opportunity to recognize the non-aquatic benefits gained from effluent discharged to otherwise dry riverbeds.

Environmental Effects of CSO and SSO

Borchardt and Reichert (2001) describe their study of the River Lahn, a moderately polluted 5th order stream in Germany for which the connectivity of surface/subsurface flows and mass fluxes within river sediments have been intensively investigated. The hyporheic flow between a downwelling and upwelling zone of a riffle-pool reach of the river was studied using tracers and continuous records of water chemical characteristics. High diurnal fluctuations of oxygen 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.

Risk Assessment

Bosley et al. (2001) described a study on the Upper Roanoke River Watershed (URRW) in southwest Virginia, using HSPF to evaluate the hydrologic impacts of land use change. Continuous simulations were conducted to investigate the hydrologic effects of various spatial arrangements of development in residential areas, with and without networks of primary and secondary roads. Beckers and Frind (2001) used a steady-state stormwater model of the Oro Moraine aquifer in Ontario to examine long-term temporal variations in the flow regime associated with changes in aquifer recharge. They found that nearby urban development would have a significant impact on the baseflow to the swamp, in addition to baseflow impacts to nearby local streams. The model also is being used as a guide to future data collection in the area.

GROUNDWATER IMPACTS

Planned Groundwater Recharge

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 recovery (ASR) wells (Dillon et al., 2001). In this study, the Membrane Filtration Index (MFI), a standard test of the rate at which water clogs a membrane filter, has been used with turbid and organic-rich waters. Waters from 12 sites (mains, urban stormwater and reclaimed water) which are or have the potential to be water sources for aquifer storage and recovery (ASR) in southern Australia, were analyzed for MFI, turbidity, total suspended solids, total organic carbon, particle size and SEM. Little more than half the variance in MFI could be explained with the measured water quality parameters, likely due to the complex nature of the inorganic and organic particles present in the waters. The ongoing field study has been designed to determine if MFI can be related to well clogging at one of the focus sites.

DECISION-SUPPORT SYSTEMS

Numerical Models

Rainfall analyses. Aerial variations in rainfall were investigated by Balascio (2001), using unbiased multiquadric analyses to reduce the problem of negative rain gauge weighting when determining the representative rain depth for an area. Willems (2001) developed a stochastic spatial rainfall generator for use in small urban catchments. For applications at small scales, the 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 that the normalized rainfall rates of different storm durations are identically distributed. They proposed a nonstationary Gauss-Markov model, based on the annual maximum events that arise from the dominant storm type to obtain the most likely hyetograph. This method allows translating hyetographs between storms of different durations. Koutsoyiannis and Onof (2001) developed a rainfall disaggregation method using adjusting procedures on a Poisson cluster model. This method allows the possible extension of a short hourly time-series with the use of longer-term daily rain data.

Rainfall – runoff modeling parameter estimation. Bates and Campbell (2001) and Campbell and Bates (2001) used a Markov chain Monte Carlo procedure to select rainfall – runoff model parameters. Regionalization of the model parameters was accomplished for all parameters simultaneously via a regional function that links the posterior means to watershed characteristics. They demonstrated the methodology using an eight-parameter conceptual rainfall-runoff model and two case studies from southeastern Australia. Perrin et al. (2001a) questioned whether the use of large numbers of modeling parameters improve model performance. They conducted an extensive comparative assessment using 19 lumped models on 429 catchments, mostly in France, and with some located in the United States, Australia, the Ivory Coast, and Brazil. They found that the bulk treatment of the data showed that the complex models outperformed the simple models in the calibration mode, but not in the verification mode. They concluded that some simple models can yield promising results, although they are not able to handle all types of problems. Kokkonen and Jakeman (2001) also found that a model with less conceptualization could provide a more accurate reproduction of streamflow for some situations. They conclude that the more complexity one wants to include in the model structure, the more types of data and higher information content are required. When only rainfall-runoff data are available, it is difficult to justify substantial conceptualization of complex processes. Wagener et al. (2001) state that many existing hydrological models do not make the best use of available information, resulting in additional uncertainties in model structure and parameters, and a lack of detailed information regarding model behavior. They propose a framework for appropriate levels of model complexity as a function of available data, hydrological system characteristics, and modeling purpose.

Liong et al. (2001) utilized a Pareto front, or trade-off curve, to obtain the best overall calibration for different conditions. Ndiritu and Daniell (2001) used an improved genetic algorithm for rainfall-runoff model calibration. Zaghloul and Kiefa (2001) employed neural network procedures for the calibration of the Transport block in SWMM.

Real-time streamflow predictions. Several papers examined real-time predictions of stream flows. Chang and Chen (2001) employed neural network and fuzzy arithmetic tools to enhance predictions for the Da-cha River, in central Taiwan. They (Chen et al., 2001b) also used the method to predict floods one hour in the future for the Chingshui River during tropical storms using the new models. Khu et al. (2001) and Soon et al. (2001) employed genetic programming to improve real time forecasting for the Orgeval catchment in France. They successfully improved the forecasting for future periods up to the time of concentration of the watershed. Their comparisons showed that genetic programming was a better updating tool for real-time flow forecasting than previous methods. Xiong et al. (2001) combined the simulation results from different models to improve real-time forecasts.

Rainfall-runoff models and new programming tools. Whigham and Crapper (2001) provided the following definition: “Genetic programming is an inductive form of machine learning that evolves a computer program to perform a task defined by a set of presented (training) examples and has been successfully applied to problems that are complex, nonlinear and where the size, shape, and overall form of the solution are not explicitly known in advance.” Genetic programming of rainfall-runoff model has also been used by Muttill and Liong (2001). Mathematical methods using linguistic variables (such as the application of fuzzy rule-based modeling), rather than conventional numerical variables, are starting to be used for hydrological studies (Hundecha et al., 2001). Ozelkan and Duckstein (2001) also recently applied fuzzy logic to rainfall-runoff modeling.

Water quality modeling and pollutant transport. Sanders et al. (2001) developed a hydraulic model to examine the tidal transport of stormwater bacteria near the southern California network of flood control channels that drain to near-shore bathing waters. Yuan and Oldham (2001) prepared a model describing the accumulation and washoff of urban area particulates, specifically examining metal binding. They monitored 47 rain events with short time intervals and obtained good agreement for predicting lead transport. Zoppou (2001) compared several different stormwater models, including statistical, empirical, hydraulic and hydrological model types.

Watershed model water balance. Jia et al. (2001) developed a distributed hydrological model, the Water and Energy Transfer Processes Model (WEP), to simulate spatially variable water and energy processes in watersheds having complex land covers. Variables include depression storage on land surfaces and canopies, soil moisture content, land surface temperature, groundwater tables, and water stages in rivers. Infiltration excess during heavy rains is simulated using a generalized Green-Ampt model, while flow routing is simulated using a one-dimensional kinematic wave method. The model was applied to the Ebi River watershed (27 km2) with a grid size of 50 m and a time step of 1 h. The model was verified through comparisons of simulated river discharges, groundwater levels, and land surface temperatures with the observed values. A comparison between the water balances at the present time and in the future was also conducted. It was found that the hydrological cycle in the future can be improved through the use of stormwater infiltration. Santini et al. (2001) modeled the Detroit Water & Sewerage Department collection system to identify flow sources. They also modeled the time needed to return to base flow conditions after wet weather events.

Model Applications

Rainfall. NEXRAD (WSR-88D) radars have made spatially distributed rainfall data available in an operational environment (Carpenter et al., 2001). The present study addressed the use of NEXRAD data using a Monte-Carlo sensitivity analysis of event streamflow to parameter and radar input for the Illinois River basin in Oklahoma and Arkansas. The main conclusions was that the distributed model forced by NEXRAD data produces results comparable to those produced by the operational spatially-lumped models using raingage data. Detection of rain/no-rain condition on the ground is needed to apply radar rainfall algorithms to hydrological models (Lui et al., 2001d). A radial basis function (RBF) neural network-based scheme for rain/no-rain determination on the ground using vertical profiles of radar data was described in this paper. Evaluation based on WSR-88D radar over central Florida indicates that rain/no-rain condition could be inferred fairly accurately. Lui et al. (2001e) presented a novel scheme for adaptively updating the structure and parameters of the neural network for rainfall estimation. The network can account for any variability in the relationship between radar measurements and precipitation estimation and also incorporate new information to the network without retraining the complete network from the beginning.. To make the monthly satellite data useful for hydrological applications (i.e. water balance studies, rainfall-runoff modeling, etc.), the monthly precipitation estimates must be disaggregated into shorter time intervals (Margulis and Entekhabi 2001). In this study, two simple statistical disaggregation schemes were developed for use with monthly precipitation estimates from satellites. Results suggested that one of the proposed disaggregation schemes could be used in hydrological applications without introducing significant error.

Rainfall data collected since the publication of NWS' Technical Paper 40 and HYDRO-35, and NOAA's Atlas 2, and the development of improved statistical methods, motivated several states to initiate update studies of precipitation distributions (Durrans and Brown 2001). Results of the Alabama study were disseminated via an Internet-based graphical user interface, which permits users to interactively point and click on a location of interest and have IDF curves or storm hyetographs returned on demand. The study by Kim and Barros (2001) modified the existing ANN model to include the evolving structure and frequency of intense weather systems in the mid-Atlantic region of the US for improved flood forecasting. Besides using radiosonde and rainfall data, the model also used the satellite-derived characteristics of storm systems such as tropical cyclones, mesoscale convective complex systems, and convective cloud clusters as input. The results from the application of the quantitative flood forecasting model in four watersheds on the leeward side of the Appalachian mountains in the mid-Atlantic region were presented.

Rainfall-runoff hydrological response. ANN methodology was applied to solve various problems concerned with hydrology and water resources engineering and planning, in particular the prediction of the index flood for several ungaged catchments in the UK (Dastorani and Wright 2001). A network with 7 inputs provided the best results. The Multi-Layer Perceptron network with three layers, Tanh function for hidden layer, and the Sigmoid function for output layer were the most accurate. The review by Dawson and Wilby (2001) considered the application of ANNs to rainfall-runoff modeling and flood forecasting, including the related themes of the division and preprocessing of data for model calibration/validation; data standardization techniques; and methods of evaluating ANN model performance. A template was proposed to assist the construction of future ANN rainfall-runoff models. ANNs was shown to be an efficient way to model the runoff process where explicit knowledge of the internal hydrology is not required (Ahmad and Simonovic 2001). ANN was used for the Red River in Manitoba, Canada to predict the peak flow, timing and shape of runoff hydrograph, based on the antecedent precipitation index, melt index, winter precipitation, spring precipitation, and timing. The percent error in simulated and observed peak flow and time of peak was 6 and 3.6 %, respectively.

A rainfall-runoff model was developed based on water balance equations (Abulohom et al., 2001). The model inputs were precipitation and potential evapotranspiration (both on monthly basis) and the output was the simulated runoff at the watershed outlet. The model was calibrated and tested for four watersheds, with a correlation coefficient between the simulated and measured data ranging between 77% and 93%. Croke and Jakeman (2001) assessed the model types available to improve the prediction of catchment flows and transport in Australia where the flows are typically peakier, base flows are of lower proportion, runoff coefficients are smaller, and dry periods are longer and more variable, than in European and North American catchments. Improvement of predictions relied on the following: more rigorous testing of models; the use of improved interpretation of spatial data; more and better monitoring of hydrological response; complementary use of conceptual and distributed models; and integration of modeling with other information.

The Garg and Sen (2001) study presented a physically based hydrologic model using derived watershed features to simulate rainfall-runoff response of a catchment. The finite-element concept was used to obtain the time-invariant weighting coefficients for estimating the rainfall on the cascade planes. Overland flow was simulated using a kinematic wave model. The fundamental premise of the AFDC approach is that maintenance of a stream's ecological integrity depends upon maintaining an appropriate flow regime (magnitude and frequency) (Good and Jacobs 2001). The AFDC provided a graphical tool to illustrate the quantity and frequency of streamflow available in a river basin and facilitated the simulation of the modified streamflow regime based on historic time series data. The AFDC methodology was illustrated in the lower Suwannee River basin in Florida. The Long-Term Hydrologic Impact Assessment (LTHIA) model run on a GIS is a relatively simple model that uses the Curve Number method to estimate changes in surface runoff between different stages of development (Grove et al., 2001). Application to a large, rapidly urbanizing watershed near Indianapolis, Indiana suggested that average annual runoff depths increased by more than 60% from 1973 to 1991. A sensitivity analysis showed that a precipitation record length of 15 years or more was required to produce consistent results with LTHIA.

Chen and Cai (2001) used the Kinematic Wave method to model the rainfall-runoff process in an idealized drainage basin. The simulation results showed that for basins with moderate to high rates of infiltration losses, the critical rainfall duration associated with the maximum peak discharge may be shorter than the time of concentration (t_c) for the basin, implying that a storm with a spatial coverage of only part of the basin may generate the maximum peak discharge. For basins with low or negligible infiltration losses, the critical rainfall duration approaches t_c. The geomorphological instantaneous unit hydrograph (GIUH) was used to relate the shape and scale of the catchment transfer function to stream network topology and channel characteristics (Hall et al., 2001c). GIUH derivation depended on a series of assumptions, including the estimation of a “characteristic velocity.” If this velocity is expressed in terms of the kinematic wave approximation, the peak and time-to-peak of the IUH may be expressed by a group of catchment and channel characteristics and by the intensity of rainfall excess. The study by Guo (2001a) expanded the rational method into the rational hydrograph method in which the time of concentration is considered the system memory and the contributing rainfall depth to the present runoff rate is defined as the accumulated precipitation over the past up to the time of concentration. Using this method, the complete runoff hydrograph could be generated under a continuous nonuniform hyetograph. A new formula for estimating the time of concentration was derived from 25 rainfall/runoff events in four urban watersheds and was confirmed in watersheds in Maryland and Colorado.

