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URBAN WET-WEATHER FLOWS

Shirley Clark, Ronald Rovansek, James Heaney, Leonard Wright, Richard Field, and Robert Pitt

This subject, Urban Wet-Weather Flows, was comprised of three basic subareas, i.e., 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)

An overview of the evolution of urban drainage, illustrating where the concept of a single design objective was replaced by the sustainability concept, was provided by Marsalek (2000a). The advances highlighted by Marsalek included improved (dynamic) control of urban drainage, source controls, integrated modelling, public and political support, innovative university training, sustainable funding, adaptive water management, and investment in research and development (Marsalek 2000b). The paper also highlighted the future challenge of involving the public in the planning of drainage systems and protection of urban waters (Marsalek 2000c). Cigana and Couture (2000) advanced a list of key steps required to achieve a global approach to Wet Weather issues.

The overall challenges of urban drainage design and monitoring were discussed by both Marsalek and Kok (2000) and by Cigana (2000). Cigana has provided a discussion of the pollution resulting from stormwater runoff and from combined sewer overflows (CSOs). The paper also reviewed the technologies available to control this pollution. Marsalek and Kok noted that the effectiveness of stormwater BMPs is not fully understood, and advocated future research into the design, operation and maintenance of these pollution control practices.

CHARACTERIZATION

General. For California's implementation of industrial stormwater discharge control, Shaver and Duke (2000) characterized Los Angeles industrial facilities as to the types of operations and exposures to rainfall that occur on a site. The results of the survey showed that the majority of sites were impervious, conducted more than one regulated activity, and had a wide range of housekeeping practices and intensities of activity that were exposed to rainfall. The authors questioned whether the general permit should be applied equally to all industrials sites or whether resource allocation should be based on sites where pollutant load reduction potential would be greatest.

Flow evaluation. A model (based on dynamic wave equations) for characterizing overland flow on paved surfaces was evaluated by James et al. (2000) and tested successfully using a laboratory-scale rig. Using chloride tracers, Kirchner et al. (2000) showed that many catchments do not have characteristic flushing times. Travel times in the catchments and streams followed an approximate power-law distribution, where contaminants will initially be flushed rapidly, but then low-level contamination will be delivered to the streams for a long time after the initial flush. Schreider et al. (2000) predicted the impact that global warming due to increased carbon dioxide concentrations would have on flood frequencies in the urban areas near Sydney and Canberra, Australia. Their results showed that storms that currently cause the 1 in 100-year flood become the 1 in 44-year event for one basin, and the 1 in 10-year event for another local basin.

Pollutant modeling. Tsanis (2000) developed a program named RUNMEAN (RUNOffMEAN) for estimating toxic-contaminant event mean concentrations (EMCs) in stormwater runoff. EMCs were analyzed by Behera et al. (2000) for areas of Toronto, Canada, that had both separate and combined sewer systems, and noted that the data followed the gamma and exponential probability distributions, in addition to the log-normal probability distribution. Lee and Bang (2000) investigated the relationship between pollutant loadings and runoff flows, especially the first flush in the urban areas of Taejon and Chongju, Korea. They found that the pollutant concentration peak occurred earlier than the flowrate peak in areas smaller than 100 ha where impervious area was more than 80%. However, in areas more than 100 ha with impervious area of less than 50%, the pollutant concentration peak followed the flow rate peak, with this order occurring more frequently in watersheds with combined sewer systems. Mattson et al. (2000) investigated the event mean concentrations of a range of pollutants in urban stormwater runoff that entered the Severn Sound. In samples from the beach areas, they found E. coli concentrations exceeding 600 organisms/100 mL when rain events were greater than 20 mm. The model of the stormwater entering the Sound estimated a phosphorus loading to the Sound of 1083 kg/yr.

As part of a modeling exercise for predicting removal of beach closure restrictions after a storm event, Jin et al. (2000) characterized the movement of indicator organisms (E. coli, Enterococci, and fecal coliforms) from stormwater outfalls in Lake Ponchartrain to Lincoln Beach in New Orleans. They found that, as expected, a rapid decrease in organism concentration occurred near the outfall and they also found that two or three days after pumping, indicator organism concentrations at Lincoln Beach were below the health standards for swimming. Their data also showed that E. coli was a better indicator organism for fresh water environments, while enterococci was more suited for use in marine or brackish environments. Ball and Abustan (2000) investigated the phosphorus export from an urban catchment in Sydney, New South Wales, Australia, and derived a relationship between inorganic suspended solids and particulate phosphorus for this catchment. These results were to be used to predict the performance of detention ponds and/or wetlands for treating this runoff. Williamson and Morrisey (2000) modeled the build-up of heavy metals (Pb, Zn, and Cu) in urban estuaries due to stormwater contamination, with the model being based upon the behavior of the metals in runoff and during transport in the estuarine system.

Urban runoff characterization studies. The known thermal pollution of Oregon’s streams and rivers was reviewed by Bullock and Eimstad (2000), and included a review of sensitive habitats for salmonid species. They presented information on the Oregon Department of Environmental Quality temperature standards for receiving waters, as well as guidance for developing a Temperature Management Plan.

Ball (2000) reported on the quantities of pollutants that entered the stormwater treatment facility at Centennial Park in Sydney, Australia, and showed that the gross pollutant trap when combined with a wetland or detention pond removed 87% of suspended solids and 50% of the entering phosphorus. Lieb and Carline (2000) investigated the effects of detention pond effluent on a headwater in central Pennsylvania and showed that the macroinvertebrate community immediately downstream of the pond was highly degraded, although recovery was seen farther downstream. Stormwater sediments in Ottawa, Ontario, Canada, were analyzed for their ecotoxic risk by vanLoon et al. (2000). The results indicated that the sediments present significant potential risks to the ecosystems that develop around passive stormwater treatment sites, such as detention ponds. Jones (2000) reported on the results of using the US EPA’s Rapid Bioassessment Protocol (RBP) in streams affected by stormwater runoff in Fulton County, Georgia. The results of their assessments from 30 stations showed that changes in habitat had a greater effect on the biological communities than did water quality and that control of total suspended solids entering the stream was necessary for habitat protection.

Armitage and Rooseboom (2000) demonstrated that large quantities of litter are being transported in South Africa in urban stormwater runoff, and that the amount of litter produced could be related to land use, vegetation, level of street cleaning and type of rainfall. The benefits of litter reduction were documented using their work in Australia and New Zealand, and design equations for sizing litter traps were proposed. Newman et al. (2000) presented work on the characterization of the flotables found in urban stormwater runoff. The results of this study were to be used to develop transport models of the movement of and controls for these flotables.

Francy et al. (2000) related potential sources of microorganisms (total coliforms, Escheria coli, and Clostridium perfringens) to receiving water quality. In general, fewer organisms were found in the groundwater. Land use was found to have the greatest influence on bacterial indicators in stream water, while presence of septic systems and well depth had the greatest influence on the bacteria concentration in groundwater. Skerrett and Holland (2000) found that Cryptosporidium oocyst occurrence in Dublin, Ireland, area waters increased after a heavy rainfall, likely due to increased the runoff volume into the receiving water. Their results also showed that Cryptosporidium oocysts were widely dispersed in the Dublin-area aquatic environment.

In the central Paris district of “Le Marais,” Gonzalez et al. (2000) found PAHs primarily in the particulate phase in all catchments, with the median concentration in combined sewer overflows of 204 ng/L. Phenanthrene, anthracene, fluoranthene and pyrene were the most observed compounds. The results indicated that atmospheric deposition was an important source of PAHs in urban stormwater runoff. Ngabe et al. (2000) analyzed urban stormwater runoff in coastal South Carolina for PAH content. The authors found the highest concentrations (5590 ng/L) of PAHs in runoff from Columbia, a major metropolitan area, and lower concentrations (282 ng/L) from the small town of Murrells Inlet. The PAH profiles in the runoff from the two urban areas were similar to those found in atmospheric deposition and unlike those in used crankcase oil. However, the aliphatic fraction of the organics in Columbia’s runoff were more similar to used crankcase oil than to urban aerosols.

Shinya et al. (2000) investigated the concentrations of metals and PAHs in the runoff from four urban-highway rainfall drains. The results showed a first flush of both metals and PAHs. Most of the metals were tied up with the particulate matter, as were the higher molecular weight PAHs. Phenanthrene, fluoranthene, and pyrene comprised about 50% of the quantified PAH constituents in each sample. Smith et al. (2000) analyzed for PAHs in stormwater runoff from four locations in an urban area: a gas station, a highway off-ramp, and a low- and a high-traffic volume parking lot. The gas station site produced the highest total PAH loading (2.24 g/yr/m2), followed by the high-traffic-volume parking lot (0.0556 g/yr/m2), the highway off-ramp (0.052 g/yr/m2), and the low-traffic-volume parking lot (0.0323 g/yr/m2). PAH concentrations were usually highest during the 'first flush' of storm-water runoff and tapered off rapidly as time progressed. The concentrations and characteristics of organic carbon (as DOC) in surface waters in Arizona were studied by Westerhoff and Anning (2000). Fluorescence measurements indicated that DOC in desert streams was from autochthonous sources; however, DOC in unregulated upland rivers and desert streams shifted from autochthonous to allochthonous sources during runoff events. The urban water system affected temporal variability in DOC concentration and composition.

Urban stormwater runoff was targeted by Neto et al. (2000) as a potential source for the elevated metals (Pb, Zn, Ni, Cu and Cr) concentrations found in Jurujuba Sound in Southeast Brazil. Investigation of sediment cores indicated that the increase in sediment metals concentration occurred at approximately the time that rapid urbanization began in the watershed. Parker et al. (2000) analyzed the sediment found in urban stormwater runoff in the Phoenix, Arizona, metropolitan area. They found that the inorganic content of the sediments was similar to that in soils that were not impacted by urban runoff. The metals concentrations (Cd, Cu, Pb, and Zn) were higher, but below levels that would recommend remediation. Arsenic concentrations were above recommended levels; however, this contribution likely was geologic not anthropogenic. Chlordane, DDT (and DDE and DDD), dieldrin, toxaphene, and PCBs were found in the sediments at all sampling locations. Sediment toxicity was seen, but could not be explained based on their chemical results. Vollertsen and Hvitved-Jacobsen (2000) investigated the resuspension of sewer solids in combined sewers. They found that sewer solids that were undisturbed for up to two weeks were more easily resuspended and their oxygen uptake rate was significantly greater than fresh solids, indicating that the flushing of these solids into receiving waters may cause oxygen depletion problems.

Pollutant Sources

General sources. Toxicity testing was performed by de Vlaming et al. (2000) in order to identify chemical causes and sources of contamination. Urban runoff was found to be toxic to *Selenastrum*. The overall results indicated that the whole-effluent toxicity (WET) tests, when combined with traditional chemical analyses, were beneficial in locating sources of toxicity within a watershed. Patty and Ahmed (2000) described the watershed assessment and protection plan being implemented in Peachtree City, Georgia, including both wet-weather and dry-weather sampling. These samples were to be used to ensure that standards are met and for model verification, where the model will be used to anticipate impacts from land development in the water. An overview of the National Cooperative Highway Rsearch Program (NCHRP) upcoming work was presented by Stein et al. (2000). This presentation included an evaluation of past work on stormwater runoff from transportation facilities and a prioritization of future research in this area.