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 to the antecedent series length) was proposed. Initial results showed the proposed index outperformed single curve number-based results, even when the curve number is fit to historic rainfall-runoff records.

Kroll et al. (2001) tested whether the inclusion of new watershed characteristics improved the prediction of extreme hydrologic events, in particular, low streamflow prediction. Preliminary results indicated that regional regression models of low streamflow quantiles, which traditionally have very high model errors, might be improved in some regions by including topographic, climatic, and hydrogeologic statistics. Lee et al. (2001a) developed a stochastic differential equation (SDE) for a lumped rainfall-runoff model and applied it to a watershed that consisted of a number of subwatersheds in series in Taiwan. The development of the moment equations of simulated outflow was based on a SDE. The outflow hydrograph was obtained by applying the Laplace transform method to the equations that describe rainfall excess. A second paper by Lee et al. (2001b) presented a geomorphic and hydrologic information system for calculating the discharge in small and midsize ungaged watersheds. A compound module, based on a digital elevation model, frequency analysis theory, kinematic-wave approximations, and geomorphic-based runoff modeling, provided enough information for calculating the design discharge for different return periods. The stochastic-conceptual rainfall-runoff simulator (SCRRS) developed by Freeze in 1980 was used to demonstrate quantitatively the interplay of the factors that control overland flow by the Horton and Dunne mechanisms (Loague and Abrams 2001). The simulation domain and input data were abstracted from the R-5 catchment (Chickasha, OK) data sets. The SCRRS simulations showed that the Horton and Dunne processes can (i) occur simultaneously at different locations during a given rainfall event, (ii) change from one process to the other with time depending on the characteristics of the rainfall event, and (iii) be strongly dependent on the initial conditions.

Corrêa et al. (2001) presented the outcome of recent work for the cities of Springfield and Columbia, Missouri using high spatial resolution satellite data to enhance or effectively replace conventional data sources for mapping impervious and bare ground surfaces, and for determining runoff curve numbers

(CNs) required by hydrologic and environmental computer models. The estimated accuracy of high-spatial resolution imagery was approximately 80%. Spatial data of primary importance to hydrologic modeling include Digital Elevation Models (DEM) for topography, imagery such as Digital Raster Graphics (DRG), hydrologic soil type, and land use for infiltration losses (Hartman and Nelson 2001). Other supporting data types may include Triangulated Irregular Networks (TIN), hydrography, precipitation, and stream stage. The GSDA website offered detailed explanations, tips, and direct links to hydrologic data sources. A case study modeling the Lost Creek watershed in Northeastern Utah provided an overview of the data acquisition process, and can also be found at the GSDA website. Land use changes over a 30 year period (1961-1990) were incorporated into a continuous simulation rainfall runoff model to investigate the effect of these changes on flood frequency in the Thames catchment at Kingston (Crooks and Davies 2001). Broad scale changes in land use over the last 120 years in the Thames catchment were determined from a variety of sources.

PCSWMM was used to calibrate the kernel function in the central rain-runoff algorithm in SWMM and to generate plots that were compared to the experimental results obtained from a laboratory rig whose impervious pavement had a 0.025 m/m/ slope over an area of 2.11 m^2 (James 2001). Results indicated that the RUNOFF algorithm produces reasonable results, even when supercritical laminar flow cases were included in the validation tests. Andreassian et al. (2001) proposed a new approach to sensitivity analysis for watershed models through a comparison between the efficiency ratings and parameter values of the models and the quality of rainfall input estimate (GORE and BALANCE indices). Although the watershed size was generally immaterial, smaller watersheds appeared to need more precise areal rainfall estimates to ensure good modeling results.

Rainfall-runoff floods. Engineering practice and works design requires the calculation of the "design flood" (Paoli et al., 2001). When there are no available records for the flood frequency analysis, different formulations, semi-empirical methods and hydrological simulation models have been used with the design storm then transformed into a maximum flow. This research concluded that the procedure to determine the design flood from frequency analysis of flow peaks (obtained of the transformation P-Q) provided better results that the one that transformed the storm design. Three indirect techniques for index flood estimation were analyzed in order to evaluate their applicability and effectiveness (Brath et al., 2001). The results showed that the statistical model had a better descriptive ability than the physically-based models. The results highlighted that 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 accurately model the nonlinear rainfall-runoff processes for increasing rainfall intensities with respect to peak flow, basin lag, and time to peak flow. Iturbe et al. (2001) used the spatial structure of storms to enhance flood estimation using a rainfall runoff process. The results suggested that interpolation was insensitive to the variogram selection. The applications of the estimation error (and of the method in general) were discussed.

CSO models. Modeling tools such as SWMM typically have been used to model I/I with sanitary collection systems (Czachorski and Van Pelt 2001). The hydrograph theory used by these models explicitly assumes that the system can be accurately modeled by linear dynamics; however, in general, this assumption is inaccurate. Nonlinear dynamics result from complex flow patterns and other transport mechanisms, but typically the dominant nonlinearity can be attributed to antecedent moisture effects. SWMM was used by Onondoga County, New York to simulate the hydrologic and hydraulic elements of its combined sewer system and to project the effects of a range of abatement alternatives (Davis et al., 2001c). The models successfully identified the maximum conveyance capacity of the collection system and showed that, following abatement, 85% of the combined sewage would be captured for primary treatment at the WWTP. To assist with hydraulic analysis for a Portland, Oregon project to reduce the potential for basement flooding, a detailed SWMM model of the basin using a suite of GIS and database tools was developed. The detailed GIS approach with virtual raingages produced model results that correlated very well with flow monitoring data. The detailed SWMM model identified the location of much of the system capacity problems. The City of Winnipeg initiated a basement flood relief program in the mid-1960s to provide a minimum five-year level of protection to the residents (Steiss and Watters 2001). Since 1977, this program has been modeled with SWMM, and to date, sewer relief works have been implemented in 21 of the City's combined sewer districts. The public notification method developed for the City of Detroit uses a continuous SWMM model for determining the occurrence and time of overflow and was approved as an interim reporting method until an instrumentation project currently under way is completed (Brink et al., 2001).

James and Young (2001b and c) developed new code for radial gates that was integrated into the Extended Transport (EXTRAN) module of SWMM. The new program, called RGEXTRAN, was capable of handling unsteady flow conditions occurring in real sewer systems with radial and regular sluice gates. The program also provided for dynamic control of the radial gates (or other gate types) based on flow conditions at remote locations in the sewer system. James and Young (2001a) demonstrated that RGEXTRAN could be used to optimize a combined sewer system operation by fully utilizing all available storage and conveyance capacity in the existing facilities. The program was applied to the combined sewer system in Vancouver, British Columbia, and verification tests demonstrated that the new program accurately represents the operation and hydraulics of the dynamic radial gates and siphon-weirs found in the system. Due to the complex number of available pathways that RDII may enter a sanitary sewer, rainfall dependent infiltration and inflow (RDII) has been one of the most difficult components of the urban wet-weather water budget to estimate (Wright et al., 2001). Various tools have been applied to estimating this special hydrologic response, including the rational method and several unit-estimation methods. The paper highlighted results from a relatively new physically based conceptual method first introduced by Kadota and Djebbar in 1998, a modification to the SWMM RUNOFF module that includes the response of a conceptual non-linear reservoir to changes in groundwater elevations resulting from permeable-area infiltration.

MOUSE, an Arcview-GIS based dynamic model, was selected to analyze the performance of the combined sewer overflow (CSO) system operated by the City of New Haven (Connecticut) and the New Haven Water Pollution Control Authority for 3-month, 6-month, 1-year and 2-year design storms (Cheung et al., 2001). In addition, an average rainfall year was simulated to determine the performance of the system under typical rainfall conditions. The short-term control plan identified minor adjustments to overflow weirs and orifices, and to pump rates, while a long-term control plan included major capital works such as storage tanks or pump station and trunk sewer replacement. Long term numerical modeling was used to verify design parameters for the new King County 7-million-gallon CSO storage and conveyance tunnel, including gate- and pump-operation rule sets for operating the storage systems (Crawford and Swarner 2001). Additional modeling was performed to determine operation strategies for extreme events such as combinations of large 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 impacts on DO in the Rouge River from CSO-treatment basins were evaluated using basin effluent monitoring, river monitoring and dynamic water quality modeling (Kluitenberg et al., 2001). Using a consensus-based approach, work groups including State personnel, CSO community representatives and consultants concluded that the demonstration basins could eliminate raw sewage, protect public health and achieve water quality standards, including the DO standard.

Reeves and Lewy (2001) discussed the representation of long term, highly attenuated runoff in collection systems, focusing on rainfall dependent groundwater infiltration. Contributions to urban drainage systems by stream ingress or from large permeable areas do not fall easily into either the runoff or baseflow categories. In addition, the increasing prevalence of Sustainable Urban Development (SUD) structures is promoting a need to represent highly attenuated groundwater contribution. The paper by Miralles et al. (2001) described the methodology that was used to evaluate wet weather flows within the sanitary sewer system in Luquillo, Puerto Rico. The methodology, based on a unit hydrograph model to predict (RDI/I), was calibrated by comparing predicted wet weather flows to those observed in the five flowmeter locations.

For municipalities to cost-effectively plan, organize, and implement infrastructure improvements, they require improved information on structural conditions, decision-making tools, operation and maintenance practices, and techniques for repair and rehabilitation (Tafuri et al., 2001). The paper reviewed European approaches for diagnosing and analyzing water and wastewater systems, and in particular the use of performance indicators and non-hydraulic models for predicting failures in these systems.

Pollutant sources and transport. Burian et al. (2001b) investigated the suitability of integrating deterministic models to estimate the relative contributions of atmospheric dry and wet deposition by stormwater runoff. The CIT airshed model and the SWMM were linked to simulate the fate and transport of nitrogen species through the atmosphere and storm drainage system in Los Angeles, California, USA. Coupling CIT and SWMM involved defining and resolving five critical issues: (1) reconciling the different modeling domain sizes, (2) accounting for dry deposition due to plant uptake, (3) estimating the fraction of deposited contaminant available for washoff, (4) defining wet deposition inputs to SWMM, and (5) parameterizing the SWMM washoff algorithm.

A mass-balance model for calculation of annual metal loads to lakes dominated by diffuse inflow and urban runoff was presented by Lindstrom and Hakanson (2001). In the lake, the variations in runoff concentrations were smoothed, making it possible to get a more stable flow assessment. The model accounted for inflow, outflow and sediment interactions (sediment resuspension is modeled using new approaches) with the most important factors in the uncertainty of model predictions being the settling velocity of particulate matter, the percentage of accumulation areas for fine particles, and the dissolved fraction of the total metal concentration. High correlations between metal accumulation and phosphorous and nitrogen concentrations indicated that the autochthonous lake production was crucial. The sources, distribution and fate of fecal coliform populations in the North Fork of the New River in Fort Lauderdale, Florida were investigated by Scarlatos (2001). In order to facilitate field sampling, computer simulations using WASP were applied to assess the likelihood of the various possible pollution scenarios. WASP accurately simulated the water hydrodynamics and coliform concentrations within the North Fork, while the neural network identified correlations between fecal coliform and the other parameters.

Swanson and Ward (2001) presented a series of applications of WQMAP, an integrated model of the circulation and pollutant transport in estuarine and coastal waters, to Narragansett Bay. Applications included circulation and temperature distributions in Mt. Hope Bay; consideration of the effects of a once-through cooling water discharge from a fossil fueled power plant; circulation in the Providence River and Upper Narragansett Bay; fecal coliform transport from combined sewer overflow (CSO) loads; and a eutrophication study of the Providence River.

BMP performance. Stormwater management systems for new urban development were traditionally analyzed using computer models employing design storm events, rather than continuous modeling using long term historical rainfall data and associated frequency analyses (Farrell et al., 2001). The differences in the results (i.e., designs) generated by the two methods have not typically been understood during the planning and design process. The different flow and storage regimes in the Town of Milton (Sixteen Mile Creek Watershed) generated by the alternate methods have been highlighted, along with a number of modeling and physical factors which are considered to contribute to the differing results. The Clinton River Watershed Council selected the Source Loading and Management Model (SLAMM) as the main instrument in its watershed plan development (Myllyoja et al., 2001). SLAMM accurately computed runoff pollutant loads and flows associated with small storm events, which was critical because most of the pollutant load was associated with the smaller, 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 distribution and enables comparison of the different components of urban water demand. Aquacycle was tested using data from the Woden Valley urban catchment in Canberra. Australia and could satisfactorily replicate its water supply, stormwater and wastewater flows.

Watershed Management and TMDLs

EPA's Technical Support Document for Toxics (1991) provided recommendations on evaluating frequency, magnitude, and duration issues, including the use of statistical permit limit derivations and techniques for dynamic wasteload analysis (Butcher and Diamond 2001). A survey of state permitting agencies found that few of these recommendations have been put into practice. Instead, most jurisdictions continued to rely on steady-state wasteload analyses. The WERF research project (98-HHE-3) is developing an Implementation Guidance document (with software) to aid permittees in deciding whether to undertake these dynamic analyses and to aid in implementing the analyses under the existing guidance. Information technologies and watershed management approaches have enabled decision-makers to establish predictive relationships between different land-use activities and the sediment and nutrient loads discharged from the watershed (Khairy et al., 2001). These approaches then have been extended to assess the impacts of these wasteloads on the receiving aquatic systems. A case study on the simulation of Tangipahoa Watershed and Lake Ponchartrain Ecosystems was used. The Integrated Plan for the Wastewater Program (IPWP) was a public-driven effort designed to develop policies for the planning and implementation for future wastewater collection, treatment, reuse and disposal projects (Lopez-Calva 2001). The integrated systems model was developed to measure the performance of policy alternatives in relation to a set of objectives and performance measures established by stakeholders. The conceptual character of the model proved to be appropriate for this policy-planning project. Monte Carlo simulations, which account for uncertainty in model parameters, were performed for a model of a 10-km stretch of the River Cam in Cambridge in Eastern England (Duchesne et al., 2001). The simulation results were used to rank wastewater treatment plant control strategies according to their impacts on river water quality. It was found that ranking was robust even with the uncertainty in the parameter values for the control strategies.