A study of heavy metal concentrations in sediments from Australian estuaries and the continental shelf by Birch (2000) showed that the concentration of metals was significantly higher in the estuaries than along the continental shelf. Also, the estuaries were found to have sediment metals concentrations that were related to the degree of urbanization/industrialization in the watershed. High metals concentrations, including Pb and Zn in Port Jackson (Sydney, New South Wales) which were at levels expected to have adverse environmental/biological effects, were found in the fluvial sediments, indicating that metals are still being added to the estuaries, potentially through stormwater runoff (including land reclamation leachate). Webster et al. (2000) analyzed the sources and transport of trace metals in the Hatea River catchment and estuary in New Zealand. They found that the recently deposited estuarine sediment has elevated levels of Cu, Pb, and Zn from the more densely-populated areas, city stormwater drains and the Cu-containing antifoulants used in the marina. All metals were transported in both dissolved and particulate form in the tributaries, with lead being shown to bind most effectively to the sediment. Levesque and De Boer (2000) investigated the impact of a large urban center on the trace metal chemistry of a surficial fine-grained sediment in the South Saskatchewan River, Canada. No effect from the urban center on the metals content of the sediment was seen - with the exception of uranium, whose concentration was measurably greater below the urban center. Smith and Swanger (2000) investigated the impact of leaching of lead-free solders in construction waste and found that alloys containing antimony had leachate concentrations above regulatory limits. Alloys containing silver also potentially could impact the environment if entrained in stormwater runoff.

De Luca-Abbott et al. (2000) used enterococci to trace the spatial and temporal impacts of stormwater discharges from an outfall in northeastern New Zealand. Both seasonal and temporal trends in enterococci concentrations were noted, with the maximum contamination being found with the high winter rainfalls and near the outfalls. The occurrence and possible sources of Giardia and Cryptosporidium in Paris rivers were investigated by Rouquet et al. (2000). The results showed that non-point sources likely influenced parasite concentrations in the rivers. Parasite sedimentation was high, as was the potential for resuspension by urban runoff. Ramirez Toro et al.

(2000) presented the study design for investigating water quality in La Parguera in relation to onshore development, stormwater outfalls, and mangroves and sewage treatment plants in the vicinity. Samples were analyzed for the following constituents: bacteriological indicators (total and fecal coliforms, Escherichia coli, Enterococcus), total suspended solids, chlorophyll, light attenuation (light reaching the bottom compared to surface insolation) and nutrients (NH3, NO3, NO2 and PO4). The research conducted by Sonoda et al. (2000) investigated the impact of land use on streamwater nutrient concentrations in an urbanizing watershed in Oregon. During the dry season, soluble reactive phosphorus (SRP) was correlated with light industry land use, while during the wet season, SRP was correlated with light industry, single family residential and mixed residential land uses. During the dry season, nitrate-plus-nitrite was correlated with rural, and heavy and light industry land uses, while during the wet season, NO3 + NO2-N was correlated with rural and heavy industry land uses. Milam et al. (2000) investigated the effects of several pesticides (chlorpyrifos, malathion, Permanone(R), Abate(R), Scourge(R), B.t.i. and Biomist(R)) on both standard toxicity-testing organisms (Ceriodaphnia dubia, Daphnia magna, Daphnia pulex, and Pimephales promelas) and resident mosquito fish and mosquito larvae. They demonstrated that the current pesticide application rates were sufficient to affect non-target organisms when the pesticides were washed off in stormwater runoff.

Industrial sources. Akan et al. (2000) noted that a significant pollutant loading to the adjacent receiving water can occur due to runoff from marine drydocks. The authors modeled the quantity and quality of marine drydock runoff by combining the two-dimensional kinematic wave and convective transport equations with an empirical formula for washoff. Lewis et al. (2000) reviewed stormwater-runoff monitoring data from industrial facilities discharging into the upper San Gabriel watershed in the Los Angeles region. The results of this review showed that while industrial facilities occupy less than 1% of the watershed area, they contribute between 10% and 70% of the total copper and between 15% and 60% of the total zinc loads. Moreno-Grau et al. (2000) investigated the heavy metal content of atmospheric aerosols and suspended particulate matter from industrial areas in Cartegena. The industries contributing to the atmospheric metals contamination included power plants, oil refineries, non-ferrous metals, fertilizer plants and a shipyard.

Atmospheric deposition and roofs. In a study on the influence of atmospheric deposition on the concentrations of mercury, cadmium and PCBs in urban runoff, Atasi et al. (2000) found that atmospheric deposition was the primary source of these compounds in runoff from controlled surfaces. The authors argued that the contribution of atmospheric deposition must be accounted for both in modeling of pollutant sources, but also in planning for pollution prevention. Zobrist et al. (2000) examined the potential effects of roof runoff on urban stormwater drainage from three different types of roofs: an inclined tile roof, an inclined polyester roof and a flat gravel roof. Runoff from the two inclined roofs showed initially high (“first flush”) concentrations of the pollutants with a rapid decline to lower levels. The flat gravel roof showed lower concentrations of most of the pollutants because of the ponding of the water on the roof surface acting like a detention pond. Pollutant loadings was similar to atmospheric deposition, with the exception of copper from drain corrosion (rate about 5 g/m2-yr). Tobiason and Logan (2000) used the whole effluent toxicity (WET) to characterize stormwater runoff samples from four outfalls at Sea-Tac International Airport. Three of the four outfalls met standards; the source of the toxicity at the fourth outfall was found to be zinc-galvanized metal rooftops. Typically, more than 50% of the total zinc in the runoff was in dissolved form and likely bioavailable.

Highway runoff. Since urban roads are typically directly connected to the drainage system and therefore respond quickly to storm events, the quality of urban road runoff in the Sydney, Australia, region was investigated by Ball (2000). This paper also proposed guidelines for estimating the transportable trace-metal loading from road surfaces. Ball et al. (2000) showed that the quality of the runoff resulting from the construction of a new highway intersection in Australia could be improved by using treatment devices such as detention ponds and sand filters. Hirsch (2000) reported on the development of a TMDL for Straight Creek in Colorado due to the sediment and pollutant loads contributed to the stream by Interstate 70 runoff. The interstate construction increased erosion in the stream due to the significant cut-and-fill, as did the snowy winter road conditions which required extensive sand applications. An investigation by Drapper et al. (2000) showed that the pollutant concentrations (heavy metals, hydrocarbons, pesticides, and physical characteristics) in ‘first flush’ road runoff in Brisbane in southeast Queensland, Australia was within the ranges reported internationally for highways. Traffic volumes were the best indicator of road runoff pollutant concentrations, with interevent duration also being statistically significant factor. Exit-lane sites were found to have higher concentrations of acid-extractable copper and zinc, likely due to brake pad and tire wear caused by rapid deceleration, and laser particle sizing showed that a significant proportion of the sediment in runoff was less than 100 um. Krein and Schorer (2000) investigated heavy metals and PAHs in road runoff and found that, as expected, an inverse relationship existed between particle size and particle-bound heavy metals concentration existed. However, particulate-bound PAHs were found to be bimodally distributed. Three-ring PAHs were mostly find in the fine sand fraction, while six-ring PAHs were mostly concentrated in the fine silt fraction. Sutherland et al. (2000) investigated the potential for road-deposited sediments in Oahu, Hawaii, to bind contaminants, and thus transporting these bound contaminants to the receiving water as part of the runoff. In the sediment fractions less than 2 mm in diameter, the origins of the aluminum, cobalt, iron, manganese and nickel were determined to be geologic. Three of the metals concentrations, copper, lead and zinc, were found to be enhanced by anthropogenic activities. Sequential extraction of the sediment determined the associations of the metals with the following fractions: acid extractable, reducible, oxidizable, and residual).

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

Pesticide use. Lee et al. (2000) found that stormwater runoff in San Diego Creek was toxic to Ceriodaphnia and Mysidopsis. About half of this toxicity was found to be attributable to the use of the organophosphate pesticides diazinon and chlorpyrifos used in the urban areas for structural termite and ant control and for lawn and garden pest control. Lutes et al. (2000) investigated an eleven-acre lake on a golf course at NAS Jacksonville in terms of potential ecological and health risks posed by sediments and fish in the lake. The identified contaminants of interest at the site; PCBs in fish, metals in sediments, pesticides in sediments, and PAHs in sediments, are most likely attributable to storm water impacts. The identified exposure pathways to the contaminants are through recreational fishing and the use of the lake by wildlife.

Wastewater treatment plants and sewer overflows. Hale et al. (2000) investigated the occurrence of nonylphenols (an endocrine disruptor often from laundry products) from a variety of outfalls, and found that the highest concentrations in the sediment (14,100 ug/kg) was detected near a federal facility's stormwater outfall. Sediment samples taken below an out-of-service sewage treatment plant indicated that nonylphenol persisted in the sediment. Hartmann et al. (2000) investigated the application of linear alkylbenzenes (LABs) as a molecular marker in marine sediments in Narragansett Bay. In the urban rivers at the head of the bay, the Providence River, Seekonk River, and Taunton River concentrations were locally high with a few values exceeding 2000 ng/g total LABs. The I/E (internal/ external C-12 isomers) ratio, a measure of the degree of degradation, indicated that treated sources (i.e. sewage effluents) and local fresh sources (e.g. combined sewer overflows and boat cleaning detergents) were major contributors of LABs to the rivers. The observed decrease in LAB concentration with distance downbay suggested that most of the LABs were deposited within a few kilometers of their source.

Lessard and Michels (2000) examined the effects of CSO basin discharge on the water quality in the Menominee River in 1997. Based on the data collected, the overflow from the CSO retention basin does meet the Michigan Water Quality Standards during the overflow discharge events, with the basin providing the equivalent of primary treatment plus disinfection. The loadings of most of the pollutants, including nutrients, metals and suspended solids, were insignificant compared to background. The CSO basin effluent also did not appear to impact the dissolved oxygen in the river to the point where the DO fell below standards. McGee et al. (2000) investigated the potential sources of indicator bacteria that closed a portion of Huntington State Beach in Orange County, California. The approach used was termed a "risk-based sanitary survey," and the investigation used both state-of-the-art technologies (radar, sonar, and infrared imaging) and conventional techniques (geo-probes, television inspection of the sewers, and monitoring wells). White et al. (2000) investigated the effects of land use change and resulting bacterial concentrations on shellfish closures in Jump Run Creek in North Carolina. The results of this project showed that the likely sources of the elevated bacterial concentrations (high during wet weather, moderate during dry weather) was the area draining an older, medium density residential neighborhood (single family homes, trailer park with two malfunctioning septic tanks and more than 100 pets, plus wildlife). Dye studies in the area indicated that flow through area was too small for bacterial mortality to occur.

Monitoring

Bertrand-Krajewski et al. (2000) reviewed their Experimental Observatory for Urban Hydrology project that demonstrated the need for improved knowledge about the interactions between urbanization, pollutant discharges, impacts on the natural environment, and socio-economics. The aim of the project will be to improve methodologies for investigating the sustainability of urban water systems. Collins et al. (2000) reviewed the USEPA's Clean Water Compliance Watch (CW2) Environmental Monitoring for Public Access and Community Tracking (EMPACT) project. EMPACT projects use state-of-the-art technology to track environmental conditions and to provide easy public access to information in easily-understood language. Dwyer and Wissing (2000) described Waterwatch Australia, a national monitoring and environmental education program. The program has involved over 2000 groups monitoring approximately 5400 sites in 246 catchments, with much of the work done by volunteers and community groups.