The BASINS system was developed to provide technical tools to support EPA's regulatory water quality programs, in particular the TMDL program (Cocca 2001). BASINS 3.0 provides a range of detail in watershed models and provides databases, data management tools, documentation, and other resources to make modeling waterbodies and watersheds easier. The three watershed models in BASINS 3.0 include the complex Hydrological Simulation Program Fortran (HSPF) model, the complex Soil and Water Assessment Tool (SWAT) model; and the simple PLOAD model. Each model has an automated GIS data extraction script. The paper by Dorn et al. (2001) reviewed BASINS-STAR (BASINS STrategy, Analysis, and Reporting system), a set of tools to assist decisions-makers identify alternative management strategies. The main engine of BASINS-STAR is a genetic algorithm-based optimization technique. BASINS-STAR forms a decision support framework for watershed management (Murray et al., 2001b). The capabilities of this framework were demonstrated through several scenarios for the Suwanee Creek watershed in Georgia. The paper illustrated a means by which a decision-maker can determine maximum allowable level of land development in a given watershed while maintaining a target level of water quality. The effect of BMPs on land use planning was also explored.

The main concern of using continuous simulation approach is that the use of data during specific representative hydrologic period does not necessarily cover the most "critical" condition and it is very data intensive (Zhang et al., 2001). A practical, event-based Critical-Flow Storm (CFS) was developed with application in the Nitrate TMDL Development for Muddy Creek/Dry River in Virginia using BASINS/HSPF.

As an alternative method for TMDL development, the CFS approach gives reasonable results and explicitly addresses the critical condition as a combination of stream flow, magnitude of storm event, and initial watershed condition. The Northeast Georgia Regional Development Center has taken a proactive stance in protecting the Alcovy River watershed (Jha et al., 2001). This project discusses the modeling portion of these larger studies. The purpose of this study was to develop a calibrated watershed water quality model in order to simulate the impact of different future scenarios. The BASINS interface to HSPF was selected as the watershed water quality model for the Alcovy River watershed. Water, sediment, phosphorus and fecal coliform were the constituents modeled. Eight future scenarios incorporating various management practices were modeled. These scenarios include the simulation of conservation subdivisions, riparian buffer ordinances, impervious surface restrictions, storm water quality controls and improved enforcement of erosion and sedimentation controls. Modeled results indicate that a combination of BMPs must be implemented in order to reduce pollutant loading to the Alcovy River.

Rockdale County, Georgia assessed its watershed in order to develop a management plan that combines water quality protection with other objectives, including expansion of water supply and wastewater treatment capacity (Clements et al., 2001). An innovative planning process linked management objectives, assessment information, predictive modeling tools, and stakeholder participation to risks. The results were effective for evaluating management options. The paper by Dymond et al. (2001) described the web-enabled integrated modeling system, including data sources, collection, analysis methods, system software and design, and issues of integrating the various component models. The integrated system contained three modeling components, namely hydrology, economics, and fish health. Earles and Jones (2001b) presented a water quality model developed for evaluating pollutant loading from development projects in the Aurora Reservoir 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 modeling showed that as the treatment plant is expanded, a reduction in effluent nutrient concentrations will eventually be required to maintain acceptable water quality.

Geographic Information Systems (GIS)

The residual inflow to combined sewers must be quantified it affects the CSO activation frequency and thus the degree of roof drainage separation that must be undertaken to eliminate CSOs (Ho et al., 2001a). Hydrologic models have employed coefficients to represent the directly connected impervious area (DCIA), with the coefficients being proportional to the total amount of impervious area in the region. Better estimation of the DCIA requires sufficient geographic information and field data. A GIS application was developed to automate the process of calculating drainage utility apportionment percentages (Hughes et al., 2001). The application used the rational formula to estimate stormwater runoff. The application was applied to the Twelve Towns Drainage District (Oakland County, Michigan) 2000 Apportionment for Improvements to their combined sewer overflow retention treatment facility.

The application of HEC-HMS, HEC-RAS and HEC-GeoRas, coupled with GIS and NEXRAD radar, efficiently analyzed proposed alternatives to previous Army Corps of Engineers' plans including voluntary floodplain property buyouts and various, smaller-scale channelization schemes in Clear Creek (Benavides et al., 2001). Applying the latest HEC tools, NEXRAD and GIS to test the viability and effectiveness of specific flood control alternatives provided acceptable results. An ArcView GIS interface was created to view and facilitate the development of EPA's SWMM RUNOFF and EXTRAN models (Heineman 2001). The interface contained Avenue scripts that allowed the user to visualize a SWMM model in conjunction with existing GIS data. The scripts permitted viewing of model input and output summary data within ArcView, but could not substitute for existing SWMM-commercial software interfaces, since they do not permit viewing of conduit profiles, dynamic display of results, or editing of input data. The EPA SWMM model was a major tool of the stormwater management master plan for Hillsborough County, Florida (Ho et al., 2001b). Hillsborough County coupled the SWMM model with a county-wide GIS model. Hussein (2001) reviewed the MODFLOW Hydrologic Modeling System (MODFLOW-HMS), a physically based model capable of simulating the land phase of the hydrologic cycle including overland and channel flow on the surface, variably saturated flow in the subsurface, as well as transport during flow in both systems. GIS utilities were developed to estimate model parameters. The paper discussed the algorithms used to process these data and estimate the spatial and temporal variation in parameters over the finite-difference mesh, using a Mad River, Ohio study as a case study. Johnson County, Kansas embarked on an aggressive program to complete stormwater master plans and new floodplain delineations county-wide (Koch et al., 2001). The primary goals included (1) developing new hydrologic and hydraulic models for both existing and ultimate development conditions; (2) updating the existing FEMA floodplain boundaries for existing development conditions; (3) providing local communities with a floodplain management tool; (4) defining flood-prone areas; (5) developing sound engineering and bio-engineering solutions to alleviate identified problem areas; and (6) developing GIS-based stormwater data for ongoing asset management purposes. HEC-1 was used for hydrologic analyses, and HEC-RAS for hydraulic analyses. GIS techniques were used to automate the process of model development.

Two of the most data-intensive programs in use include computerized maintenance management systems (CMMS) and GIS (Ratliff and Schmitz 2001). The integration of these systems would result in greater efficiency of resources, improved data collection processes, and reduced data redundancy and data maintenance requirements. The paper discussed the major phases of a project that included asset inventory and a multi-year condition assessment program for sanitary sewers and storm drains. This paper presented lessons learned from the project and highlighted recommendations for the successful integration of inventory and condition data into CMMS and GIS. Xu et al. (2001) reported on the integration of a physically-based distributed model with a GIS in watershed-based water resources management. The integration facilitated the examination of a wider range of alternatives than could be done using conventional methods, and provided a 'living' management tool that could be modified and updated if the watershed condition changed. With the 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 was developed by the City of Atlanta, Georgia (Smith et al., 2001b). The holistic approach considered future land use and urban development within the combined sewer area basins, and determined the additional sewer conveyance capacity needed to accommodate the City's future growth. The GIS-based tool will provide Atlanta with the ability to store and analyze data related to existing and proposed land uses, transportation improvements, storm water detention and other water quality enhancement projects. Due to the pending SSO Rule and CMOM requirements, the City of Phoenix (COP) needed to manage the large amount of data generated by the required studies (Malone et al., 2001). The COP used the Water Department's GIS database as the format. Direct electronic collection of data and a "hands-off" data transfer and collection of data into the COP's GIS was established.

A GIS model was developed for the Bushkill Creek in eastern Pennsylvania watershed to address the needs of various constituencies (Ruggles et al., 2001). This paper described the development of the GIS that supports the needs of each group having an interest in the Bushkill Creek watershed and provided examples of the information currently available. The application of GIS technology to the field of urban storm-water modeling was reviewed by Sample et al. (2001b), and an application in urban stormwater management at a neighborhood scale was presented. Using economic analysis to compare the cost of controls, including the total cost for land intensive controls, the optimal mix of BMPs was found. The paper by Shamsi and Cigana (2001) demonstrated the reduction of wet weather overflows by conducting TV inspection of sewers using multimedia computer technology and GIS, and using the information to improve the maintenance of sewer systems. The paper proposed a four-step method for implementing a GIS-based TV inspection program.

Shamsi (2001) showed how digital elevation models (DEM) can be used to develop hydrologic models using the off-the-shelf GIS software. The chapter showed how to automatically delineate watershed subbasins and streams using DEM. A case study was presented that compared the DEM results with the conventional manual delineation approach. The work described by Sibiga et al. (2001) attempted to quantify pollutant loading sources as a function of land use within the Cazenovia Creek sub-basin of the Upper Buffalo River watershed by applying a GIS-based Watershed Loading Model (WLM). The model was also used to evaluate reduction options for meeting water quality criteria in the Cazenovia Creek. A program developed within Arc-Info GIS was used to identify storm characteristics from a set of rainfall gages (Tsanis and Gad 2001). Three different interpolation techniques (spline, inverse distance weighted, and kriging) were used to visualize the spatial distribution of rainfall using an example in the Hamilton-Wentworth Region in Ontario, Canada. Supported by GIS, snowmelt runoff simulation models have been built for the Qushenan basin in the west of China (Wang and Li 2001). Digital Terrain Factors (DTF) were employed to divide the basin. The results showed that this approach was significant and practical.

REGULATORY POLICIES AND FINANCIAL ASPECTS

Policy

After over 20 years of progress, many rivers, lakes and stream still failed to meet water quality standards (Kwan 2001). Studies and monitoring data have shown that stormwater runoff was a major source of water quality impairment. Currently, five regional states have reported stormwater runoff as a major cause of water quality impairment. An effective, integrated and coordinated storm water enforcement strategy will need to be established in full partnership with the eight Region 4 states.

EPA has been completing a series of federal initiatives to address wet weather discharges due to CSOs and SSOs (Hall et al., 2001a). As a result, communities nationwide will need sewer system/treatment plant improvements to address these wet weather discharge issues. Little attention has been paid thus far to a series of subtle changes in EPA's implementation of its existing bypass regulations and secondary treatment requirements for controllable CSO and SSO flows. Reducing wet weather discharges is a core activity of EPA's Office of Wastewater Management (Cook 2001). The office's programs include combined sewer overflows, sanitary sewer overflows, storm water, and animal feeding operations. Several current regulatory initiatives have been designed to improve water quality by reducing the environmental impacts of wet weather events. Bell and Powell (2001) described the pending SSO regulations, where there are three standard permit conditions for sanitary sewer collection system owners: capacity, management operation and maintenance (CMOM); prohibition on SSOs; and reporting, record keeping and public notification. The paper focused on the CMOM aspect of the permit conditions. Although the SSO Rule is not currently effective, Sowatzka et al. (2001) advocated using the draft Rule to provide system owners and operators guidance on EPA's expectations for systems, including satellite facilities, for their (CMOM) program.

Centilla and Slack (2001) reported on the outreach efforts of the EPA. EPA has been working with stakeholders during the "toolbox" development. The "toolbox" includes fact sheets, case studies, technical guidance documents, training and outreach efforts, sample self-audit reports, sample model ordinances, technical research, and compliance monitoring and assistance tools. The paper by Foess and McNitt (2001) presented the methodology, scope, and key results of collection system management, operation, and maintenance (MOM) program audits for two Florida wastewater utilities. Selected MOM program performance metrics for the two utilities were compared to data from other well-operating utilities and published guidelines in order to assess the effectiveness of the programs. In mid-2000, the City of Thousand Oaks's Public Works Department updated its Wastewater System Master Plan (Giguere et al., 2001). Anticipating the future Sanitary Sewer Overflow (SSO) Rule and the Capacity, Management, Operations, and Maintenance (CMOM) program requirements, the City included in the Master Plan a task to perform a preliminary CMOM program assessment. Integrating the CMOM assessment into the Master Plan provided a convenient mechanism for the City to tap into the expertise of the engineering consultants who were working on the Master Plan.

Gwinnett County, Georgia recently revised their storm water regulations in order to improve the water quality in the county's receiving streams and to meet the designated uses of the waters for fishing and drinking water supply (Chastant 2001). To meet that goal, a Watershed Protection Plan was developed, with the six major components being public education/participation, pollution prevention, development regulation, planning, engineering and construction, and maintenance. The current management strategy has been based on four key storm events: protection from major flooding events, overbank flooding bank protection from moderate events, channel bank protection for the 1-year storm, and water quality treatment for rainfall events of 1.2 inches and smaller. Atlanta's Clean Water Initiative was developed in order to coordinate water resource management for the Atlanta region and to generate the political momentum necessary for implementation (Green 2001). The task force recommended the creation of a "Metro Atlanta Water Planning District," which would be charged with developing watershed protection, wastewater, water supply and conservation plans. These recommendations and the District were enacted into law in 2001. In 1999, the City of Atlanta completed negotiations with the EPA and the Georgia Environmental Protection Division (EPD). The consent decree and an amendment required implementation of management, operation and maintenance (MOM) plans for CSO treatment facilities, Water Reclamation Centers (WRCs) and gravity wastewater collection and transmission systems (Griffin and Sukenik 2001). The MOM plans for the wastewater collection and transmission systems included emergency response plans; long- and short-term operation plans; maintenance plans; pump station evaluations; grease management plans; sewer mapping plans; safety and general training plans; and a short-term capacity certification plan. Hamid et al. (2001) presented an overview of Atlanta's Wastewater Systems Improvement Program. Three specific regulatory requirements drove this program: Senate Bill 500 enforcing phosphorus level compliance at WRCs and CSO control facilities by December 2000; the CSO Consent Decree requiring completion of the long-term plan by 2007; and a second Consent Decree requiring WRCs, pumping stations and sewer improvements by 2014. The City's preferred option for the CSO plan included consolidated storage/conveyance tunnels, two CSO treatment facilities, and sewer separation in selected areas costing about $1 billion. The total capital cost of the program was estimated between $2.5 and 3 billion with a 14-year completion schedules. In November 1997, a Federal District judge ruled that the City of Atlanta's CSO discharges violated water quality standards for metals and fecal coliform. In addition, the Georgia EPD required compliance with water quality standards at the point of discharge for CSO facilities with no allowance for dilution (Richards and Kreutzberger 2001). Data is being collected in order to characterize water quality related to metals toxicity.