Fernando et al. (2000) presented the development of effectiveness indicators ("a measurable feature that provides managerially and scientifically useful evidence of stormwater and ecosystem quality or reliable evidence of trends in stormwater quality and program effectiveness") for stormwater and watershed management programs and the development of a regional monitoring program for the Hampton Roads Planning District Commission (Virginia). As reported by Schaad and Kam (2000), the City of Kelowna completed a State of the Environment Report which examined air, land and water quality. Thirteen of the twenty-two indicators directly addressed watershed health. These indicators were designed to show current watershed health and future trends. Cloak (2000) described the implementation of twenty of the Center for Watershed Protection's Environmental Indicators to Assess Stormwater Programs and Practice, and showed that the indicators were most useful when organized into a framework that could be used to inform stakeholders and the public. The investigation (Cloak et al. 2000) separated the indicators into two groups: The first group, the programmatic indicators targeted at measuring specific program activities, was useful for documenting and understanding pollution-prevention efforts. The second group of indicators (application of physical, water-quality, and biological measurements at a watershed scale) were useful for an overall assessment of stream function and an understanding of the natural and anthropogenic factors influencing those functions.

Toxicity testing. Baker et al. (2000) reviewed a project undertaken as part of Mecklenberg County's Surface Water Improvement and Management (SWIM) program, and which included restoration in the highly-urbanized Edwards Branch watershed. The project emphasized the importance of using a variety of monitoring techniques - EPA stream habitat assessment protocol, ambient water quality monitoring, fish and benthic macroinvertebrate surveys, and channel cross-section monitoring - to investigate the effectiveness of the installed BMPs and other restoration techniques. The bioasssessment approach used in the Camp Creek Watershed in Fulton County, Georgia was reviewed by Jones (2000). By linking the biological results with the water quality monitoring data, management goals were set and improvements were focused on critical management areas. The paper by Rochfort et al. (2000) encouraged the use of benthic assessment techniques, in conjunction with toxicity testing and sediment and water chemistry analyses, to determine the impacts of stormwater and combined sewer overflows (CSOs) on receiving water and the biota. The results from all three analysis techniques showed that the sediment chemistry could not be correlated to either the toxicity testing or the benthic community impacts, and that a combination of techniques was necessary to show a complete picture of stream health.

Chappie and Burton (2000) described the application of in-situ aquatic sediment toxicity testing for stormwater runoff assessment. Burton et al. (2000) described the problems associated with using traditional toxicity testing methods for assessing the biological impacts of stormwater runoff. The problems noted include the inability to produce reliable conclusions when this technique was used to detect the adverse effects of fluctuating stressor exposures, nutrients, suspended solids, temperature, UV light, flow, mutagenicity, carcinogenicity, teratogenicity, endocrine disruption, or other important subcellular responses. In watersheds receiving multiple sources of stressors, accurate assessments should use a range of laboratory (such as WET tests) and novel in situ toxicity and bioaccumulation assays, and should include a simultaneous characterizations of physicochemical conditions and indigenous communities. de Vlaming et al. (2000) used USEPA protocols for freshwater toxicity testing to evaluate ambient water quality in California. Testing since 1986 showed that the three whole effluent toxicity (WET) tests, when performed along with toxicity identification evaluations (TIEs) and chemical analyses, were useful in identifying pollutant sources and identifying potential benefits of alternate land uses or best management practices. Tobiason and Logan (2000) reported on the benefits of using whole effluent toxicity (WET) testing of stormwater at outfalls to trace sources of pollution at Sea-Tac International Airport. WET testing was found to be very effective in helping to identify a zinc-galvanized metal rooftop as the source of zinc contamination and therefore the source of the toxicity of the stormwater runoff. Ellis (2000) reviewed using in-situ biomarker techniques to evaluate the effects of transient pollution events, such as the inflow of stormwater runoff, in urban receiving waters. This paper also discussed the limitations of more traditional toxicity tests such as the Direct Toxicity Assessment (DTA) procedures for assessing transient events that leave sub-lethal stresses on the biota.

Microbiological indicators. Quintero-Betancourt and Rose (2000) investigated the potential use of stormwater and/or reclaimed water to rehydrate wetlands in St. Petersburg, Florida. The adequacy of using these waters was assessed through microbial water quality testing using bacterial indicators, coliphages, Cryptosporidium and Giardia. Long et al. (2000) evaluated the potential of using three alternative (compared to traditional coliform testing) source-specific indicator organisms for determining the human health risks associated with a water source and for determining if the source of the bacterial contamination was human or grazing animal. These alternative organisms were sorbitol-fermenting Bifidobacteria, Rhodococcus coprophilus, and serogroups of F+ coliphases), and they were found to correlate well with predictions of land use contributions to a receiving water. Rex (2000) reported on the impacts of changing from coliforms to enterococcus as the indicator organism of water quality. The paper advocated that more studies need to be done to improve the understanding of enterococcus behavior during treatment so that its use can provide information about the quality of CSO control. Brion and Mao (2000) researched the use of atypical colonies found in the total coliform test as a part of watershed monitoring. The ratio of atypical colonies to coliphage concentrations correlated well with the degree of known fecal pollution. Meek et al. (2000) advocated the use of shellfish as indicators of bacterial pollution of water. When compared to coliforms, the shellfish gave a better representation of the pollution levels and the changes over time of bacterial concentrations in the water. An evaluation of the naturally-forming algal community in stormwater detention ponds by Olding (2000) showed that this algal community could be used to demonstrate the effectiveness of the detention pond as a treatment device. The taxonomic breakdown of the community also provided information about the pond influent water quality.

Physical-chemical water-quality indicators. Hartmann et al. (2000) investigated the usefulness of linear alkylbenzenes (LABs), a byproduct of LAS detergents, as a marker of sewage in the marine environment. Their usefulness was confirmed in Narragansett Bay where LABs were found in higher concentrations near the urban outfalls and in the upper layers of the sediment. Standley et al. (2000) investigated the potential for using molecular tracers of organic matter, such as fecal steroids, caffeine, consumer product fragrance materials, and petroleum and combustion byproducts to trace sources of organic matter in a watershed. The authors showed that molecular tracer content could be correlated with watershed-scale land uses and that wastewater treatment plant effluents were associated with caffeine and fragrance materials while urban runoff was associated with the PAHs. Allison et al. (2000) described the two-year monitoring and characterization of litter (material larger than 5 mm) in freeway runoff in California.

Flow monitoring. Chao and Hegwald (2000) documented procedures for deploying flow meters and for data evaluation to ensure that a flow-monitoring program would be successful. Stonehouse et al. (2000) reported on the work of the Flow Metering Task Force (FMTF) in Detroit, whose purpose was to evaluate and improve the current flow metering occurring in the Detroit sewer system. The guidelines developed by this group included procedures for meter evaluation, data collection and review, and information sharing. This group also developed a dye dilution testing protocol that provided more accurate results than prior protocols. A specialized probe using time-domain reflectometry (TDR) was developed, calibrated and field tested for continuously measuring soil-water content and surface runoff during studies of water erosion and sediment transport (Thomsen et al. 2000). The laboratory investigation of this TDR probe showed that water levels could be measured with a standard deviation of less than 2 mm. Zandbergen and Schreier (2000) investigated the current methodologies used to assess the impervious cover in a watershed. These included ground surveys, stereo-photogrammetry, air photo interpretation, and satellite image analysis. The following factors were found to influence the accuracy of imperviousness measurements (in order of decreasing importance): selection of imperviousness factors; accuracy and scale of land use mapping; consideration of land cover in addition to land use; and watershed delineation.

Surface Receiving Water Effects

The impact of three demographic and cultural trends - global urbanization, “quality of life” emphasis, and a move towards flexible management - on technology and the regulatory system was discussed by Ruta (2000), especially given the fact that many thousands of U.S. waterbodies still do not meet water quality standards. One example of the watershed-view of impacts was the Urban Pollution Management (UPM) procedure described by Artina and Maglionico (2000). This procedure was developed in England to evaluate the impact on receiving waters of pollutants discharged from sewer overflows during rainfall events. Garland and Pfeffer (2000) proposed using a watershed-based approach to evaluate the impacts of runoff from contaminated sites at the Oak Ridge DOE Reservation and for determining the optimum location and type of pollution control measures. They documented that pollutants released from the contaminated sites typically are transported to the Clinch River through subsurface shallow flow to surface waters where, if they bind well to sediments, they accumulate in aquatic sediments. Otherwise, they are transported off-site via the Cinch River.

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

Microbiological water quality. An investigation of shoreline microbiological contamination conducted by Robertson et al. (2000) in Orange County, California, showed that the likely cause of the elevated fecal coliforms was dry weather urban runoff from the San Gabriel River and storm drains up the coast, rather than the Orange County’s WWTP effluent ocean outfall. As a result of seventeen E.coli O157:H7 cases, investigation of the potential contamination on the Mar del Plata beaches due to combined sewer overflows was performed by Perez Guzzi et al. (2000). Their investigation detected no E. coli O157:H7, although other strains of E. coli were detected in 75% of the samples. None of the 98 strains detected in the outfalls were the strains that were known to cause human illness. However, the presence of E. coli in the drainage water indicated fecal contamination and the resulting potential for illness should a toxic strain be present in the sewage. Rose et al. (2000), through climate and epidemiological records, demonstrated a potential correlation between extreme precipitation events and waterborne disease outbreaks. The authors found that statistically significant relationships could be developed between large precipitation events and waterborne disease outbreaks for both surface and ground water, although the relationship was much stronger for surface water outbreaks. The impact of urban runoff and the potential resuspension of settled parasites in Paris rivers at the drinking water intakes was investigated by Rouquet et al. (2000). Their results showed that parasite sedimentation was high, but that resuspension due to urban runoff was also likely. Rangarajan et al. (2000) developed a model for the City of Edmonton for predicting the impact of rainfall on combined sewer overflows and hence on river water quality. This model would be used to predict elevated fecal coliforms in the river, and hence, for determining when microbiological standards for recreational waters would be exceeded.

Chemical water quality. Work by Standley et al. (2000) demonstrated that the source of the impacts on a receiving water could be determined using molecular tracers. Polycyclic aromatic hydrocarbons were seen to be excellent tracers for evaluating pollution from urban runoff, while caffeine plus consumer product fragrance materials were excellent markers for WWTP effluent. The investigation by Foster et al. (2000) showed that higher amounts of PCBs, PAHs and organochlorine pesticides in the Anacostia River were associated primarily with the particulates and occurred during high flow events. Analysis of the PAHs showed that they were characteristic of weathered or combusted petroleum products. Aromatic hydrocarbons in urban runoff were found to be likely sources of PAH fluxes to the tidal waters of Chesapeake Bay. O’Meara et al. (2000) described the work done to remove 556,000 Mg of sediment and 12,700 kg of fish contaminated with PCBs from Newburgh Lake in Wayne County, Michigan. The result was that the lake was found to be fit for human recreational activity. Shinya et al. (2000) investigated the concentrations of metals and PAHs in the runoff from four urban-highway rainfall drains. The results showed a first flush of both metals and PAHs. Most of the metals were tied up with the particulate matter, as were the higher molecular weight PAHs. Mutagenicity was appreciably associated with the PAHs in the particulate fraction, although the dissolved fraction also showed positive mutagenic response.

The impacts of combined sewer overflow solids were predicted using a model that could describe the solids movement and the erosion of previously-deposited solids in the sewers (Saul et al. 2000). This model was then used to predict the quantity and arrival time of the first flush of sewer solids into a receiving water after a rainfall.

Oberts et al. (2000) reviewed the impacts of snowmelt on urban water quality. They reviewed research on urban snowpacks accumulating large quantities of solids and other pollutants from sources such as airborne fallout, vehicular deposition, and applied grit and salt. They also reported on instances where the first flush of snowmelt has been found to be highly toxic and where water quality deterioration due to snowmelt runoff have been documented.