Clark et al. (2001a) combined hydrologic models of flood control and biotic models of ecologic risk with economic models of willingness-to-pay and psychological models of risk processing and planned behavior in order to evaluate these two alternative policy objectives. The findings reveal that flood risk exposure does influence the willingness-to-pay of local residents for a flood control project. Other important determinants include demographic factors, such as income, and attitudinal measures of the respondent.

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 the stormwater drainage from the development area.

Augustenborg and Duke (2001) evaluated the effectiveness of current regulations for stormwater pollutant control from industrial facilities, and resulting efforts by the regulated community to reduce pollutants. Using the Notice of Intents filed by industries in three municipalities, trends and patterns of compliance were characterized. The research has evaluated the relative effectiveness of municipal programs at achieving the pollutant reduction goals of the storm water NPDES regulations. The wastewater and stormwater infrastructure in the U.S. was a significant financial investment; however, the maintenance of these systems has often been lacking (Kosco et al., 2001). Maintenance problems on private lands, particularly I/I from private sewer laterals, have been shown to represent a significant part of the water quality problems on a system. Many communities have aggressively addressed O&M issues of wastewater and stormwater systems on private property, with these programs backed up by local ordinances with penalties. Recently, Portland, Oregon revised their Erosion Control Program to have almost a zero tolerance for erosion and sediment leaving a site (Launder 2001). The program also placed additional controls on construction site pollutants. The program required some new technology, but mostly management techniques and management issues were targeted. PDR Engineers, Inc. and the Louisville and Jefferson County Metropolitan Sewer District (MSD) produced the Watershed Approach to Environmentally Responsible Stewardship (WATERS) of Jefferson County report (Potempa et al., 2001). The report reviewed MSD's activities involving the Municipal Separate Storm Sewer System (MS4), the Combined Sewer Operational Plan (CSOP), and the Sanitary Sewer Overflow Abatement and Elimination Plan (SSOAEP). The unique nature of the WATERS report is that the reader can view information from a programmatic and watershed approach. The Louisville and Jefferson County MSD prepares facility and watershed action plans with 20-year planning horizons (Wilson et al., 2001). This allows consideration of multiple factors, such as population projections, land use, environmental conditions, capital and operation and maintenance requirements, political issues, projections of economic conditions, etc. Using the multi-variable risk model has allowed MSD to assess the performance of a wastewater service area configuration over a range of views of the future.

The Federal Water Pollution Control Act Amendments of 1972 (a.k.a., the Clean Water Act (CWA)) mandated that States lead aquatic resource protection and restoration activities. Congress directed the states to establish water quality standards for waterbodies based on use, identify waters that were not attaining those standards, and develop plans to improve the impaired waterbodies (Savage 2001). As Congress fashioned the statute, the EPA's role was to oversee the program. Although the Total Maximum Daily Loads (TMDLs) statutes (§303(d)) have not changed, the regulations promulgated by the USEPA regarding TMDLs have grown more complicated. While §303(d) and its regulations are a comprehensive approach to water management, they also have the potential to become a bureaucratic exercise in meeting deadlines and satisfying requirements that do not improve or protect the nation's water resources. Cited causes of impairment are often from sources that are not managed under Clean Water Act programs (Staveley et al., 2001), and are instead regulated under other statutes. These include sources such as atmospheric emissions, discharges of groundwater contaminated by past waste disposal practices, surface runoff from inadequately controlled landfills, historically contaminated in-place sediments, and the legal application of pesticides and herbicides. Thus, the possibility exists for overlap or conflict between the TMDL regulations and other statutes. Additional complications have arisen when comparing the provisions of the Safe Drinking Water Act (SDWA) and the Endangered Species Act (ESA) with the CWA.

Watershed Management

Fulton County has begun addressing the surface water issues created by stormwater runoff (Ammons 2001). The resulting Water Resource Management Plans have a 15-year program to improve the surface waters of Fulton County. In order to increase wastewater plant capacity and effluent discharge, the Georgia EPD required development and implementation of a watershed protection plan to address the "secondary" pollution impacts created by stormwater runoff from the development supported by the increased wastewater treatment capacity. The State of Georgia required watershed assessments to control nonpoint source pollution associated with degradation of surface water quality and non-attainment of designated uses (Ahmad 2001). EPD required local governments to conduct watershed assessments as a part of the NPDES permitting process for wastewater treatment plant expansion. The study objectives included identifying the current aquatic health of the watershed; predicting the impacts from the proposed development; and identifying and assessing the performance of BMPs. The conclusions were that the creek currently meets all adopted and recommended water quality standards; the aquatic habitat show some degradation of biotic integrity; the planned level of development in the watershed will increase pollutant (and sediment) loads; the structural BMPs will mitigate the increased pollutant loads; nonstructural BMPs should be implemented as part of a long-term Water Resources Management Plan (WRMP); and a long-term water quality monitoring and sampling program should be implemented.

Batchelor and Rogers (2001), in response to the lack of improvement in some of the nation's waters, advocated finding smarter, more cost-effective ways of water quality and watershed restoration. Work in the Saginaw Bay Region showed that a point-source and non-point source trading program could be effective (Faeth, 1995). Two important points were made. (1) The current regulatory system needs to change to incentive-based systems. (2) Trading systems work for integrated water quality, air quality and natural resource programs. A trading program, on a watershed basis for trading, should provide major watershed restoration in the fastest time and for the least money. Bhimini et al. (2001) presented the findings, conclusions, and recommendations from a trading program for TMDLs on the Truckee River. In addition, the viability of a seasonal TMDL and a discussion on the phased approach towards developing pollutant trading permits were discussed. The development of the trading program included establishing the technical basis for modifying the TMDLs and WLAs and for identifying the optimum mix of structural and nonstructural BMPs. Kochoba 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 characterization of non-point source loads. Active involvement in the TMDL development process by contributing entities was advocated to help ensure that TMDLs are based on good science and result in reasonable, achievable WLAs and LAs.

As the first phase in its Integrated Resources Planning (IRP) process, the City of Los Angeles embarked on a program to restructure and redefine the future of water resources for the City and its neighbors (Boyle et al., 2001). The City developed the Integrated Plan for the Wastewater Program (IPWP), a set of policies to guide the next phases of wastewater facilities planning. The IPWP process used by the City integrated water supply, water conservation, water recycling, and stormwater management issues with wastewater facilities planning through a regional watershed approach. It also solicited and relied on public input in establishing planning-level policies. Philadelphia Water Department's Office of Watersheds was charged with integrating traditionally separate tasked programs, including the Combined Sewer Overflow (CSO) Program, the Stormwater Management Program, and the Source Water Protection Program (Dahme 2001). The goal was to maximize the resources allocated to these programs and to ensure the comprehensive achievement of each of their goals. The paper focused on the Darby-Cobbs Watershed Partnership.

The watershed storm water regulatory framework from the Rouge River National Wet Weather Demonstration Project (Rouge Project) in southeast Michigan was institutionalized in 1997 as a new statewide watershed-based general storm water National Pollutant Discharge Elimination System (NPDES) permit ("General Permit") (Cave et al., 2001). The General Permit required the immediate initiation of some activities such as illicit discharge elimination and participation in watershed management planning. The paper reported on the effectiveness of the subwatershed management plans developed under the General Permit in (1) contributing to the overall restoration of the Rouge River; (2) meeting the requirements of the state's Storm Water General Permit, and (3) satisfying the federal mandates contained in the Phase II Storm Water Regulations. Two years ago, most of the Rouge River Watershed communities became covered under the state's voluntary general stormwater permit program (Powell and Ball 2001). The permit required that the communities create a public education plan that included programs on the Rouge River, its impairments, stormwater pollution, and individual responsibility and stewardship. This paper discussed the initiatives and tools used by Wayne County's Rouge River National Wet Weather Demonstration Project and the involved communities to obtain public input during the subwatershed management planning process. In most cases, public meeting participation was the most difficult to predict and ultimately the least dependable, and many approaches were required.

Disaster mitigation related to floods and debris flows were discussed in the context of sustainable land and water management in Taiwan (Chen et al., 2001a). Engineering approaches to modify natural systems were contrasted with approaches that require changing human behavior. Mitigation success depended not only on the characteristics and magnitudes of the disasters but also on human responses related to socioeconomic, cultural, and political factors. Herricks (2001) discussed the renewed emphasis on watershed management programs that are based on ecosystem protection and restoration. The integration of ecosystem-based objectives into watershed management programs has demanded a substantial shift from past practices. This new paradigm integrated past management science and practice with ecosystem protection. This has assisted in the development of projects that produce needed ecosystem benefits.

Public involvement in watershed protection and stormwater management was reviewed by Cole (2001). Focused public involvement has encouraged residents to acknowledge individual responsibility for the impact of their actions on area waterways. It ahs also fostered voluntary participation in Watershed Management Plan recommendations. The paper discussed the objectives of a well-managed public involvement plan. Ames and Neilson (2001) presented an Internet-based, Bayesian Decision Network model to aid watershed stakeholders in collaborative decision-making. Bayesian Decision Networks (BDNs) have been shown to be a useful tool for diagramming the decision process, for describing relationships between variables, and for analyzing the anticipated effects of management decisions while still accounting for the associated uncertainties. An Internet-based BDN was described using the East Canyon watershed in Utah. Public participation was a key factor in the success of watershed management (Lu 2001). China Time's ten-year experience of promoting watershed planning was analyzed for public participation. Piasecki (2001) presented a methodology to compute sensitivities between benefits and costs that can be used to develop an efficient WLA procedure for CBOD/DO load scenarios. Steady state and unsteady flow scenarios were presented along with method sensitivities. The 2-dimensional dynamic modeling approach permitted identification of a large number of temporally distributed sensitivities for sources along an estuary. The project described by Watkins and Paladino (2001) educated and mobilized watershed residents and other stakeholders to participate in the activities of a local watershed council. The underlying strategy was to engage stakeholders in discourse on watershed issues, as well as in activities that promote the decision-making skills necessary for sustainable watershed planning and management.

A watershed approach to Sanitary Sewer Overflow (SSO) management was applied for the Vallejo Sanitation and Flood Control District in Northern California (Dent et al., 2001). This watershed approach was used to estimate the total pollutant loads from SSOs, urban stormwater, and flows from the Napa River watershed. The results were then used to set permit limits for wet weather events. The watershed approach combined monitoring and modeling techniques to estimate the water quality improvements for a variety of SSO elimination activities. A joint stormwater initiative for the City of Lincoln and the Lower Platte South Natural Resources District was successful in achieving three goals: adoption of comprehensive stormwater ordinances for new development; implementation of revised, comprehensive design criteria; and completion of the City's first stormwater basin plan (Masters et al., 2001). Ordinance and design standard revisions addressed maintenance issues for stormwater storage facilities, erosion and sediment control, localized flooding, water quality, and the specific criteria for meeting objectives in these areas. Holmberg et al. (2001) reviewed the need for municipalities to balance establishing peak flow standards with these other issues: dynamic sewer flows resulting mostly from I/I originating on private property; capital funding; risks of public health and environmental effects from SSOs; and threats of third-party citizen lawsuits. The Water Works and Sanitary Sewer Board of the City of Montgomery (Board) advocated the watershed approach to manage collection systems. The Board used the watershed approach in two of its three sewer basins – the Towassa and the Catoma Basins. The Board also recently used the watershed approach process to set peak flows in the Towassa Basin. Lewis and Hilson (2001) explained how environmental benefits were optimized against cost through integrated catchment modeling in North West England. These solutions were obtained from detailed modeling of the wastewater networks, along with the modeling of the wastewater treatment works and the receiving waters. The stormwater management system in Calgary is a zero discharge system incorporating sedimentation, biological uptake/treatment and irrigation for disposal of stormwater runoff (MacKenzie and Dumont 2001). The system was designed and implemented, and is in successful operation. The zero discharge stormwater system allowed the development area to proceed without off-site treatment facilities. The system controlled/mitigated the effects of stormwater runoff on receiving waters. Continuous simulation, using long-term records of precipitation, temperature, and evaporation combined with estimates of plant moisture requirements formed the basis for the design of the system.

McGrath (2001) discussed the growing need to forecast land use changes and urbanization patterns over longer time frames so that regional environmental and hydrologic consequences can be forecasted and the consequences of different development scenarios compared. Obstacles to achieving such forecasting capability included the integration of spatial environmental/hydrological and spatial economic models. In addition, the econometric problems associated with estimating spatial economic changes were reviewed. The recognized difficulties in combining the relevant disciplines to produce accurate long-range forecasts of land use change were discussed. Ecological impairment and flooding caused by urbanization was expressed numerically by calculating the risks throughout the watershed (floodplain) and along the main stems of the streams (Novotny et al., 2001). The methodologies for ascertaining the risks in the Geographical Information Systems (GIS) environment were described. The objectives of urban flood controls and ecological preservation/ restoration of urban waters often have conflicted. A solution to this may be achieved by linking the risks to the concepts of risk communication, risk perception, and public willingness to pay for projects with ecological restoration and ecologically sustainable flood control. Reeves et al. (2001) developed a method that would incorporate the effects of both chemical and physical parameters on aquatic life (Reeves et al., 2001). The resulting method, termed the Integrated Impact Analysis method, used existing analytical methods, including Principle Components Analysis, All Possible Regressions, and Chi-Square Automatic Interaction Detection (CHAID), to identify key variables. Non-linear interactions between the key variables were identified using a three-dimensional modeling program. The method was refined using three datasets (Santa Ana River in California, South Platte River in Colorado, and Cuyahoga River in Ohio). Webster et al. (2001) considered the problems of developing a perceptive and efficient rehabilitation strategy for a large urbanized catchment, specifically the River Tame in the West Midlands. The following were considered: (a) rainfall-runoff relationships, (b) water quality and ecological status, and (c) the impact of various management strategies. Spalding and Sweeney (2001) advocated the use of the Internet by wastewater utilities to achieve closer customer and production integration. A “Digital Utility” approach using the Internet to create new, robust, customer-oriented applications was described.

In Cleveland, Ohio, channel erosion and flooding, water quality, and aquatic life and habitat were evaluated (Yingling 2001). The purpose of both the Mill Creek and Doan Brook Watershed Studies was to develop comprehensive approaches for controlling wet-weather impacts on the respective streams. The cost and effort involved in actually performing the watershed studies, as well as the potential for overall cost savings and creativity in developing final solutions, were 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.

Permitting

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 industrial activities (Duke 2001). However, evidence suggests the pollution prevention approach is widely failing. In targeted case studies, evaluation of chemical constituents in runoff shows no evidence of pollutant reduction over time. Effective implementation of the pollution prevention approach may require more resources by regulators compared to classical command-and-control approaches, but instead agencies have devoted far fewer resources and relied on voluntary compliance. Therefore, it is important for the Industrial community to understand what these regulations are trying to accomplish and how these regulations will be locally specific. The paper by Gates and Resiak (2001) discussed when the State of Indiana will implement the Phase II regulations, who will need to apply for Phase II permit coverage, and what requirements will be in those permits. These were illustrated by a specific case study.

Georgia EPD and the Board of Natural Resources have to decide how and who should do watershed protection (Scarbrough 2001). Georgia concluded that POTWs should be the responsible party since the County/City controls land use in Georgia. The purpose of the Gwinnett County Watershed Assessment was to evaluate stream conditions within the County and recommend a watershed protection strategy to improve the streams which were not meeting the designated use. Patel (2001) provided a general background and state perspective for municipalities to approach the regulatory requirements for the new EPA Phase II Stormwater regulations. The description of the proposed Pennsylvania State Strategy summarized what the Phase II regulations will require of the regulated communities, and answered basic questions of who is affected, what is required, when permit applications are to be submitted, what permitting options are available, what types of permits may be available, what minimum information on permit applications may be necessary, and what, if any, funding assistance may be available. The CMOM approach in the SSO Rule will require "a dynamic system management framework that encourages evaluating and prioritizing efforts to identify and correct performance-limiting situations in the collection system" (Ruggard 2001). The goal of the ultimate elimination of any type of overflow from the sanitary sewer system was established at the Stege Sanitary District in 1996. The paper reviewed the improvements to the District's management, engineering, maintenance and data management systems in order to achieve that goal.

Cost Analysis and Financing

Stormwater controls and Best Management Practices (BMPs) were evaluated within a land development context (Sample et al., 2001a). Costs were developed from published literature and standard cost estimation guides. Data gaps and research needs were then explored. Many communities across the country have developed user-charges – and their delivery vehicles, stormwater utilities – as the primary funding source for expanded maintenance and new infrastructure (Rose 2001). With the implementation of a new funding source (e.g., user fee or special assessment) for stormwater management programs, a municipality imposes a new financial burden on the public (McClelland 2001). Therefore, the key to a successful stormwater utility implementation is public approval. The article presented methods for public education and approval, particularly the shift in focus from the fees to the stormwater service the new revenue will provide. Sound rate methodology should draw upon key concepts from public finance, utility theory, economics, law and engineering science. Most rate structures have been built around the "runoff" theory. Within this "runoff" theory are four related but different basic models: (1) the "impervious area" model, (2) the "weighted pervious plus impervious area" model, (3) the "land use" or "density" model, and (4) the newly emerging "pollutant loading" model. Fitting a basic model to a community is largely a matter of community political context.

Hall et al. (2001a and b) reviewed EPA's development of requirements applicable to design and permitting of wet-weather flow management facilities. These include issuance of various combined sewer overflow policies, development of regulations to require elimination of SSOs, enforcement actions against municipal entities, objections to state program permits; informal guidance to Regional Offices, and Regional Office initiatives. The paper reviewed the major inconsistencies in current program implementation, evaluated the applicable federal regulations and permit approaches, and recommended broadly, how communities with SSOs and CSOs should approach state and federal agencies to resolve these matters. Salo (2001) reported on the comprehensive assessment of the City of Atlanta's water and wastewater operations. Internal and external management approaches were considered after it was found that a substantial rate increase would be required to fund a Capital Improvement Program. The adopted plan combined approaches through contract operation of the entire Water System, contract operation of the largest wastewater treatment plant, and reengineering of the other City wastewater and sewer operations.

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 performance accountability and state-of-the art operations and maintenance (O&M) technologies. The Kansas City Missouri Water Services Department (WSD) developed a Competitive Business Plan (CBP) (Salo and Turner 2001). The CBP identified how WSD will improve service levels and minimize annual operating costs. Implementation of this CBP will require significant additional capital investment. O&M savings are expected to be between $129 and $217 million over the next 10 years.

CONTROL AND TREATMENT TECHNOLOGY

General

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 this study, a large scale water reclamation evaluation and demonstration facility was constructed at the Millennium Dome, London, UK. Greywater, rainwater and poor quality groundwater were treated by a combination of processes including biological oxidation, constructed wetlands, chemical oxidation, adsorption, ultrafiltration and reverse osmosis. Chemical and bacteriological results for each process were presented and discussed.

The WERF report on controlling pollution at its source documented the application of effectiveness measurement tools at demonstration projects that controlled wastewater and stormwater pollution at its source (WERF 2001a). The report described the demonstration projects, the tools tested, identified the costs involved, and assessed the feasibility of measuring a source control program’s impact. The Minnehaha Creek Watershed District has funded a multi-component project focused on improving the water quality in Lake Nokomis (part of the chain of lakes in Minnesota) (Hettiarachchi et al., 2001). The project components included constructed wetlands and grit chambers to treat runoff from surrounding residential neighborhoods, an inflatable weir to prevent Minnehaha Creek water from flowing back into the lake, and rough fish removal and alum treatment to reduce the internal phosphorus loading.

Drainage Design and Hydraulics

As part of the Clean Water Act, EPA required local governments to control urban storm water runoff (Ports 2001). asked the General Accounting Office (GAO) to report on the amount of runoff from urban areas, particularly from roads and other impervious surfaces, and its effects on water quality, and to perform an overall evaluation of the urban runoff control programs that federal regulations require, including their cost and effectiveness. The results from the GAO evaluation were summarized in a report titled, “WATER QUALITY, Better Data and Evaluation of Urban Runoff Programs Needed to Assess Effectiveness.” The paper by Pazwash and Boswell (2001) presented an overview of design methodology of various stormwater management systems, including detention basins, wet ponds, infiltration beds and underground detention/retention chambers. It discussed shortcomings in design and recommended improvements. The paper also described differences in local and state stormwater management regulations in New Jersey and offered suggestions for unifying the regulations.

Parsons Engineering Science, Inc., as part of an EPA project, reviewed industry and state practices for sizing both new and rehabilitated sanitary sewers (Mauro et al., 2001). Several new tools for estimating peak flows with reflect current technology and water use habits were identified. The research has found that peak flows in sanitary sewers depended on a complex set of variables. Tools used by communities to evaluate the operation of sewer systems were identified through interviews with experienced practitioners, research on federal and local regulations and industry guidance documents. The wastewater industry has been performing detailed I/I studies for the past 25 years (Lyon and Nelson 2001). The lessons learned can be applied to sanitary sewer design criteria to reduce the future occurrence of SSOs. Data from I/I studies for 20 wastewater agencies in six states (Kansas, Kentucky, Minnesota, Missouri, Ohio, and Texas) were compared, and 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 operating conditions by maximizing in-line storage while meeting all required constraints (e.g., overflow, pumping capacity, control flow devices, sewer capacity). The paper by McConico et al. (2001b) described a mechanical flushing system located in the confined space of the CSO Outfall Structure for the Shockoe Creek Basin in Richmond, Virginia. Over time, deposition of solids in the twin river crossing has reduced the flow capacity of the inverted siphon pipelines, reducing transfer capacity to the wastewater treatment plant. The mechanical flushing system was designed to store and release a large volume of wastewater to flush the twin river crossing with a high volume, high velocity stream while avoiding accidental releases of dry weather overflow to the river.

Many areas in the United States have established stormwater detention pond ordinances that require the postdeveloped outflow from a site to discharge at a rate equal to or less than the predeveloped peak flow rate (Glazner 2001). The impacts of increased stormwater runoff volume due to development were reviewed. Using a hypothetical catchment in Chicago, Illinois, Guo (2001b) compared three different approaches for the hydrologic design of flood control detention ponds that service urban catchments: (1) design storm approach; (2) continuous simulation approach; and (3) analytical probabilistic approach. While all three approaches generated similar results, the results from the design storm approach were shown to vary by 40% to 50% depending on the choice of models and design storms. The results further verified the suitability of the analytical probabilistic approach for the hydrologic design of urban flood control detention ponds. Hsieh et al. (2001) evaluated the flood mitigation performance of various long-term regulated plans (protecting banks, pumping stations, diversion works, and retention reservoirs) for the middle-upstream of Kee-Lung River Basin in northern Taiwan through simulations of both 1-D unsteady flow and 2-D overland flow. The models evaluated the flood mitigation effect of each measure based on three criteria, including flood stages, runoff peaks, and inundation depths and ranges. The results showed that none of proposed regulated plans was best at resolving the flood and inundation problem. Storm water detention pond design is frequently part of each site or land development project (Ovcharovichova 2001). One critical aspect of the design is the determination of the boundaries of drainage areas for both existing and future conditions. The paper compared two different models of the same pond, with the only difference being in the existing and future drainage area delineation. Consequently, the results are different. The paper suggested which approach should be preferred to simulate the basin as it truly functions in the field. The paper by Wong (2001) contended that for drainage design to be based on a consistent theory, the kinematic wave time of travel formula for channel flow ought to be used in conjunction with the kinematic wave overland time of concentration formula. The paper contains the kinematic wave time of travel formulas for channels of seven different cross sections. A model of a hydrologically isolated section of the M6 motorway in the United Kingdom was used to calculate the times of travel in a channel with a vertical curb section for rainfall intensities ranging from 20 to 100 mm h^{-1}. A comparison of the time of travel estimates from the computer model, and from the time of travel formula, shows that the differences are less than 5%. The derived time of travel formulas could be used to design drainage channels whose properties fit the kinematic wave approximation.

Stormwater Best Management Practices (BMPs)

BMPs can range from management operations (such as street sweeping or reducing pesticides used on urban lawns) to structural treatment options (such as detention/retention ponds, swales, filter/buffer strips and constructed wetlands) (Sullivan and Borst 2001). This paper focused on structural BMPs and reviewed the state of the knowledge, the unknowns, and research programs being undertaken by the U.S. Environmental Protection Agency and other key organizations to address the unknowns.

The final report will document the effectiveness of these BMPs to improve water quality and will address BMP stability, longevity, and operation and maintenance issues. BMP manuals have been developed that address the control of urban runoff to protect receiving water quality (Roesner et al., 2001). Investigations of both design practices and effectiveness revealed that there is a lack of knowledge in the scientific and engineering community about what constitutes a properly designed BMP and what the BMP should achieve. This paper discussed the state-of-practice in BMP design in the US and pointed out the strengths and weaknesses with respect to water protection. An approach to design criteria development for a wide variety of climatologic, topologic, and geologic conditions was recommended to protect receiving waters systems. Strecker et al. (2001) reported on the EPA-funded cooperative research program with the ASCE to develop a more useful set of data on the effectiveness of stormwater BMPs in urban development. The paper described the comparability problems encountered between different BMP effectiveness studies and the considerations that affect data transferability, such as methods used for determining efficiency and statistical significance. Finally, it recommended that effluent quality be used to measure BMP efficiency. In the paper by Yu and Zhen (2001), a methodology is developed to assist in the determination of BMPs placement strategies at the watershed level. The AGricultural Non-Point Source Pollution Model 2001 (AGNPS 2001) developed by USDA, was used for BMP placement analysis, and the relative effectiveness of BMPs 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 (BMPs) 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 BMPs 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, and suspension; water chemistry; and regulatory requirements related to water quality and wetlands protection, and included examples of structural BMPs. Yamada et al. (2001a) analyzed the mass balance of pollutants during both dry periods and storm events on Lake Biwa and discussed the effects of pollutant removal systems, land use planning and new drainage systems by simulation. The project included estimation of influent pollutant loadings from existing data, collection of additional samples from road surfaces, house roofs and parking lots, and evaluation of ongoing BMP projects. Hambridge and Stein (2001) studied a 33-acre lake in Duke Power State Park where lake water quality is deteriorating. The EPA “Simple Method” screening model was used to estimate the contribution of pollutants from each land use category, and a goal for BMPs to reduce phosphorus loadings by 34% was determined. Restoration options included dredging; developing an in-lake wetland; and carp eradication. Watershed BMPs included regional stormwater treatment; parking lot bioretention; wetland treatment at a local high school; strengthening stream buffer restrictions; agricultural BMPs; education; and septic maintenance programs. In Onondoga County, an Amended Consent Judgment required the County to perform a NPS environmental benefit project (EPB) in Onondaga Lake watershed (LaGorga et al., 2001). BMPs were implemented on three farms and at two urban sites in the Onondaga Lake watershed. The Staten Island Bluebelt Program represents New York City’s first large-scale use of stormwater BMPs to alleviate chronic flooding and provide drainage infrastructure (Vokral et al., 2001). The BMPs used by the t Program included constructed wetlands with extended detention, stilling basins, underground sand filters, and meandering streams. These BMPs were effective on a large scale (even preventing flooding during Hurricane Floyd). The enhanced wetlands and improved water quality greatly promoted biodiversity. Public support was enthusiastic and valuable educational/recreational resources and cost-effective drainage infrastructure resulted.