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

Groundwater Effects

Dale, M.S.; Koch, B.; Losee, R.F.; Crofts, E.W.; and Davis, M.K. (2000). MTBE in Southern California water. J. Am. Water Works Assoc. 92 (8), 42 (-51). Abstract: Methyl tertiary butyl ether (MTBE) is a common fuel oxygenate used in motor vehicle fuels to control emissions and boost octane. It is more water-soluble than other fuel constituents and does not adsorb well to substrates such as soil. It can contaminate groundwater supplies through leaking underground fuel storage tanks and pipelines, and through spills, urban storm runoff, and precipitation. It can also contaminate open water reservoirs through exhaust from motorized watercraft. The Metropolitan Water District of Southern California surveyed six reservoirs that supply drinking water in Southern California. Recreation on these reservoirs ranged from none at all to high activity with personal watercraft. It was found that motorized watercraft can contribute a significant amount of MTBE to the water supply.

Di Carlo, G. W., and Fuentes, H. R. (2000). Potential Transport of the Herbicide MSMA and Arsenate(+5) from Golf Courses to Groundwater in Southeastern Florida. WEFTEC2000, 73rd Annual Conference and Exposition, October 2000, Anaheim, CA. Abstract: Monosodium methanearsonate (MSMA) is an arsenical organic compound, extremely soluble, that is frequently used as a herbicide for the postemergent control of grassy weeds in turf grasses at golf courses in southeastern Florida. Typical application rates range from 0.45 to 1.96 lb of MSMA/acre. Recent characterizations undergone in Dade County, Florida, by the Florida Department of Environmental Protection (FDEP) found dissolved arsenic concentrations up to 12 mg/L in samples taken from golf course monitoring wells. These wells monitor local water quality in the unconfined Biscayne aquifer, which is the sole source of drinking water supply in the county. The FDEP has set maximum contaminant levels for groundwater quality at 50 ::g/L. This study examined the potential susceptibility of the local shallow groundwater to arsenic contamination from the use of MSMA, with normal application rates, at a local golf course. Soil samples were taken from the West Palm Beach Country Club, located in southeastern Florida, to conduct batch type adsorption experiments for determining the sorptivity (Kd) of MSMA and its expected inorganic byproduct, arsenate As (+5), to local soils. Background characterization of 4 distinct soil horizons, from which 5 representative samples were taken at even intervals, indicated non-detectable levels of Total Arsenic in the soil column down to the water table (approximately 8.5 feet below grade at boring site). Each horizon consisted predominantly (99% by weight) of sands, with phosphorus (P) and iron (Fe) concentrations increasing with depth. The soil samples provided a background experimental reference, showing not detectable levels of either naturally occurring or anthropogenic arsenic. Previous findings, which were experimentally confirmed by this study, reported that most inorganic arsenic (As) species need approximately 48 hours to reach equilibrium between the adsorbed phase and the dissolved phase. Batch reactor tests of this study yielded data to select best sorption isotherms, for both MSMA and As (+5), with the 5 different soil samples, which represented 5 vertical horizons. Results indicated that all contaminant/soil systems displayed a linear sorptivity relationship (R 2 ranging from 0.8262 to 0.9779) with Kd values (units of L/g) ranging from 0.0102 to 0.2295. Results also showed that As(+5) had a higher affinity for the 5 different soil fractions than MSMA. Utilizing laboratory derived Kd values, as well as available physical, chemical, and daily meteorological data, modeling of the MSMA/As(+5) soil systems was performed to illustrate the potential fate and transport of MSMA at golf courses in southeastern Florida. Simulations of contaminant movement in the unsaturated zone were conducted with a U.S. Environmental Protection Agency (USEPA) documented model, Pesticide Root Zone Model 2.0 (PRZM 2.0). PRZM 2.0 is a one-dimensional, dynamic, compartmental model that is able to estimate chemical movement in unsaturated soil systems, within and immediately below the plant root zone. Eight scenarios were evaluated to illustrate the effect of varying field conditions such as irrigation, dispersion, and Kd values. In each of the eight scenarios there was transport of both MSMA and arsenate, which resulted in: (1) significant migration of MSMA and As(+5) out of the vadose zone and into the water table within 1 month from only 1 application; and (2) Total Dissolved As concentrations were persistently found at the water table interface that exceeded 50 ::g/L and ranged from 0.0 to 400 :g/L.

Malecki, J., and Matyjasik, M. (2000). Characteristics of Rain Chemistry and Its Effects on Ground Water Chemistry in Poland. 2000 Annual Meeting and International Conference of the American Institute of Hydrology, Research Triangle Park, NC, November, 2000. Abstract: Factors affecting chemistry of atmospheric precipitation, such as acid precipitation and regional variability of rain chemistry, are discussed based on data collected from selected monitoring stations in Poland. In order to document differences between heavily urbanized areas and regions distant from industrial and urban centers in Poland, rain water chemistry was monitored in four stations located in southern Poland (Hala Gasienicowa and Szarow), central Poland (Kampinos), and north-eastern Poland (Bialystok). All of the monitoring stations are located at different distances from urban and industrial centers. These differences result in a significant difference in the average amount of total dissolved solids (TDS) between monitoring stations ranging from 15 mg/L (Hala Gasienicowa) to 80.5 mg/L (Szarow). Values of TDS correspond closely to the total amount of dust fall monitored in four locations. Water chemistry from these four locations is also compared to other regions in Poland. Discussion of water chemistry focuses on pH, electric conductivity, major and minor ions and ionic ratios. Electric conductivity and pH were determined for every rain precipitation greater than 3 mm. In areas located closer to urban centers, characterized by greater amount of dust falls, sulfur dioxide and nitrogen oxides are neutralized by alkaline dust resulting in higher pH values. Minimum values of pH in monitoring stations ranged from between 3.2 and 3.9, and maximum values differ more significantly, ranging from 6.4 in Hala Gasienicowa to 8.4 in Bialystok. Dominant values of electric conductivity range from 10-30 μS/cm to 110-120 μS/cm. While minimum values vary only between 5.6 μS/cm to 24.2 μS/cm between different regions, differences between maximum values are significantly larger (90 μS/cm - 283 μS/cm). Ionic composition of rain water in all monitoring stations was relatively similar. Sulfates, chlorides, nitrates and bicarbonates are dominant anions while calcium, ammonium, and in lower concentrations sodium, potassium, and magnesium are dominant cations. Initial stages of rain precipitation have significantly higher amounts of sulfate and calcium ions. The highest concentrations of calcium characterize short-term precipitations. Variability of sulfur content in rain precipitations in monitoring stations (108.3 kg/kmz/month - 125.0 kg/km^2/month) are discussed in comparison to other regions in Poland. Four different ionic ratios (calcium/magnesium; sulfate/bicarbonate; chloride/sodium; sum of sodium and potassium divided by calcium and magnesium) were used to analyze effects of oceanic and continental air masses on the rain water chemistry in the monitored areas. Among trace elements zinc, iron, manganese were dominant, while copper, strontium and barium typically occurred in smaller concentrations.

Standish-Lee, P. (2000). Moving from Source Assessment to Protection - The Palmdale Water District Experience. Watershed 2000 Management Conference, July 2000. Abstract: Source water protection is the first and foremost barrier required for inclusion in a well-developed multiple-barrier protection and treatment plan for public drinking water supplies. A comprehensive source water protection program can prevent contaminants from entering the public water supply, reduce treatment costs, and increase public confidence in the quality, reliability and safety of its drinking water. The 1996 SDWA Reauthorization includes requirements for the states to conduct source water assessments as a first step in achieving source water protection. The State of California in adopting their source assessment plan is encouraging large water systems to conduct their own assessments. Palmdale Water District approached conducting their assessments as the first step in developing a Wellhead Protection Plan for its groundwater supply. This first step included the following elements: ·Delineation of the boundaries of the protection areas for wells providing source water for District customers. ·Inventory of the sources of regulated and certain unregulated, contaminants of concern in the delineated areas (to the extent practical). ·Determination of the vulnerability of each well to contamination. ·Public education and outreach. The delineated area is divided into time of travel zones for 2, 5 and 10 year times of travel. The delineated protection areas allow the District to focus its protection and management strategies and resources on the areas where most of the benefits to the water resource will occur. After conducting the Potential Contaminating Activities (PCAs) inventory, a vulnerability analysis was conducted. The Vulnerability Ranking is a prioritized list of the PCAs identified in the source water assessment and a relative ranking of the well exposure to potential sources of contamination. The order of the ranking is based on: ♦The class of PCA, ♦Its respective risk ranking (relative risk to drinking water supplies), ♦The protection zone in which the PCA occurs, and ♦The Physical Barrier Effectiveness rating (how effective the source and site are at preventing contaminants from reaching the drinking water). These factors are used to determine the PCAs to which the drinking water source is most vulnerable. The sum of the risk rankings for all the PCAs for a well provides the relative risk ranking for that well. The activities at the top of the Palmdale Water District's Vulnerability Ranking include: Septic tanks believed to be the source of contaminants found in well 17 and 5 (nitrate, TDS), Illegal Activities/Dumping, trunk sewer lines, US Air Force Plant 42, Dry Wells, Gas Stations (current and historic), Junk/Scrap yards, and Leaking Underground Storage Tanks. Other activities near the top of the District's Vulnerability Ranking include Detention Basins, Highways, a Railroad, Golf Course, Housing Developments, Hardware Store and Repair Shops. The District completed the assessment in January 1999 and proceeded with developing a source water protection plan. To facilitate development of a Wellhead Protection Plan, the District has

invited stakeholders to form an Advisory Group to help identify, develop and implement local measures that will advance protection of the District's groundwater supply. The stakeholders met during 1999 and developed approaches to protect their groundwater including developing an overlay district, developing a groundwater ordinance, public education programs, cooperation with other agencies with regulatory powers to help with inspection and identification of problem areas, a program for dealing with illegal dumping, and contingency planning. The paper describes the assessment process, development of the management plan, and the status of the plan and its implementation program.

Stuurman, R.J. (2000). Groundwater Flow Systems and Topsystem Analysis on a Nation-wide Scale as a Tool for Spatial Planning. 2000 Annual Meeting and International Conference of the American Institute of Hydrology, Research Triangle Park, NC, November, 2000. Abstract: The watersystem in the Netherlands is stressed by drought (dewatering), flooding and pollution. Until recently, earth sciences in general and groundwater hydrology in particular were considered of minor interest for spatial planners, urban planners and architects. The advice an earth scientist could give was the adjustment of the surface water level or the depth of piles. Interest in groundwater and surface water is increasing rapidly during the last years. The reasons are the afore-mentioned flooding and drying-up problems, and local problems in the urban areas as damage to constructions due to wooden piles partially becoming situated above the phreatic level; rising groundwater levels due to reduced groundwater abstractions for industries; and land subsidence elsewhere as a result of groundwater level declines. National and regional water managers understood that it is important to think in terms of integrated water systems at different scales and levels. They started to stimulate a new attitude in planning with respect to the water system, minimizing damage of ecological values and minimizing changes in the local water system, adapting the design to the natural geomorphology of the zone to be developed. The project "National Groundwater Flow Systems Analysis (NGFSA)" in the Netherlands aimed at the mapping of the regional groundwater flow systems to support policy makers at national and regional levels and water/nature resources management. The project was carried out for three Dutch Ministries (Traffics and Water works, Spatial Planning and Environment, Agriculture and Nature). Much emphasis is put on the biotic aspects like the relation between groundwater (including water quality) and patterns in vegetation. All relevant abiotic and biotic data were collected and processed with GIS techniques. The results are presented for seven subareas which correspond more or less to the major physio-graphical regions and/or are positioned around the major groundwater recharge areas in the Netherlands. The results can be used as background documents in water management and as starting points for more detailed studies in the fields of ecology, spatial planning or groundwater hydrology. In succession to the NGFSA anew phase of nation-wide hydrogeotogical mapping just started, the so-called "National Top Systems Analysis (NTSA)". The project aims to please the need for more detailed hydrogeological information or data. These data will be used by waterboards, nature managers and drinking water companies for operational use and/or detailed numerical modeling. The NTSA will provide detailed (hectare) information about the hydrogeology of the top layer (0-25 m bsl); dimensions of the drainage system, permeability, resistivity, soil characteristics, flow direction (infiltration or exfiltration), groundwater/ surtace water relation etc. The results are presented in 'classic' atlases and modem gis-formats.

Thomas, M.A. (2000). The effect of residential development on ground-water quality near Detroit, Michigan. J. Am. Water Resour. Assoc. 36 (5), 1023 (-1038). Abstract: Two water-quality studies were done on the outskirts of the Detroit metropolitan area to determine how recent residential development has affected ground-water quality. Pairs of monitor and domestic wells were sampled in areas where residential land use overlies glacial outwash deposits. Young, shallow waters had significantly higher median concentrations of nitrate, chloride, and dissolved solids than older, deeper waters. Analysis of chloride/bromide ratios indicates that elevated salinities are due to human activities rather than natural factors, such as upward migration of brine. Trace concentrations of volatile organic compounds were detected in samples from 97 percent of the monitor wells. Pesticides were detected infrequently even though they are routinely applied to lawns and roadways in the study area. The greatest influence on ground-water quality appears to be from septic-system effluent (domestic sewage, household solvents, water-softener backwash) and infiltration of stormwater runoff from paved surfaces (road salt, fuel residue). No health-related drinking-water standards were exceeded in samples from domestic wells. However, the effects of human activities are apparent in 76 percent of young waters, and at depths far below 25 feet, which is the current minimum well-depth requirement.

Uddin, F. (2000). Deteriorating Groundwater in Peninsular Malaysia due to Dumping Chemical Wastage of Industries and Human Activities. 2000 Annual Meeting and International Conference of the American Institute of Hydrology, Research Triangle Park, NC, November, 2000. Abstract: Groundwater has an important sources of water supply to Peninsular Malaysia. Groundwater primarily stored in alluvial aquifer and hardrock aquifer. It is extremely susceptible to contamination from a variety of agricultural, industrial, and human activity. Dept. of Environment (DOE) Malaysia, decided to establish a comprehensive groundwater monitoring network in Peninsular Malaysia. Review and prioritize 119 sites for the needs of groundwater monitoring. Establish the groundwater monitoring

network at 36 selected sites. Conduct three rounds of groundwater monitoring and developed a groundwater modeling. Conducted potential pollution confirmation: 1. identified and performed soil and groundwater sampling at 21 of the 54 sites, 2. low levels of petroleum hydrocarbons were detected in soil and groundwater, and 3. elevated levels of Al, Fe, As, and Mn were detected in grab groundwater samples (predominantly at landfills). Number of Wells and locations at each site were determined based on the following: a. local hydro-geologic framework, b. focusing on top unconfined aquifer, c. groundwater flow direction, d. locations of known or potential pollution sources, and e. locations of production wells / surface water bodies. Types of pollution sources: 1. Non-point sources (agricultural, rural, and golf course), 2. Point source (urban/suburban and industrial), 3. Landfill and toxic waste site, and 4. Line source (saltwater intrusion). Established chemical analyses protocol: total dissolved solids, hardness, anions, heavy metals, phenols, petroleum hydrocarbons, and pesticides. Analyses were selected based on potential pollution sources at the sites. Groundwater quality evaluation: 1. low levels of petroleum hydrocarbons were detected, no BTEX were detected in the associated groundwater samples, 2. Minor pesticides were found in some groundwater samples (only one dection of aldrin were slightly above the bench mark), and 3. Phenolic compounds, coliform, iron, manganese, and mercury are found with highest frequencies of exceeding the bench marks. General evaluation approach: a. prevent exposure to contaminated groundwater, b. protect uncontaminated ground and surface water for present and future use, c. restore contaminated groundwater for future use, and d. protect environmental receptors.

Zobrist, J.; Muller, S.R.; Ammann, A.; Bucheli, T.D.; Mottier, V.; Ochs, M.; Schoenenberger, R.; Eugster, J.; and Boller, M. (2000). Quality of roof runoff for groundwater infiltration. Water Res. (G.B.). 34 (5), 1455 (-1462). Abstract: The assumption that roof runoff can be considered as non-polluted stormwater that can be discharged directly into natural water bodies without impairing their quality and use was examined in a field study. Concentrations of major ions; total C, N, and P; heavy metals (Cu, Zn, Pb, Cd, Cr, Mn, Fe) and pesticides (triazines, acetamides, phenoxy acids) were measured in runoff from an inclined tile roof, an inclined polyester roof and a flat gravel roof. Runoff from the first two roofs showed initially very high concentrations declining rapidly to lower constant levels. This first-flush effect was modelled using a first-order rate law (wash-off function). For most constituents, concentrations were in the range of the wet deposition after the first few mm runoff depth and total loads in the runoff corresponded approximately to the total (dry and wet) atmospheric deposition load. The flat gravel roof depicted a different behaviour. Rainwater was first retained before it overflowed. Consequently gravel will be weathered and most pollutants were partially retained in the gravel layer. However, corrosion of Cu in drains (rate about 5 g m-2 y-1) produced such high Cu concentrations that direct disposal of runoff is questionable.

DECISION-SUPPORT SYSTEMS

Modeling and Model Applications

Modeling

Ponds/Treatment ***{tc "Ponds/Treatment " \l 2}***
XP-SWMM was used to evaluate the performance of a retention treatment facility in Oakland County, Michigan (Buchholz et al. 2000). The results showed the amount of storage that is necessary to reduce the number of overflow events by 30%. A two-dimensional, vertically averaged hydrodynamic model has been adapted to predict the circulation and sedimentation patterns in stormwater detention ponds (Dewey et al. 2000). The performance of the model for a pond system in Toronto is presented. The Storage-Treatment block of SWMM was used to model the effectiveness of extended detention ponds (Newman et al. 2000). The results showed much improved designs over using traditional methods. The Corrugated Steel Pipe Institute has developed software for designing underground stormwater detention tanks (Finlay, 2000). Designers can use the program to quickly perform the calculations associated with the design of underground storage detention facilities. Analytical probabilistic models were applied to analyze the runoff quantity/quality control performance of various combinations of storage and treatment systems (Li and Adams 2000). These models provide closed-formed solutions of the performance equations that are efficient in both a conceptual and computational sense.

Collection and treatment systems ***{****tc "Collection and treatment systems " \l 2****}***

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

An abatement strategy was developed for three CSO outfalls in the Bronx, NY. (Brilhante et al.2000). The EPA SWMM was used along with cost and receiving water quality modeling to define the optimal level of in-line storage required to meet regulatory requirements. To achieve desired CSO control for the City of Edmonton's Gold Bar Wastewater Treatment Plant (GBWWTP), the hydraulic relationship between the upstream collection system and the GBWWTP was evaluated by including a detailed hydraulic model of the treatment plant as part of the collection system hydraulic model (Gray et al. 2000). This study provides details on the approach used to simulate these two system components in an integrated model. Hydraulic/hydrologic modeling was conducted using the EPA SWMM in support of the design of a CSO consolidation/ relocation project in South Boston (Walker et al. 2000). Findings indicated that an original facilities planning model was reasonably accurate in predicting peak flows in extreme storm events, despite only being calibrated to a 3-month storm.

The City of Columbus Inflow and Infiltration Program utilizes a comprehensive sewer system evaluation and hydraulic modeling approach to mitigate sanitary sewer overflow and water-in-basement occurrences (Chase et al. 2000). By identifying problems in the collection system and incorporating them into a hydraulic model prior to SSO mitigation alternatives analysis, the City of Columbus will be able to spend capital improvement and maintenance dollars to correct the problems in the collection system and reduce SSOs. The Miami-Dade Water and Sewer Department used wet weather data from a supervisory Control and Data Acquisition telemetry system to quantify rainfall dependent infiltration and inflow (RDII) (Christ et al. 2000). The MS Access application developed to quantify the individual pump station's RDII response is discussed. A detailed computer model of the Metropolitan Sewerage District of Buncombe County, North Carolina collection system was used to identify collection system improvement alternatives (Harris 2000). Alternatives include strategic application of sewer rehabilitation and upgrades, off-line storage and additional treatment capacity. The Encina Wastewater Authority developed a Peak Flow Management Plan, in which effluent equalization storage as an alternative to a new ocean outfall was evaluated using a risk-based approach (Hogan et al. 2000). A continuous simulation model of wet weather flows and storage/outfall facilities was used to generate estimates of peak flows, storage volume requirements, and project costs over a range of return periods.

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

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

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

Wet-weather flow prediction ***{****tc "Wet-weather flow prediction " \l 2****}***

The Hydrologic Modeling System (HEC-HMS) is "next generation" software for precipitation-runoff simulation that will supersede the HEC-1 Flood Hydrograph Package. The program is a significant advancement over HEC-1 in terms of both hydrologic engineering and computer science (Scharffenberg and Feldman, 2000). Current capabilities of the HEC-HMS program that are not found in HEC-1 are discussed. Nguyen et al. (2000) apply two different optimization methods to calibrate the RUNOFF block of the SWMM model: the Downhill Simplex Method, and the Shuffled Complex Evolution (SCE) Approach. Better results were found using the SCE approach. A semi-distributed conceptual rainfall-runoff model for urban catchments was developed (Aronica and Cannarozzo 2000). The urban drainage network is idealized as a cascade of non-linear cells with kinematic wave routing. The results indicate that both the variation in the spatial representation of the rainfall and the variation in the spatial discretization of the catchment influence the outlet hydrographs.

New developments in information technology can be used to estimate spatially variable parameters for hydrologic simulation systems (Ball 2000b). Control parameter estimation philosophies are discussed, and techniques are demonstrated on the use of hydroinformatic systems in parameter estimation. The development of urban databases has provided a convenient means of accessing information for the purpose of hydrological modeling (Rodriguez et al. 2000). A recently developed model, `SURF' (semi-urbanized runoff flow), was specifically designed to couple with a GIS. SURF was evaluated with a 7-year continuous data series and was shown to compare favorably to both measured data and results from URBAN, another popular urban hydrologic model.

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

The National Weather Service's WSR-88D radar (NEXRAD) was used to estimate the spatial distribution of rainfall for three storms over the Brays Bayou watershed in Houston for hydrologic modeling purposes (Bedient et al. 2000). The results from the radar proved to be as accurate, and in some cases more accurate, than the rain gauge model when predicting runoff volume, peak flow, and time of peak. Chan (2000) explores the spectral behavior of rainfall of various temporal resolutions and presents a method of generating rainfall data that combines the approaches of stochastic modeling with a disaggregation goal. The total rainfall volumes of the generated data compare well with observed values but tend to produce lower rainfall intensities and longer rainfall durations per event.