Low Impact Development (LID) combines hydrologically-functional site designs with pollution prevention measures as compensation for land development impacts on receiving waters (Clar 2001). This paper summarized the results of a number of demonstration projects, and introduced a strategic framework for the application of LID technology to ultra urban areas. It reviewed the hydrologic characteristics of ultra urban areas and related them to identified stormwater management goals in ultra urban areas. LID combines conservation strategies, distributed micro-scale source control BMPs, and pollution prevention to control the volume and peak runoff rate, and to treat the pollutants (Weinstein et al. 2001). LID practices can be incorporated into buildings, sidewalks, streets and landscaping. Because they are small scale, the issues associated with conventional large-scale, end-of-pipe controls, such as large-scale traffic and property disruptions, utility conflicts and large capital costs, can be avoided. The paper documented the issues and efforts of a multi-year monitoring and construction effort of the Maryland State Highway Administration (MSHA) to determine the effectiveness of LID at addressing regulatory and ecological protection goals for highway construction. The development and use of environmentally sensitive construction materials as a low-cost component to stormwater management has gained interest recently (Pitt and Lalor 2001). However, there is little data for specific alternative building materials, although information exists targeting selected sources, especially the role of roof runoff as a significant source of zinc and other metals. Relative pollutant contributions from construction materials themselves are also a concern that has not been adequately addressed. Due to the common use of these materials in the urban environment, material substitution would seem a good place to start in implementing source reduction.

To assess the effectiveness of sedimentation and erosion controls during highway construction, the impact on water quality in adjacent wetlands was monitored (Huang and Ehrlich 2001). Downstream measurements were equivalent statistically to upstream measurements except once when erosion controls were neglected and when culverts were constructed. Attention to sedimentation and erosion controls and seasonal scheduling of highway construction were advocated to protect adjacent wetlands. Clopper et al. (2001) reported on an erosion control study that examined the 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 selection of a suitable TSS control technique. Levee sump systems have been used by many riverine communities for temporary storage of urban wet weather flows (Smith et al., 2001d). This paper presented a case study that demonstrated a procedure for assessing the hydraulic performance of flood control sumps in an urban watershed. A hydrologic modeling package was used to estimate the flow hydrograph for each outfall as part of the flow balance for the sump. In addition, these sumps may function as sedimentation basins. Yu et al. (2001b) monitored several ultra-urban BMPs: manhole-type treatment structures (such as the Stormceptor), a bioretention area, and the Vortechs Stormwater Treatment System. Resuspension of sediment during large storm events has been a concern for these BMPs. A cost analysis showed that bioretention might be the most cost-effective in terms of cost per unit pollutant removal. However, the bioretention area may export pollutants before the soil-plant system stabilizes.
NPDES Stormwater Phase II and TMDL regulations have placed additional pressure on industrial facilities to reduce stormwater pollutant levels by implementing source controls and stormwater treatment (Mas and Curtis 2001). This paper presented an overview of the assessment and planning phases of industrial stormwater treatment evaluations, with a focus on structural control measures for removal of dissolved metals and other industrial stormwater pollutants common to the Northeast U.S. Chang and

Duke (2001a) evaluated actions taken by auto dismantling facilities in the Los Angeles, California, region to comply with industrial stormwater discharge regulations. The research evaluated a sample of complying facilities, and involved stormwater sampling at a smaller number of case study facilities. The study found that a large proportion have measured effluent concentrations that exceed U.S. guidelines for stormwater. Estimates of pollutant loads contributed by the dismantling industry appear substantial. The Ford Rouge Center complex on the Rouge River is undergoing dramatic revitalization, including substantial redevelopment of the existing plant structures and the addition of several new buildings (Houston et al., 2001). Cahill Associates developed a stormwater master plan that provides providing the facility with onsite stormwater storage and water quality improvement for the smaller, more frequent storms. A general strategy of retention and treatment through water quality swales was adopted. The two-year storm volume was used as the minimum storage volume required for each system.

The Dubai International Airport expansion plans required a stormwater management strategy that met international regulatory authority requirements, addressed time-sensitive milestones, and remained cost-effective (Darnell et al., 2001a). The stormwater management system must achieve the minimum drainage requirements and also provide a multitude of management options that could address the unpredictability of desert-climate storms. When modifications were done to the Camarillo (Ventura County), California, Airport in 1997, a high efficiency oil-water separator was installed to treat the stormwater runoff from the area where the refueling trucks were filled (Mohr et al., 2001). The system included a precast concrete separator vessel with multiple-angle enhanced gravity separator plate packs. Performance tests were performed on the system as part of the acceptance procedure. The results were presented along with the results of three year's operations and maintenance.

Public Works Practices

Because more than 780,000 tonnes of solids washed is washed into the drainage system in South Africa, the Water Research Commission of South Africa and the Cape Metropolitan Council are funding a four year investigation into the reduction of urban litter in the drainage systems through the development of catchment specific litter management plans (Armitage et al., 2001). The results of the litter audits from eight catchments will measure the effectiveness of the various litter management strategies. The California Department of Transportation (Caltrans) conducted a 2-year litter management pilot study in the Los Angeles area to investigate the characteristics of highway litter and the effectiveness of BMPs for removing the litter (Lippner et al., 2001). Half the catchments were treated with one of five BMPs; the others were controls. The BMPs tested were increased street sweeping frequency, increased frequency of manual litter pickup, a modified drain inlet, a bicycle grate inlet, and a litter inlet deflector (LID). Roughly half the freeway storm water litter was paper, plastic, and Styrofoam. Except for cigarette butts, the origins of most litter could not be identified because of its small size. Of the five BMPs tested, only increased litter pickup and the modified drain inlet demonstrated some apparent reduction of litter in stormwater runoff, although the data were highly variable.

Some people have advocated annually removing sediment, vegetation and litter from drain inlet vaults as a best management practice to improve the quality of Caltrans run-off before it enters the receiving waters (Dammel et al., 2001). In response, Caltrans implemented an annual drain inlet inspection and cleaning program in selected urban areas, and conducted the Drain Inlet Cleaning Efficiency (DICE) Study to evaluate if this practice improved effluent water quality. Irgang et al. (2001) evaluated the effect of catch basin cleaning on stormwater quality. Catch basins within two of the four drainage areas were cleaned at the beginning of the study, while those within the other two areas were not cleaned. Pollutant concentrations and runoff loadings were compared between the two areas. It was observed that fine particle deposits remaining in catch basins after cleaning could cause higher pollutant concentrations and loadings for several months when compared to control areas where catch basins were not cleaned. Untreated stormwater runoff reaches Santa Monica Bay (Los Angeles, California) primarily through catch basins or inserts to storm drains that terminate at the beach or in shallow coastal areas (Lau et al., 2001). Commercially available drain inlet devices for pollutant capture exist but few have been evaluated by independent parties in full-scale applications. Laboratory- and full-scale tests of inserts were conducted to evaluate their ability to remove trash and debris, suspended solids and oil and grease in stormwaters, with the results providing a basis for future insert development and application. The performance of Drain Inlet Inserts (Fossil Filter and StreamGuard) and an oil/water separator in treating runoff from four California Department of Transportation (Caltrans) maintenance stations was evaluated (Othmer et al., 2001). Drain Inlet Insert results to date showed that reductions in metals, hydrocarbons, and solids were consistent with expectations; however, frequent flow bypass required more maintenance than anticipated. Oil/water separator results showed no discernable difference between influent and effluent hydrocarbon concentrations at the low levels measured.

Newman (2001) described an analytical framework for the design and/or analysis of baffles to reduce floatables discharges from CSOs. This simple analytical framework, which is supported with a spreadsheet model, was compared to its predecessors and its advantages illustrated. The advantages included ease of use, improved applicability to typical installation configurations, and refined analyses of floatables-removal mechanisms. Model results were compared to previous results and to available laboratory test data for four test cases.

Interest in urban stream restoration has grown (Hession 2001). However, a scientific basis for restoring urbanized streams currently does not exist, although it is known that riparian vegetation along streams significantly impacted stream channel morphology, which in turn influences aquatic ecosystem structure and function. Watershed urbanization also has a significant, but typically conflicting, influence on channel morphology and aquatic habitat.

Infiltration and Biofiltration

The use of porous bituminous pavement for infiltration as a method to reduce the peak discharge and runoff volume into a receiving water was examined by Adams et al. (2001). In addition, this paper reviews the literature for infiltration meadows, trenches, swales, porous concrete sidewalks, bioretention gardens, etc. The design, installation, and performance of these methods at actual sites, “lessons learned,” and the effectiveness of these infiltration methods were reviewed. Infiltration of stormwater in the southeast of France was studied by Bardin et al. (2001) at the Venissieux infiltration basin that drains a 380-ha industrial catchment. The study quantified the effects of the infiltration system in terms of pollutant transport in the groundwater system, including pollutant removal performance of the basin and the pretreatment devices. In-situ performance monitoring of an infiltration system that collected the runoff of a school roof and paved area was reported by Abbott and Comino-Mateos (2001). The resulting data was used to verify the typical design procedures for these infiltration systems. Govindaraju et al. (2001) investigated the difficulty of modeling infiltration through soils that had spatially varying saturated hydraulic conductivities, but which can be represented by a homogeneous correlated lognormal random field. The Green-Ampt equation described the infiltration at the local scale. Approximate expressions based on a series expansion and a parameterization of the local cumulative infiltration were also presented for describing the ensemble-averaged field-scale infiltration.

Gharabaghi et al. (2001) monitored the sediment removal efficiencies of vegetative filter strips. Fifty percent removal efficiencies were seen when the flow length was 2.44 m and were increased to 98% when the flowpath length was 20 m. However, small-sized particulates were not effectively removed in the grass strips. Improved removal efficiency of very-fine sediments was achieved through the installation of a drainage system (e.g. a French drain) to increase infiltration. Reinforcement of vegetation with various geosynthetic products reduced flow channelization and short-circuiting. Yu et al. (2001a) field tested grass swales in Virginia and Taiwan. Average pollutant removal efficiencies varied from 14 to 99% for total suspended solids (TSS), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP). Water and sediment transport in grass swales and filter strips were modeled by Deletic (2001). The one-dimensional model simulated runoff generation and sediment transport. The modified Green - Ampt model was used for infiltration assessment, while a kinematic wave model was used for overland-flow simulation.

Limitations to vegetation establishment and abundance in biofiltration swales and other vegetated storm-water facilities that treat runoff were studied through field monitoring and greenhouse experimentation (Mazer and Ewing 2001). With adequate light, vegetation and organic litter biomass was strongly inversely related to the proportion of time that the bioswales are inundated above 2.5-cm depth during the driest time of year. For most bioswales, both flow velocity and hydraulic loading were too large for sedimentation of silt and clay particles, even with dense vegetation and abundant organic litter. A lack of correlation between vegetation abundance and pollutant removal was seen.

Detention/Retention Ponds

Design. To reduce flooding, the City of Austin, Texas initiated a watershed-based program to use regional stormwater detention facilities (Altman and Nuccitelli, 2001). The new program provided an alternative to using only on-site detention facilities. In addition, the City wanted to develop multi-objective facilities for recreation, water quality, flood-tolerant commercial uses, and/or other benefits. Dechesne et al. (2001) evaluated the long-term performance of infiltration basins by modeling their structural and environmental evolution through a LCA (Life Cycle Assessment) point of view. Sustainable infiltration basins were found to have good economic performance. Alternative configurations of detention ponds and land management plans have been generated using a genetic algorithm (GA)-based method to meet target pollutant removal levels at a relatively low cost (Harrell 2001). The GA-based method has been extended to incorporate reliability estimation into the evaluation of solutions in order to determine cost-effective pond configurations and land management plans to achieve a specified reliability level.

Barbosa and Hvitved-Jacobsen (2001) suggested a method for design and evaluation of the design of infiltration ponds for treating highway runoff in semiarid climates. The design was based on capture and infiltration of the most polluted runoff and accounted for the rainfall and soil hydraulic characteristics in the determination of the design volume. Seasonal 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 use of a bioretention basin as an advanced BMP that can achieve very high levels of pollutant removal. The bioretention basin would manage and treat stormwater runoff using a conditioned planting soil bed and planting materials to filter runoff captured by a collection system and transmitted to the basin. Fennessey et al. (2001) used a continuous simulation stormwater management model (with 33 years of historical precipitation) to determine how the design criteria from five different stormwater management pond ordinances changed the runoff from a 7.77 ha watershed after hypothetical development. All five ordinances required that the postdevelopment runoff rates be less than or equal to the predevelopment runoff rates for each return period. None of the five ordinances limited the increase in runoff peak rates for the 1- and 2-year return periods. This indicated that the lower frequency runoff events should always be analyzed for a basin's design.

Operational and maintenance practices. The objective of the study by Jacopin et al. (2001) was to develop new operational management practices for detention basins in order to limit flooding risk and to reduce pollutant discharges through optimizing the settling process. Current basin operation and “on/off” regulation studies were first carried out to quantify the freedom to act to change the control schemes. New operational rules were then elaborated and tested using a hydraulic model with their efficiency to protect against flooding and to reduce pollutant discharges being assessed.

Field monitoring. Konrad and Burges (2001) used a three-year rainfall record from a site in the Puget lowland, Washington in a mass-balance model to simulate outflow from single- and multiple- purpose detention systems, with the results compared to time series of measured runoff from Evans Creek. The discharge from a small on-site reservoir was sensitive to both the storage capacity and maximum controlled release rate for extreme high flows (those exceeded 1% of the time) and low flows (those exceeded 80% of the time). Using wetland filtration, the North Griffin Regional Detention Pond has proven to be an effective BMP for improving water quality to receiving waters and for reducing flooding (Feldner and Greuel 2001). The 30-year-old Expo Park regional stormwater detention facility in Aurora, Colorado needed renewal (Hamilton et al., 2001). Improvements to the multi-use 60-acre park facility were made to provide water quality, improve site drainage, increase flood control detention, improve recreational usefulness and aesthetics, and upgrade the facility to meet jurisdictional State dam safety requirements. Dam safety related improvements included new outlet works, spillway improvements, and acceptance by the Engineer's Office for using irrigated turf grass as overtopping erosion protection for the emergency spillway.