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

BMPs **{***tc "BMPs " \l 2***}**

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

Urban watershed evaluations **{***tc "Urban watershed evaluations " \l 2***}**

A methodology was developed by the Greater Vancouver Sewerage & Drainage District to estimate future percent total impervious area using population density (Hicks et al. 2000). Percent total impervious area is an indicator of watershed health, therefore, future imperviousness can be forecast based on population growth and land use estimates. The value of benefit-cost evaluation for stormwater quality management decisions at a local level is explored using a benefit-cost analysis (BCA) screening method (Kalman et al. 2000). Ballona Creek, a major urban storm drain in Los Angeles, is used to illustrate the practicality of the benefit-cost evaluation.

Water Quality **{***tc "Water Quality " \l 2***}**

The results of a number of investigations indicate that contaminant transport should consider the speciation of nutrients and metals in stormwater runoff (Ball 2000a). From the results of these studies, a new approach for the simulation of contaminant transport is presented which considers the speciation of the contaminants. Statistical models are proposed to predict the total mass of specific pollutants removed with stormwater runoff from an urban residential catchment (LeBoutillier et al. 2000). The models are based on analysis of data collected during an on-going research program in Saskatchewan. A method for predicting the thermal enhancement of stormwater runoff from paved surfaces is documented for a test facility in Kingston, Ontario, Canada (Van Buren et al. 2000). Prediction of runoff temperature is based on TRMPAVE, a mathematical model that was developed using a thermal energy balance approach and the one-dimensional heat equation to predict the surface temperature and temperature gradient in asphalt during dry-weather and wet-weather periods. An export coefficient modeling approach was used to assess the influence of land use on phosphorus loading to a Southern Ontario stream (Winter and Duthie 2000). It was found that runoff from urban areas contributed most to the loading of phosphorus to the stream. An existing model of sediment wash-off from paved surfaces was been extended to predict fine granular sediment inputs into drainage systems via roadside gully-pots (Deletic et al. 2000). The model was applied to two catchments in Dundee, Scotland where it was concluded that only two calibration parameters are required to estimate the input of fine granular sediment into storm drainage systems via gully-pots.

Urban flooding **{***tc "Urban flooding " \l 2***}**

In many cities of the world, urban cells may be hydraulically defined where built-up areas are highly subpartitioned into walled properties (Hicks et al. 2000). A method is proposed to quantify flood damage vulnerability based on hydraulic properties of the urban cell and on peak flow and time to peak. A flood inundation model was developed by combining a SWMM-based model of a storm sewer network and a two-dimensional (2D) overland-flow model (Hsu et al. 2000). SWMM was employed to solve the storm sewer flow component and to provide the surcharged flow hydrographs for surface runoff exceeding the capacity of the storm sewers.

US EPA Activities: Software and Policy **{***tc "US EPA Activities\: Software and Policy " \l 2***}**
Many enhancements have been made to the EPA SWMM since the last official EPA release in 1994 (Huber et al. 2000). These include improvements to the model engine, enhancements to input/output options, and "hooks" for easier interfacing with graphical user interfaces and ancillary software. The US EPA Office of Research and Development (ORD) Urban Watershed Management Branch (UWMB) has identified two major objectives for urban modeling research: to develop a standard operating procedure for the user community and to develop a BASINS-compatible SWMM - GIS interface (Koustas 2000). Koustas (2000) provides the SWMM-user community with a description of the UWMB approach to urban watershed modeling research and provides an update on current ORD SWMM-related projects. The US EPA is in the final stage of issuing an SSO Rule that will add control of SSOs to the NPDES permit requirements (Lai et al. 2000). Lai (2000) provides a preview of the rule and describes the advantages of employing a modeling approach for capacity assurance of various components of a collection system and development of SSO mitigation plan.

Watersheds/TMDL{tc "Watersheds/TMDL"}
The watershed approach can be used as an integrated method for implementing Total Maximum Daily Loads (TMDLs) (Haas et al. 2000). A discussion of how this approach can be used in Massachusetts is presented. A watershed-based assessment program that identified urban stormwater discharges to small streams to be one of the most significant environmental issues in the region's long-term management plan (McCallum et al. 2000). A bacteria TMDL for the Shawsheen River in Massachusetts is described (Mockus et al. 2000). Urban stormwater was found to be the largest source of pathogens. Copper and nickel TMDL for San Francisco Bay were integrated into the ongoing Santa Clara Basin Watershed Management Initiative with a major emphasis placed on establishing and maintaining public and industry involvement through a specially established TMDL stakeholder group (Olivieri et al. 2000). The TMDL process provided a systematic framework for dealing with long-standing water quality issues in the South Bay.

GIS{tc "GIS"}
Automated Mapping/Facilities Management, and geographical information system (AM/FM/GIS) applications for stormwater systems are reviewed by Shamsi and Fletcher (2000). Popular AM/FM/GIS software is reviewed and six case studies are presented of applications for urban stormwater systems. Traditional hydrologic models focus on peak discharges and NPS pollution from high-magnitude storms, but are usually of limited use in assessing the long-term impacts of land-use change (Bhaduri et al. 2000). A long-term hydrologic impact assessment model has been developed using the curve number (CN) method linked to a GIS for convenient generation and management of model input and output. The City of Greensboro, NC is developing a Municipal Stormwater and Watershed Management Program to prioritize infrastructure maintenance, assist with stormwater permitting, track water quality data, enhance floodplain management, and facilitate stormwater management master planning (Bryant et al. 2000). Due to the flexibility of GIS tools and databases, the program may be expanded to include water supply system optimization, sanitary sewer system inventory and modeling, and advanced water quality modeling to support TMDL programs. A successful approach was used by the Sanitary District of Decatur, IL to develop a flexible and expandable information management platform (Kuchy et al. 2000). The platform is used to integrate GIS and database applications, a collection system hydraulic model, and a graphical user interface built specifically to satisfy end-user needs. A macro urban inundation model was created for Yokohama City, Japan to support benefit-cost analyses of flood control projects (Nakata et al. 2000). While the accuracy of the macro model (250 meter grid size) does not produce highly accurate results, the solution speed has made it an effective planning and decision-screening tool. The City of Livonia, Michigan is using GIS technology to enhance the implementation of its illicit discharge elimination program (Rohrer and Beckley 2000). As a result of the GIS integration, record keeping is improved, problem areas are identified earlier, and joint efforts with surrounding communities are simplified.

A GIS-based system designed to manage both sewer maintenance and I/I reduction programs was developed to integrate a wide range of over-lapping data types for these two activities (Shaffer and Greiner 2000). The system includes inventory, complaints, and reporting components of the collection system. Methods for differentiating between agricultural and urban/suburban sources of water quality impairment are of interest in New England, where farms are generally located in "mixed-use" land-use areas (Sturdevant Rees and Long 2000). This study utilizes source-specific indicator monitoring techniques and a grid-based, distributed hydrologic model into a single GIS-based watershed management tool. A spatially variable rainfall model for a small-urbanized catchment based on records stored in a time series database was developed in Australia (Umakhanthan and Ball 2000). From the spatial patterns of rainfall, it was possible to develop individual hyetographs for each of the 42 subcatchments within this catchment. The City of Columbus used an integrated GIS/hydraulic model to address SSOs and flooding (Wolff et al. 2000). Project goals included reduction of inflow and infiltration, reduction of basement and surface flooding and improved system operations and preventative maintenance. The methods and advantages of using a GIS to plan a future sanitary sewer expansion to minimize the likelihood of SSO's is presented by Young (2000). Future flows were projected for this study based on the number of proposed new homes with existing flows being added as a known quantity.

REGULATORY POLICIES AND FINANCIAL IMPACTS

Policy and Permitting

The year 2000 saw several new stormwater regulations issued nationally, and a variety of guidance documents published in support of new and existing regulations. USEPA published the final Storm Water Phase II rules in December, 1999 (Anonymous 2000b), and the members of the Sanitary Sewer Overflow (SSO) Federal Advisory Subcommittee voted unanimously to support the EPA's draft proposal for developing federal SSO regulations (Anonymous 2000a). EPA also announced plans to release a draft guidance on water quality and designated use reviews for combined sewer overflow (CSO) receiving waters in April, but not everyone is happy with the current guidance outline (Anonymous 2000c). Urban and agricultural wet weather sources are the most significant causes of impairment to our Nation's rivers and streams. However, these "impairments" are typically assessed in reference to water quality standards developed in the context of historical efforts to control dry weather wastewater sources. Therefore, the significance of wet weather impairments and the need for costly controls is under debate. Freedman (2000) explores the issue of wet weather water quality standards for CSO impacted waters, provides an overview of the obstacles to undertaking and completing the water quality standards review and revision (WQSRR) process, and includes a summary of the steps that EPA and other organizations are taking to support scientifically sound and regulatory compliant WQSRRs (Freedman 2000). The amount of hydrocarbons allowed in industrial and stormwater effluents varies greatly from one locality to another or from one country to another. Some countries mandate hardware solutions to the effluent problem and others stipulate a specific concentration allowable. Mohr (2000) presents the regulations governing effluents in many countries, as well as states and localities within the US and offers discussions of some of the hardware systems required by various jurisdictions. Implementation of the Total Maximum Daily Load (TMDL) provisions of Section 303(d) of the Clean Water Act will impact both point and nonpoint sources of pollution. Programs related to TMDLs often reach beyond the purview of the agency responsible for the TMDL and cross into programs that operate under different regulations administered by other agencies. TMDLs will thus have significant cross-media and cross-programmatic impacts (Staveley and Christman 2000). The Center for Environmental Research and Service (2000) at Troy State University, Alabama published a guide to developing a storm water control program to comply with Phase II requirements.

Other regulatory issues involve local stormwater managers trying to develop stormwater management efforts that meet both local needs and regulatory requirements. As currently designed, TMDL limits are based on the assumptions that there is a direct correspondence between the total mass of waste loads and ambient water quality, and that an annual cap on total wasteload allocations (WLAs) can sufficiently maintain water quality. Based on a study of the nutrient loads and water quality in the tidal freshwater Potomac River over the period 1985-1995, Sklarew (2000) suggests that hydrology is an important factor to consider in developing adequate WLAs for metropolitan tidal rivers. Furthermore, the hydrograph could be a vital tool in designing flexible and adaptive TMDLs for such areas. The City of Portage, MI is pioneering a comprehensive approach to storm water management in light of the Phase II Storm Water regulations. The city will endeavor to define "Maximum Extent Practicable" (MEP) within the constraints of available space for treatment facilities, city budget, and community support. This approach can be used by other municipalities with existing infrastructure and limited controls that now face similar storm water regulations, and illustrates opportunities and benefits of storm water controls implemented beyond the minimum requirement (Breidenbach et al. 2000). In November 1999, the City of High Point, North Carolina adopted a watershed protection ordinance that initiated "Phosphorus Banking" and provided greater water quality protection than the state requirements while also accommodating planned growth. Brewer et al. (2000) document the watershed assessment and modeling approach, the successful involvement of key stakeholders, and the innovative phosphorus banking strategy adopted. A major new effort, the Use and Standards Attainment (USA) Project, was launched by the New York City Department of Environmental Protection in August 1999 as part of its continuing efforts to maintain and improve water quality in New York Harbor and its environs. A watershed-based approach is being utilized to conduct an integrated evaluation of the interdependent factors affecting receiving water uses, including storm water, combined sewer overflows (CSOs), wastewater treatment, upland uses, shoreline uses, habitats, sediment and water quality with the active participation of major stakeholders from the start of the process (McMillin et al. 2000). The New York City Department of Environmental Protection enacted final watershed regulations prohibiting surface discharges from wastewater treatment plants, and subsequently stopped the Kent Manor housing project in the Town of Kent, Putnam County, New York. The watershed regulations had provisions for a pilot phosphorus offset program, whereby projects within the watershed with surface discharges would be approved, provided that any increase in phosphorus loading would be offset somewhere else in the watershed. van der Heijden (2000) described the steps taken to offset expected phosphorous loadings from the Kent Manor project by reducing phosphorous discharges elsewhere in the watershed. Vlier and Sandquist (2000) highlight some lessons, guidelines, and patterns emerging from the growing field of watershed-based trading. by identifying the similarities and differences in program design and linking key elements to scientific, economic, and institutional conditions in the watershed community. The Rouge River National Wet Weather Demonstration Project in Michigan (Rouge Project) has attempted to identify the requirements of a generic comprehensive watershed management plan to meet multiple program objectives, requirements or recommendations in a wide range of individual Federal, State, and local programs to restore and protect water resources. Cave et al. (2000) identify what the Rouge Project has found to be the elements of a "comprehensive watershed management plan" which will achieve multiple program objectives, such as the reissuance of NPDES permits on a watershed basis, implementation of the water quality trading programs that are currently under development, implementation of the Section 319 non-point source program, development and implementation of Watershed Restoration Action Strategies envisioned under the Clean Water Action Plan, implementation of monitoring programs and for addressing the requirements of the TMDL program. McDonald et al. (2000a) present the preliminary findings, conclusions, and recommendations for the development of a pollutant load trading program and the modification of the existing nutrient (nitrogen and phosphorous) and TDS TMDLs and WLAs on the Truckee River, Nevada. As a result of the TMDL process, the Truckee Meadows Water Reclamation Facility had WLAs incorporated into their NPDES permit which has resulted in potential restrictions on planned growth. In order to accommodate for planned growth and to meet water quality objectives, a pollutant load trading program to develop "watershed offsets" is being implemented. McDonald et al. (2000b) multiyear project to develop revised TMDLs and a pollutant-load trading program for the Truckee River.