Karouna-Renier and Sparling (2001) investigated the accumulation of Cu, Zn, and Pb by macroinvertebrates collected in Maryland stormwater treatment ponds serving commercial, highway, residential and open-space watersheds to determine if watershed land-use classification influenced metal concentrations in macroinvertebrates, sediments, and water. Composite Zn concentrations in odonates from ponds with commercial development (mean = 113.82 µg g^{-1}) were significantly higher than concentrations in the other land-use categories. Similarly, Cu levels in odonates from commercial ponds (mean = 27.12 µg g^{-1}) were significantly higher than from highway (mean = 20.23 µg g^{-1}) and open space (mean = 17.79 µg g^{-1}) ponds. However, metal concentrations in sediments and water did not differ significantly among land-uses. The levels of Cu, Zn, and Pb in invertebrates from all ponds were less than dietary concentrations considered toxic to fish. Caltrans initiated a study in two Districts (Los Angeles and San Diego, California) to examine the benefits, technical feasibility, costs and operation and maintenance requirements of retrofitting extended detention facilities into existing highway and related infrastructure (Taylor et al., 2001). Monitored constituents will include suspended solids, metals, nutrients, and organics (e.g., gasoline). Detailed records will also be kept for maintenance and operations requirements. Sampling results showed average suspended solids removal was 73%, total metals removal varied between 61% and 75%, while dissolved metals removal varied between 16% and 44%. Removal was lowest for nutrients, especially nitrate, which was about 17%. Concrete lined basin showed generally lower removal rates. Major removal of sediment is estimated to be required every 10 years.

Wetlands

It has been hypothesized that smaller lot sizes in a development need not seriously decrease quality of life but instead, may result in increased use of local open space (Syme et al., 2001). This hypothesis was investigated with matched small and larger blocks in four areas in Perth, Western Australia. Households with smaller lots had increased visitation to the wetlands. Wetlands, while improving stormwater management, also fulfilled demands caused by higher urban densities. The City of Edmonton, Alberta issued "Draft Guidelines for Constructed Stormwater Wetlands" to assist developers who use constructed wetlands for stormwater management (Lilley and Labatiuk, 2001). Edmonton has accepted constructed wetlands as an alternative means of managing stormwater, while providing benefits of aesthetics, public enjoyment and wildlife habitat. The City's draft guidelines are intended to optimize the design of constructed wetlands for water quality improvements including suspended solids removal, drainage area, soil permeability, vegetation, water depth, wetland area, wetland volume, length to width ratio, forebays, inlets and outlets, grading, floatables and oil and grease, maintenance, monitoring, signage, secondary uses, land ownership, access, fencing, wildlife and mosquitoes. The research presented by Fassman and Yu (2001) examined the relative pollutant removal capability for specific wetland vegetation. Results of water quality analysis show various trends with respect to pollutant removal and time. In general, export of TP was shown in all vegetated cells. Maximum export for vegetated cells was observed usually during the first week of a treatment, especially for *Typha* spp. and *Phragmites* spp. By the end of most treatments, TP removal was observed in all cells. COD removal was seen in all cells for all weeks of each treatment (average removal ranged from 54-78%). TSS results were inconsistent. Export of Cu was noted for *Scirpus* spp. whereas all other plants showed positive removal. TOC was removed by all plants (average removal 24 – 69%), with the exception of the *Scirpus* spp. cell.

Data from 35 studies on 49 stormwater treatment wetland systems were examined for obvious trends that may aid future design efforts (Carleton et al., 2001). Despite the intermittent nature of hydrologic and pollutant inputs from stormwater runoff, steady-state first-order plug-flow models commonly used to analyze wastewater treatment wetlands could be adapted for use with stormwater wetlands. First-order removal rate constants for TP, NH_3, and NO_3 for stormwater wetlands were similar to values reported in the literature for wastewater treatment wetlands. Constituent removals were demonstrated via regression analyses to be functions of the ratio of wetland area to watershed area. Goulet et al. (2001) tested a first-order removal model to predict metal retention in a young constructed wetland receiving agricultural and urban runoff. The wetland retained metals best during summer and fall. The first-order removal model predicted Fe and Mn retention in the spring and dissolved Zn retention from spring to fall in both years. However, first-order removal models failed to fit summer, fall and winter data fur almost every metal under investigation (Fe, Mn, dissolved Cu, dissolved As) suggesting that HRTs (< 1-25 days) did not affect metal retention during these seasons. Therefore, the first-order removal model is inadequate to predict metal retention on a seasonal basis. Constructed wetlands design models for cold climates must consider seasonal changes that affect biological as well as hydrological variables. Wetland BMPs have focused on smaller storms, encouraging long retention times and vegetative contact for pollutant removal, design elements not typically considered for detention basins (Traver 2001). It was hypothesized that traditional storage - indication routing may not be appropriate for stormwater wetlands, especially for smaller water quality storms. To test this hypothesis, a recently constructed wetland was monitored for rainfall and flow. Sediment behavior in a stormwater wetland in Adelaide, Australia was studied using models that were based on solving hydrodynamic and transport equations, with the results compared to field-observed deposition patterns (Walker 2001). The long-term residence time distribution was useful in predicting overall sediment removal rates. Comparisons between the model and field observations indicated generally good agreement. The importance of the transient nature of the flow events was 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.

Critical Source Area Controls – Filtration, Treatment Systems, Treatment Train Systems

Bennett and Curtis (2001) tested a soil and vegetative contact treatment system (modified Howland Swale) for stormwater runoff from a fuel cell manufacturing facility. It was designed to remove copper and zinc (and thus overall effluent toxicity) to the point where the toxicity guidelines for the daphnid, *Daphnia pulex*, were met. The paper detailed the design and construction of the treatment system. To better understand the cost, maintenance requirements, and pollutant removal ability of sand filters, the California Department of Transportation retrofitted five Austin-style and one Delaware-style sand filters in the Los Angeles and San Diego metropolitan areas (Barrett and Borroum 2001) at their maintenance yards and park-and-ride facilities. Contributing areas averaged less than 0.7 ha. They had a relatively high cost of implementation, about $350,000/ha treated. Pollutant removal was comparable to the performance observed in various City of Austin studies. Average suspended solids removal was 85%, total metals removal varied between 51% and 85%, while dissolved metals removal varied between 19% and 77%. Poor removal occurred for nutrients, especially nitrate, which was generally negative. No major maintenance has been required, although evidence of clogging is beginning to appear.

Hird et al. (2001) tested a passive treatment system, called a sorptive buoyant media clarifier (SBMC), for highway-runoff treatment. Pollutant removal efficiencies approached 95% on a mass basis total suspended solids (TSS), turbidity and particulate-bound chemical oxygen demand (COD), with the efficiencies not being affected by highly variable influents or extended periods of non-operation between storms. Prototype treatment capacity, at breakthrough, was 1000 pore-volumes treated. Liu et al. (2001a) investigated the potential of manganese oxide coated polymeric media (MOPM) for urban stormwater runoff treatment. The adsorption onto the MOPM was shown to be very sensitive to the pH, with the order of adsorption affinity on MOPM for the four divalent heavy metals studied being Pb(II) > Cu(II) > Cd(II) > Zn(II). MOPM was seen to be a viable alternative adsorption medium for heavy metal removal in upflow BMP filters, such as a SBMC. Further investigations of the surface of the MOPM (with a specific gravity of less than 1) showed that the surface area increased from 0.05 m^2/g (uncoated media) to 27 m^2/g for the same media after oxide coating (Liu et al., 2001b). The multiple-layer coatings enhanced filtration and adsorption of heavy metals. Investigation of materials (Liu et al., 2001c) with specific gravities greater than 1 demonstrated that cementitious materials could be coated effectively for use in stormwater treatment devices. The increase in surface area resulting from coating sand was not as significant as it was for the coating of the cementitious materials.

Pitt et al. (2001) reported on the results of laboratory-scale investigations into of upflow filtration as a means of increasing the run times of traditional stormwater filters (which tend to clog rapidly due to the small size of particles in urban runoff). Using laboratory-scale columns (4.8-cm inner diameter (ID)), a power equation to model downflow filtration was demonstrated. However, the coefficients for the laboratory sand filter were significantly different from those of the Lakewood, CO sand filters reported by Urbonas. Testing with a larger diameter column has been performed. Comparison of the two clogging tests indicated that a significant scale-up effect exists. Clark et al. (2001b) investigated the ability of filter media to retain previously-trapped pollutants under aerobic conditions, as would be expected if the filters were operated in an upflow mode. Permanent retention of heavy metals occurred even in an anaerobic environment. However, retention of nutrients did not occur. These results showed that aerobic conditions must be maintained in the media if nutrient removal and retention is important. The permanent retention of the heavy metals indicated that upflow filtration may be feasible where the primary stormwater pollutants are metals.

The use of jute and mulch as filtration media for stormwater runoff treatment was investigated by Wojtenkio et al. (2001b). The effectiveness depended on the physical characteristics of the media. Both the sand content and the particle size of the filter media affected stormwater flowrates and the media's pollutant removal capacities. Removals as high as 100 % of copper (Cu) were observed for both mulch or jute. The removal of benzo(a)pyrene (B(a)P) depended on the media-to-sand ratios and ranged from 68 to 94%. Brown et al. (2001) assessed the use of kudzu (*Pueraria lobata ohwi*) as a medium for of copper, cadmium, and zinc removal from low concentration waters. Kudzu was an effective adsorbent for heavy metals. Although its capacity for metals removal is less than commercial-grade ion-exchange resins, kudzu could be used at much lower cost, and may be useful in treating dilute mixed-matrix metal wastestreams, such as urban runoff, where the application of resins is not practical. Davis et al. (2001b) investigated laboratory-scale bioretention facilities to treat urban runoff. The roles of the soil, mulch, and plants for the removal of heavy metals and nutrients were evaluated. Reductions of specific metal removals ranged from 15 to 145 mg/m^3 per event. Moderate reductions of TKN, ammonium, and phosphorus levels were found (60 to 80%). Little nitrate was removed, with nitrate production noted in several cases. The mulch later in metal removal was found to be important.

Five sets of field test results of the Storm and Groundwater Enhancement System (SAGES) device were presented by Koustas and VanEgmond (2001). The SAGES device, a three-stage filtering system designed to be retrofitted to existing catchbasins/stormwater inlets, consisted of three separate filtering sacks consisting of gravel on top, sand in the middle, and granulated activated carbon on the bottom. The testing showed that the highest removal efficiencies occurred in conjunction with elevated influent suspended solids concentrations. Washout from the modified catchbasin appeared to contribute to increased effluent suspended solids concentrations that clogged the SAGES filter sacks.

Airport Deicer Control

The paper by Switzenbaum et al. (2001) provided a theoretical assessment of the potential environmental impact of airport stormwater runoff. It also described in detail current information on alternative deicing fluid application methods and materials, collection and treatment practices.

Combined Sewer Overflow/Sanitary Sewer Overflow Control

<u>Innovative CSO Controls – Source Controls</u>. The methodologies used by several sewerage agencies to control combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) were presented/reviewed during 2001. Jewell (2001) outlined the methodology used by the Boston Water and Sewer Commission to identify and correct illicit connections to the storm drain system, as detailed in the Massachusetts Water Resources Authority's Combined Sewer Overflow Facilities Plan. The Plan proposed improvements to the system infrastructure to reduce the frequency and duration of CSOs. The CSO control plan proposed by the City of Springfield, Massachusetts to meet EPA and Massachusetts DEP requirements was reviewed by Heath and Donahue (2001). The cost for the various alternatives ranged from $144 million (reduce discharges to 12 per year) to $525 million (complete sewer separation to eliminate CSOs). Economic analyses were coupled with a regional water quality model to evaluate the benefits of various proposed alternatives for CSO control. Lai et al. (2001) reviewed the SSO Control Plan developed for Henrico County, Virginia. The paper discussed the following components: (1) dry-weather wastewater flow projections using GIS, water consumption records, and flow monitoring; (2) rainfall-dependent infiltration/inflow predictions; (3) capacity analysis (present and future conditions) using the SWMM EXTRAN model; (4) hydraulic and process capacity analysis of the wastewater treatment facility, including expansion requirements; and (5) implementation of a capital improvement program for additional facilities (sewers, storage tanks, pump stations, force mains, and wastewater treatment plant expansion or process retrofitting). O'Rourke et al. (2001) presented the Northeast Ohio Regional Sewer District's long-term control plan (LTCP) for bringing the District into compliance with EPA's CSO control policy. This approach included traditional and non-traditional cost issues, including non-cost issues that were deemed important by the public. The paper presented by Stupar and Dierksheide (2001) reviewed the new integrated maintenance, inventory and purchasing system implemented by the Ocean County Utilities Authority. The goal of integrating the system was to not only ensure that high quality WWTP effluent is discharged but also to reduce the probability of sanitary sewer overflows. Scott et al. (2001) reported on the Emergency Response Plan implemented by the City of Baltimore, Maryland as a response to the EPA's guidelines for developing a CMOM program. In this Plan, critical facilities (pumping stations, pipelines, valves, and other components with a high risk of failure) were identified and their impact on public health and the environment was ranked. This Plan is guiding the implementation of recommended mitigation measures.