Other authors examined community and political issues related to WWF control programs. Lindsey et al. (2000) explore five programs led by EPA's Office of Water that address today's environmental issues in wastewater management. Many of the programs are voluntary but regulatory programs continue to play a role in wastewater management. Through humor, Jones (2000) focused upon constraints that now inhibit a watershed solution to environmental, multi-media problems, and proposed potential remedies which may enable certain attributes of watershed management philosophy to successfully proceed in the future. The Tollgate Drainage District (Ingham County, Mich.) had to convince reluctant stakeholders that a sewer separation and stormwater outlet project had to be undertaken (and locally funded). After 2 years of education and outreach, the stakeholders not only accepted that a solution was needed, but approved a nontraditional approach (Lindemann 2000). Tonning (2000) takes a look at what the business community is hearing about planning and links it directly to the watershed approach. Lessons from management consultants are matched to startlingly similar advice from watershed experts from federal, state and private organizations. Recommendations to focus on action and avoid "paralysis by analysis" may provide a refreshing perspective for those burdened with the minutiae and sometimes drudgery of the often interminable planning process (Tonning 2000). If all social and political needs of the community are not also considered and addressed in a watershed protection effort, a proposed project, though technically sound and within budget, may still meet with significant community opposition. Halloran et al. (2000) present one project where a front-end loaded, proactive, community oriented approach turned the neighborhood opposition into enthusiasm. A new comprehensive land use plan was recently adopted to guide development of the undeveloped land area in the City of Battle Creek, Michigan. The results of this project will allow the City to gain a Certificate of Coverage under Michigan's Voluntary General Permit for Municipal Storm Water Discharges, which has been accepted by the EPA as fulfilling the requirements of the Phase II Storm Water Regulations. As a result of performing this project, the City of Battle Creek, Michigan has learned the value of gaining stakeholder input during the watershed planning process, and will form a Steering Committee to guide the implementation of the proposed Watershed Management Plan (Scholl et al. 2000) . The decision to include the public in public works and utility projects is often made without any real consultation with the public or consideration of the issues that the public will be interested in. Kunz et al. (2000) discuss how the right amount and type of public involvement early in the project planning process can mean the difference between a successful project completed on time and within budget or a cancelled project after millions have been spent on design.

Cost Analysis and Financing

New federal funding sources have recently become available in the US for WWF control activities. The proposed budget for the U.S. EPA in fiscal year (FY) 2001 continues the agency's attempts to reduce funding of traditional clean water infra-structure and boost spending for projects addressing nonpoint source pollution (Calamita 2000). The Water Pollution Program Enhancements Act of 2000 (S 2417), which was introduced to congress in April, 2000 would significantly increase federal funding for states to implement programs to address nonpoint source pollution, to assess the quality of their rivers and streams, and to collect the data needed to prepare TMDLs (Anonymous 2000).

Several authors examined the costs of stormwater and non-point source pollution control programs. Butt and Brown (2000) report that over $3.5 billion were spent toward nutrient controls in the Chesapeake Bay watershed between 1985 and 1996. Despite nutrient reductions, no significant improvements in bottom-dissolved oxygen levels were detected along the Bay mainstem during the warmer months, and the mouth of Chesapeake Bay showed marginally significant degradation during the 11-year-period. It was determined that dissolved oxygen conditions were influenced more by nitrogen than phosphorus reductions and that nutrient controls aimed at the mid-Bay region had the greatest potential for improving low dissolved oxygen conditions in the Bay's bottom waters. Fan et al. (2000) present a critical review of information on the costs of stormwater pollution control facilities in urban areas, including collection, control, and treatment systems. Jorgensen and Syme (2000) examined contingent valuation (CV) surveys which are used to evaluate public support for stormwater pollution abatement efforts. Their study reveals that attitude toward paying underpinned protest beliefs regarding the role of government in stormwater management and individual rights to unpolluted waterways. They caution that censoring protest responses in the present study would bias CV samples toward those individuals who are favorably disposed toward paying for environmental public goods and those from higher income households. Kalman et al. (2000) explore the potential value of benefit-cost evaluation for stormwater quality management decisions at a local level. A preliminary benefit-cost analysis screening method is used for maximum extent practicable (MEP) analysis, identifying promising management practices, and identifying societal and economic tradeoffs for local stormwater problems. In the case of Ballona Creek, a major urban storm drain in Los Angeles, California, USA, benefit-cost analysis is found to be useful for evaluating and understanding stormwater management alternatives despite the uncertainties in characterizing stormwater quality and the effects of stormwater management on improving receiving water quality (Kalman et al. 2000). The Clean Water State Revolving Fund is the United States' largest source of continuing financing for water quality projects. The 50 state managed funds are specifically authorized to, among other things, finance nonpoint source water quality projects that implement the states' nonpoint source water quality management plans that they have developed pursuant to Section 319 of the federal Clean Water Act. Steinborn (2000) describes the Clean Water State Revolving Fund program and discusses potential uses of the funds for nonpoint source water quality projects. The Minnesota Legislature commissioned a six-month study to investigate the framework for a cost-benefit model to analyze water quality standards through a watershed-based approach that evaluates both point and nonpoint pollution sources (Laws of Minnesota 1998, Chapter 401, Section 59). Although watershed management has been practiced in Minnesota for decades to protect and restore water quality, this study was undertaken because of the growing understanding of the complex and often conflicting choices facing those who live in, use, and manage watersheds if watershed integrity is to be maintained over the long term (Ward 2000).

Other authors examined costs for controlling sanitary sewer overflows (SSO) and combined sewer overflows (CSO). A problem common to many SSO equalization facilities is that the planning level cost estimates were significantly less than the final implementation costs. Keller et al (2000) present guidance for developing the costs of SSO equalization facilities so that their cost-effectiveness can be properly evaluated during the planning phase. New regulations governing discharge of untreated combined sewage (defined as wastewater consisting of both sanitary and storm flows during rain events) to the nation's receiving streams have challenged the traditional methods for determining cost responsibility and sewer rates for municipal wastewater utilities for the City of Detroit and Southeastern Michigan (Foster and Fujita 2000). A number of asset management tools and techniques that have been used in utilities, including wastewater utilities, throughout the world are discussed by Morgan and Wagner (2000), who outline a new approach for integrating these tools called Infrastructure Capital Assets Management (ICAM). The approach includes modeling tools, decision support tools, and rational methodology that provide decision-makers the tools needed to develop strategies and justify retaining revenues for informed management of their assets (Morgan and Wagner 2000). Spartanburg Sanitary Sewer District (SSSD) in Spartanburg County, South Carolina, experienced rapid growth during the last decade, occurring primarily in rural areas. This growth created a demand for investments in all types of infrastructure. Through the use of an innovative and unique financing structure, SSSD was able to raise the required capital to finance significant sewer system improvements with minimal rate impact on existing customers, while contemporaneously improving wastewater treatment facility permit ("NPDES") compliance and reducing pollutant loading into area streams (Rich et al. 2000). In January 1998, the Milwaukee Metropolitan Sewerage District approved a ten-year Operations and Maintenance service contract with United Water Services. Tobel and Jankowski (2000) discuss the ongoing success of this award-winning project.

CONTROL AND TREATMENT TECHNOLOGIES

Stormwater Best Management Practices (BMPs)

A variety of projects employ stormwater control as part of a larger environmental restoration effort. Aichinger (2000) reported on a stormwater BMP program that includes the construction of three stormwater treatment basins, implementation of a watershed education program, and completion of an Alum injection system for removal of phosphorus from stormwater. The application of alum treatment has several unique features: its design to address treatment of base stream flows, storm event flows, and seasonal changes in stormwater temperature and pH; its off-line system design; its thorough bench testing to address dosing for optimal phosphorus removal under various conditions; and, its design to comply with specific dissolved and total aluminum discharge standards. Mecklenburg County North Carolina’s Department of Environmental Protection (MCDEP), is undertaking comprehensive restoration in the Edwards Branch watershed. The basin-wide BMP plan includes design and construction/implementation of wet ponds, multiple pond/marsh systems, sand filters, bioretention areas, riparian forest buffers, level spreaders, filter strips, stream bank stabilization, stream channel restoration, constructed wetlands, and targeted public education programs, designed as retrofits of existing facilities in the developed watershed or integrated into the existing land uses. Baseline, construction, and post construction monitoring, using EPA stream habitat assessment protocols, ambient water quality monitoring, fish and benthic macroinvertebrate surveys, and channel cross section monitoring, have been and will continue to be used to collect data to justify implementation of successful practices County-wide. (Baker et al. 2000). In Portage, Michigan a storm water treatment system is currently under design which will significantly increase the quality of life for city residents while meeting and exceeding regulatory requirements. This new regional facility will be integrally linked to a recreational trail way system, provide treatment for runoff from 1.9 km^2 (463 acres) within the highly developed urban core targeting 80% pollutant removal rates, and double the length of existing trail ways in the city (Jacobson et al. 2000). Mattson et al. (2000) presented a study of urban stormwater impacts in the Severn Sound Area of Ontario, Canada. The study objectives were (1) characterization of dry weather and runoff quantity and quality; (2) monitoring effects of stormwater runoff on the bacterial concentrations at an urban bathing area; and (3) development of pollution control plans for the participating urban municipalities in the Severn Sound watershed with an overall goal of a 20% reduction of stormwater phosphorus loads. The City of Rockledge, Florida has been developing and implementing a Stormwater Management Program using a watershed-wide management approach included stormwater facility inventory maps along with necessary hydrologic, hydraulic, and water quality data (Schmidt et al. 2000a). The Stormwater Master Plan for Miami International Airport (Florida) included comprehensive evaluations of hydrology, hydraulics, water quality, BMPs, and facility planning in phases to allow cost-effective implementation of the CIP while aircraft operations continued and increased. A variety of constraints were identified including the protection of aircraft passenger safety (no fog or bird attractants) and the environment (water quality, manatees, and hazardous material cleanups) (Schmidt et al. 2000b). Lake Macatawa , near Holland, Michigan, is listed by the Michigan Department of Environmental Quality’s 303(d) nonattainment list; high phosphorus concentrations from nonpoint sources and excessive turbidity are the main contributors to poor water quality. A list of 44 BMPs were considered as controls for reduction of the nonpoint phosphorus load. An objective and quantitative procedure, based on economic production theory and marginal cost analysis, was developed to assign the proposed level of effort and subarea watershed locations for each BMP (Scholl 2000). In order to comply with the County's MS4 Stormwater NPDES permit, the Anne Arundel County (Maryland) Department of Public Works (DPW) is field locating all storm drain outfalls and stormwater management ponds, assessing their structural condition, performing a general assessment of stability of downstream channel conditions, and identifying stormwater management retrofit opportunities for implementation as County capital improvement projects. A relational database has been developed for data management and analysis, with a direct link to GIS coverages (Smith et al. 2000c). Templeton (2000) presents an overview of the Nutrient Management Strategy for point source dischargers to North Carolina's Neuse River and the State’s experience in implementing the Strategy thus far. Whitman et al (2000) describe two efforts to test new stormwater retention technologies in the Los Angeles, California watershed to better manage stormwater and address the impacts of urbanization and imperviousness. The efforts include reducing impervious cover and planting trees at public schools. The state of Florida is developing urban BMPs to control urban runoff impacts on the Everglades (McPherson et al. 2000).