The use of analyzing utility data relative to sanitary sewer overflows was presented by Nelson et al. (2001). The purpose was to establish protocols for identifying SSOs through data already collected by utilities. Turner et al. (2001b) reported on Columbus, Georgia's development of plans for managing CSOs and SSOs. The strategy was based on the "further-reasonable-progress" approach to attaining water quality standards. The keys to success have been the demonstration of sustainable watershed solutions and the results from continued receiving water monitoring. The EPA BASINS model, with field-data calibration, was used to digitally represent the watershed and evaluate potential improvements. According to McConico et al. (2001a), in 2000, the City of Richmond, Virginia conducted a bacteriological monitoring. The purpose of this data collection was to monitor the effectiveness of the City's long-term CSO control program through comparing the new data to data collected in the 1980s and 1990s. The data was also used in the combined sewer system and James River tidal models that predicted for the effectiveness of long-range CSO planning. Carr (2001) reviewed the concept of micromanagement of stormwater flows to reduce SSOs and CSOs. Micromanagement of stormwater advocates temporarily storing stormwater in many and varied locations on the surface (off-street and on-street) and, as needed, below the land surface, near to the source. The paper reviewed the application of stormwater micromanagement in Skokie, Illinois and the lessons learned from the implementation.

Sewerage Repairs and I&I. As reported by Lai and Field (2001), the USEPA has conducted a series of research, development and demonstration projects on the characterization, cause, consequence, and control of infiltration/inflow (I/I) in both sanitary and combined 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.

Public Education. White (2001) reviewed the joint agency program of King County and the City of Seattle (in conjunction with the Seattle-King County Health Department) for public notification of combined sewer overflows. The program included posting warning signs at over 100 CSO locations, developing a website, information line, brochure, fact sheet and other materials. According to the review of Rozelman and Loncar (2001), the 1995 New York State Discharge Notification Act (DNA) (aka "Fisherman's Right to Know Act") caused the New York City Department of Environmental Protection to enhance their public education program regarding CSOs and encouraged the public to provide the City with early notification of sewer problems such as dry-weather discharges.

Tunnels and Interceptors. Three major tunnel construction projects were presented during WEFTEC 2001. Jones and Robison (2001) reviewed the history, the design, and the construction of the Chattahoochee Tunnel in Metropolitan Atlanta. This tunnel was designed to accomplish two purposes: relieve the existing Chattahoochee Interceptor and provide flow equalization for the existing water reclamation facility. Wood et al. (2001) presented an overview of the decisions that went into the design of the interconnected Westside and Eastside CSO tunnels in the City of Portland. The analyses included comprehensive hydrologic and hydraulic modeling of the combined sewer drainage system and the tunnel system, RTC simulation of gates, weirs, and pumping facilities, and planning for instrumentation, monitoring, operation, control, and maintenance. Roll and Lannon (2001) reviewed the repair of the Falls Street Tunnel in Niagara Falls, New York. The repair was designed to reduce the 6-MGD of groundwater infiltration into the tunnel. The contractor payment for the project was based on the infiltration reduction, which was estimated to be approximately 4 MGD.

Ab Razak and Christensen (2001) investigated the benefits of the Milwaukee deep tunnel for temporary storage of storm water and sewage, on the water quality of the Milwaukee, Menomonee, and Kinnickinnic Rivers. Statistical analysis of BOD, phosphorus, suspended solids, fecal coliforms, zinc, and chloride indicated that the Menomonee River benefited the most from the deep tunnel since 1994 when the tunnel came on line. Fecal coliforms inside the CSO area, and to a certain extent BOD and zinc levels, exhibited the most significant decline.

Litter, Floatables and Settled Solids. The paper by Fan et al. (2001a) reviewed the causes of sewer deterioration and the control methods that can be used to prevent or postpone this deterioration. The remedy reviewed in the paper was inline and combined sewer overflow tank flushing systems to remove sediments and thus minimize hydrogen sulfide production in the sewer system. The two technologies reviewed were the tipping flusher and the flushing gate, both of whom have been demonstrated to perform well in facilities in Germany, Canada and the United States.

Real-Time Control (RTC). O'Connor and Field (2001) reviewed the USEPA Capstone Report on control system optimization, including a management strategy that will maximize the use of the existing system. This will postpone construction of new facilities and will size storage volumes in concert with the treatment rate to obtain the lowest-cost storage-treatment system. The components, hardware, and strategies to create such a system were described. An RTC methodology was used to measure the discharge problem from an urban area (Yamada et al., 2001b), and was used in conjunction with a stormwater tank to retain flows. The results showed that COD in the stormwater runoff was reduced to approximately 0.45 mg/L.

The sewer system evaluation by the Milwaukee Metropolitan Sewer District (MMSD) proposed that flow regulation in the system be controlled not by specific flow rate from the tributaries but instead by maintaining a constant hydraulic grade line in the system, i.e., the flow allowed in the system will be determined by the available capacity of the downstream pipes (Bate 2001). The paper by Schultz et al. (2001a) explained how controlling the interceptor system, rather than just relieving it, enabled the Milwaukee MSD to achieve far more than merely reducing bypass and overflow frequency. The collection systems controls allow the MMSD to meet tight overflow restrictions in a manner flexible to variable precipitation patterns, growth patterns, and lake and groundwater levels. In addition to more efficient use of intercepting sewer capacity, the regulation strategy also provided a significant cost savings when compared to conventional flowrate regulation. The Louisville and Jefferson County Metropolitan Sewer District (MSD) is considering Real Time Control as a possible alternative in the Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) (Charron et al., 2001). Two successive studies have produced very promising results – the first implying an overall reduction of 64% in annual overflow, and the second currently showing similar results to the first.

Chowdhury et al. (2001) reviewed the RTC control model developed for the District of Columbia. The model was applied to evaluate existing and potential improvements to the system, and also used to evaluate the effectiveness of previously-installed controls. The model results indicated that significant reductions in overflows had been achieved through the controls installed in the past. Real-time control (RTC) operations strategies for the Quebec Urban Community (QUC) were discussed by Colas et al. (2001). Simulation of each RTC strategy using 32 real back-to-back rainfalls showed that the existing system performs better under RTC than with conventional control. Efficient in-system storage and treatment capacities and the elimination of flood risks were the main benefits of this type of real-time management. The results of the first year of operation of the optimized real-time control system for the QUC were presented by Lavallee et al. (2001). These results confirmed the model results for the benefits of the QUC RTC. RTC use in Philadelphia was reviewed by Marengo et al. (2001). The implemented RTC system provides the capability to prioritize capture of combined flow in the collection system, to minimize overflows to sensitive receiving streams, and to optimize the use of available interceptor sewer-system storage during wet weather. SWMM model simulations were performed to quantify the benefits of RTC implementation in PWD's SWDD.

<u>CSO Storage Tanks and Structures</u>. Carr et al. (2001) reviewed the use of street-storage systems to prevent combined sewer overflows and mitigate basement flooding, based on the idea of accepting the complete volume of water but reducing the inflow rate of the stormwater to the sewer system. System components included street berms, flow regulators and surface and sub-surface storage facilities. Charlotte-Mecklenberg Utilities also found that they were able to service new development without creating overflows by storing peak flows upstream (Crowley and Howard 2001), thus delaying a system-wide expansion. Carter et al. (2001) reported on the evaluation of inflatable dams for use in Philadelphia as part of its Long Term Combined Sewer Overflow Control Plan (LTCP). These dams were operated under real-time controls to storage and treat flows upstream, thus reducing the frequency and volume of CSOs. Based on model results (using EXTRAN) with three inflatable dams operated by RTC, a 70% (50-million gallon) reduction in average annual CSO volumes to the Schuylkill River would be expected.

Murphy and Ring (2001) reviewed the use of pre-cast concrete box sections to create CSO storage facilities. The savings from using pre-cast versus cast-in-place boxes was estimated at $3.1 million dollars for the 1.2-million gallon Kenduskeag East CSO Storage Facility. The Pollution Control Plan (PCP) for Hamilton-Wentworth recommended the construction of 10 – 12 underground storage tanks to intercept CSO waters for subsequent conveyance to the treatment plant (Stirrup 2001). The sizing of the tanks was performed using SWMM. The premise was that continuous modeling would be the only reliable way to ensure that the tank performs to those control criteria under real operating conditions for long periods of time. Freedmand et al. (2001) reported on the use of unused aeration basins for receiving and equalizing industrial and CSO flows to the treatment plants in Rockland, Maine.

<u>CSO Treatment</u>. Wojtenko et al. (2001a) reviewed the chapter of the EPA Capstone Report on control and treatment of CSOs, SSOs, and stormwater runoff. The paper discussed inline and offline storage systems as well as in-receiving water storage systems. Three major types of treatment systems and their associated costs were also discussed: (1) physical (screening and sedimentation), including comparing high-rate vs. conventional processes; (2) physical/chemical (filtration and high-rate sedimentation); and (3) biological (trickling filters, activated sludge, aerated lagoons, and rotating biological contactors).

Project Review – General. Gaffoglio et al. (2001) reviewed the City of New York's $1.8 billion Citywide CSO Program that addressed CSO discharges from the more than 450 CSO locations within the City. Four open water projects (East River, Jamaica Bay, Inner Harbor and Outer Harbor), and four tributary projects (Flushing Bay, Paerdegat Basin, Newtown Creek, and Jamaica Tributaries) were included in the program. The paper described the CSO facilities NYC is building and planning under this major capital planning and construction effort, and it discussed the challenges faced by the City in implementing the program. Mynhier et al. (2001) summarized the City of Atlanta's recommendations for their Long-Term Control Plan for CSOs. The City proposed three options ranging from separating about 80 percent of the CSO service area ($1.25 billion) to solely adding large consolidated storage and treatment facilities ($710 million). The preferred option was between the two extremes, with some separation and consolidated storage and treatment facilities capable of treating all storm water runoff from the CSO area ($950 million). Turner et al. (2001a) reviewed the CSO technology-testing program implemented in Columbus, Georgia. Results included protocols for characterization, model calibration and watershed yield quantification. Overall program findings included load generation rates and yields for aquatic biology indices. CSO treatment demonstrations indicate high-rate compressed media filtration as a cost-effective technology that may also be applied to stormwater as an impervious area flush-control. Schenk et al. (2001b) presented an overview of the EPA's Environmental Technology Verification (ETV) Program, with a focus on two areas of technology: flow meters and stormwater source-control devices. The Wet Weather Flow Technologies Pilot (WWF Pilot) program balances the desire for comprehensive testing (full characterization of equipment performance under a variety of water quality and facility conditions) against the need to keep testing costs reasonable.

Disinfection. Atasi et al. (2001c) presented the work performed by the City of Detroit Water and Sewerage Department (DWSD) that evaluated chemical disinfectants for the Baby Creek CSO water. EPA's ETV Program developed generic protocols for the testing of mixing needs in high-rate disinfection, such as that needed for CSO treatment (Moffa et al., 2001). The ETV program is also investigating alternative disinfectants. The New York City pilot study addressed, and an ongoing WERF project is addressing, alternative technologies. As part of the ETV Program, the WWF Pilot investigated the potential of high-rate disinfection technologies for wet-weather flow applications (Schenk et al., 2001a). The benefits of using simulated flows were described, as were the potential limitations associated with applying the data to actual wet weather collection systems. Wojtenko et al. (2001c) presented the results of several major pilot-scale studies to evaluate the effectiveness of UV light to disinfect CSO flows. UV light irradiation, when correctly applied, was found to be an effective alternative to chlorination for CSO disinfection. However, the success of disinfecting with UV light seemed to be strongly dependent on water quality. Wojtenko et al. (2001d) reviewed the chapter of the EPA Capstone Report on disinfection. Locating effective alternate disinfectants has proved to be very difficult.

High-rate clarification (including ballasted flocculation). Jolis and Ahmad (2001) reviewed the use of high-rate clarification at the wet-weather treatment plants in San Francisco. The process was found to be highly effective for CSO pollutant removal. Suspended solids removal in excess of 80% of influent concentrations were achieved consistently. COD and BOD_5 removal exceeded 60%. Keller et al. (2001) reviewed the design of a ballasted flocculation system for the Lawrence (Kansas) WWTP. The ballasted flocculation system was used to treat excess flows from wet-weather events. The paper reviewed the jar test results, the performance of liquid versus dry polymers, and other design issues. The City of Rocky River, Ohio reduced their SSOs through expansion of the WWTP's primary treatment capacity (Leffler and Harrington 2001). The primary-treated effluent in excess of what the secondary treatment could handle was then blended with fully-treated effluent waters prior to discharge to the receiving water. This blending allowed the overall plant effluent to meet regulatory standards with the concurrent elimination of headworks bypassing. Ballasted flocculation to improve WWTP performance during wet-weather flow periods was reviewed by Scruggs and Wallis-Lage (2001). Based on pilot and bench scale testing performed at three facilities, the ballasted flocculation technology was found to be compatible with client needs. In all cases, the ballasted flocculation system removed 75 to 95% of influent storm flow TSS at hydraulic loading rates varying from 60 to 80 gpm/sf when ferric chloride was used as the coagulant. The use of ballasted flocculation was also cost-effective at the three plants.

Filtration. Three western New York State treatment plants have retrofitted their existing sand filters to a coarse monomedia (Bentivogli and Smith 2001). The new media filters use less peak backwash water, have increased filter run times and have maintained the same effluent quality as the older sand filters with the smaller diameter media. Testing is ongoing for CSO treatment. The Niagara County Sewer District No. 1 Water Pollution Control Center installed mono media filtration to increase capacity in order to treat additional flows during wet-weather events. The result is that the Sewer District has met their goal of increasing filtrating capacity and filter run times, while eliminating filter bypassing.

Flow control in WWTP. In Flanders, Belgium, the potential to treat additional flow in the biological system of a WWTP was investigated by 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 could regulate the flows through activated sludge process sufficiently to maximize the treatment plant performance. Niemann and Orth (2001) modeled three modifications to traditional WWTPs in order to maintain a high efficiency of treatment during wet-weather flows. The three measures were increasing the nitrification volume, bypassing the primary sedimentation, and adding flocculants before secondary sedimentation. All three measures were effective.

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