Stormwater can be treated an used for irrigation or similar reuse. Heggen (2000) reviews the challenges of rainwater catchment in sustainable development. Fan et al. (2000) discuss current urban stormwater control and treatment technologies, and the feasibility of reclaiming urban stormwater for various purposes, including a hypothetical-case study illustrating the cost-effectiveness of reclaiming urban stormwater for complete industrial supply. In connection with efforts to restore water quality in Santa Monica Bay, The City of Santa Monica, California has diverted its major dry-weather stormwater flows from the Pico-Kenter and Pier Storm Drains to the City of Los Angeles' Hyperion Wastewater Treatment Plant located a few miles to the south. Recently the city concluded that the dry-weather flows could be treated and economically reused in place of potable irrigation water and has begun design and construction of the Santa Monica Urban Runoff Reclamation Facility (SMURRF). When a resource such as urban runoff, considered a waste, is managed in a watershed approach, numerous hidden economic and environmental benefits result. Perkins and Shapiro (2000) report that the City of Santa Monica, California is using both a micro- and a macro-scale approach to watershed BMP implementation. Stormwater and treated sewerage effluent, previously regarded as waste, are now being reused in South Australia through the innovative aquifer storage and recharge technique. After pretreatment in wetlands, this water is stored in otherwise unused brackish aquifers for summer irrigation of parklands. Barnett et al. (2000) present several case studies where the aquifer storage and recharge technique has been successful, with savings in water and infrastructure costs, as well as providing environmental benefits. Domestic harvesting of rainwater as a source of water for flushing toilets and watering gardens are being assessed in Berlin, Germany. Rainwater harvesting relieves demand on potable water supplies and rainwater drainage in Berlin's urban districts (Koenig 2000).

Urban streams are often badly degraded from their natural state. Restoration of these streams is becoming a widespread practice, and is oftern done in conjunction with WWF control efforts. Athanasakes et al. (2000) describe the holistic stream restoration program which has been developed by the Louisville and Jefferson County, Kentucky, Metropolitan Sewer District. Their discussion focuses on issues involved in developing and managing a streambank stabilization/stream restoration program, such as getting a program started, a brief overview of stream restoration techniques, items to consider during construction and a summary of items learned throughout the development of the program. Stormwater management in an urbanized basin near Dallas, Texas included channalization of a creek which was eroding private property. (Amick 2000). Since the watershed is nearly fully developed, areas where mitigation could be accomplished were limited. Mitigation was required; leading to some restoration of another urban stream that had previously been channelized. The creeks in the Kelowna, British Columbia, Canada area, like those throughout North America, have been impacted by human development. Urban, agricultural, industrial and forestry activities have resulted in increased erosion and pollution, altered drainage patterns and reduced riparian vegetation. The City of Kelowna initiated the Lower Mill Creek Watershed Program in 1997; objectives of the program include: To improve Mill Creek water quality by preventing streambank erosion, and creating riparian areas to filter, trap and break down pollutants from nearby runoff. To restore and enhance instream and streamside habitat for both aquatic and terrestrial life. To educate the public, private landowners and developers on the importance of Mill Creek as well to encourage these groups to become stewards of the creek (Gow and Kam 2000). The U.S. Environmental Protection Agency (EPA) is allowing local governments to establish natural vegetative buffers (greenways) along stream corridors in lieu of incurring other EPA enforcement actions associated with violations of the Clean Water Act. Kleckley and Kungu (2000) identify the role of greenways in protecting water quality and aquatic and stream corridor habitats, and describe an on-going greenways project in Jefferson County, Alabama. Rodriguez at al. (2000) present a pool-riffle design for straight urban streams where existing infrastructure prevents re-alignment of channel planform. The proposed structures fulfill four main requirements: they increase flow variability during low and moderate flows; they produce minimal increase in the water levels during high flows; they self-maintain in terms of bed erosion and sediment deposition, and they provide in-stream habitat for fish. Von Euw and Boisyert (2000) present two case studies that focus on the partnership process, design and implementation, and lessons learned from the construction of two riffle weirs in urbanized streams in Vancouver. Key conclusions include that partnerships are an effective tool for implementing stream improvement projects in a cost-effective manner; and that riffle weirs can function effectively in an urban setting to mimic natural stream morphology, thereby improving fish habitat and channel stability.

Urban watershed managers are increasingly looking at stormwater control programs as a whole, rather than focusing on individual BMPs. Chocat et al. (2000) describe the evolution of urban drainage; even though urban drainage has been practiced for more than 5000 years, many challenges arising from growing demands on drainage still remain with respect to runoff quantity and quality, landscape aesthetics, ecology and beneficial uses, and operation of existing urban wastewater systems. Integrated stormwater management is based on the natural processes in the water cycle and the criteria for sustainable development. based on literature reviews and studies made in Lulea, Northern Sweden, Backstrom and Viklander (2000) investigated which integrated stormwater system components might be suitable in cold climate regions. It was found that porous pavement, grassed waterways (swales, ditches), wet pond, and percolation basin were the most suitable integrated stormwater system components in cold regions whereas dry basin, stormwater infiltration surfaces, and stormwater reuse seemed to be the less suitable. The Delaware Canal is a unique 60-mile long, 167-year-old man-made waterway which was built and operated commercially to haul coal and other goods from Bristol, Pennsylvania to Easton, Pennsylvania. Environmental Liability Management, Inc. prepared a map of the Delaware Canal Watershed, analyzed potential strategies to reduce accelerated erosion and sedimentation in the canal watershed, and produced a report intended to educate local residents and township and county officials on land use/management practices that can be incorporated into local ordinance to reduce the excessive sedimentation in the canal (Brussock et al. 2000). Barrett (2000) discusses the potential for BMPs to adequately address receiving water impairments in southern California. He concludes that pollutant removal rates for conventional BMPs will not enable BMPs to reverse receiving water impacts.

Several innovative watershed management approaches attempt to preserve the natural runoff-controlling features of a site in combination with an system of BMPs integrated throughout the site. Low Impact Development (LID) is rapidly being recognized as an ecologically sustainable and cost effective strategy to protect receiving waters from the water quality, volume, magnitude, and frequency effects of stormwater runoff. The LID strategy is based on creating hydrologically functional equivalent design features that replicate the pre-development conditions through the use of pollution prevention, precision engineering, and integrated micro-scale BMPs that are distributed throughout a site. Coffman et al. (2000) present the management strategies, protocols, and technological approaches incorporated in the development of an LID management strategy for the control of WWF in urban areas. Two publications that describe LID are the *Low-Impact Development an Integrated Design Approach* and *Low-Impact Development Hydrologic Analysis*, which can be obtained from the National Service Center for Environmental Publications (NSCEP) 1-800/490-9198. Daniil et al. (2000) present general design considerations and principles for flood protection and related stormwater design, based on an integrated environmental approach, involving less technical works and preservation of the physical condition of streams and creeks. The application of the above mentioned considerations is illustrated in two specific case studies from the suburbs of Athens, Greece. Hall and Scarbrough (2000) discuss the development and implementation of requirements for new development aimed at watershed protection in Gwinnett County, Georgia, USA. An approach is presented that is simple to use and encourages site design that takes advantage of the natural site amenities and minimizes impervious surfaces. Kauffman and Brant (2000) advocate amending existing zoning codes to establish watershed-zoning districts based on percent impervious cover thresholds in the Christina River Basin of Delaware.

The Storm Water Phase II Rule, published in the Federal Register on December 8, 1999, brings approximately 5,000 small municipal separate storm sewer systems (MS4s) and over 100,000 small construction sites into the National Pollutant Discharge Elimination System (NPDES) permitting program by 2003. USEPA is supporting implementation of this rule through the development of a ‘tool box.’ This tool box will consist of fact sheets, guidance, a menu of BMPs, an information clearinghouse, training and outreach efforts, technical research, support for demonstration projects, and compliance monitoring/assistance tools (Kosco 2000). The City of Portage, MI is pioneering a comprehensive approach to storm water management in light of the Phase II Storm Water regulations. The approach will serve to define the application of the now elusive "Maximum Extent Practicable" (MEP). Breidenbach et al. (2000) presents the approach for selecting design parameters to define MEP for the project and identifies how the minimum control measures for Phase II regulations are incorporated into the passive storm water treatment system design.

After a watershed management study is conducted and a plan adopted, local planners and engineers are often faced with the questions, How do we practically translate these recommended management strategies or best management practices recommendations into zoning and subdivision regulations, capital improvement plans, and assistance programs? How do we encourage effective site design and also provide flexibility in meeting environmental objectives ? Is there a practical, economical way to track how the design and best management practices are working? Brewer et al. (2000) document Rockdale County’s innovative Development Performance Review, including its procedures, and program cost/staffing requirements. Fernando et al. (2000) describe the development of effectiveness indicators for stormwater and watershed management programs and the development of a regional monitoring program. The study was conducted for the jurisdictions encompassed by the Hampton Roads Planning District Commission, with specific focus on the six cities that currently have Virginia Pollutant Discharge Elimination System stormwater permits. New Jersey is developing a rule proposal that will standardize its approach to the watershed planning process, goals and objectives for watershed planning. Van Abs (2000) proposes a conceptual basis for watershed planning objectives and thresholds, and then describes how New Jersey’s planning and regulatory system currently and prospectively addresses the issues. As part of the stormwater planning process for the Greater Vancouver area, a watershed classification system was developed to help evaluate the current and future impacts of stormwater discharges on the receiving environment. The system was designed to easily communicate these impacts along with potential mitigation strategies to stakeholders and decision-makers. Woods et al (2000) describe the watershed classification system, presents the classification results for 1996 and 2036, and outlines some of the experiences with developing and using this watershed management tool.

Design, modeling, and verification methods for BMPs continue to be refined and improved. Under the USEPA Environmental Technology Verification (ETV) Program's wet -weather flow Pilot, a protocol is being developed to standardize the testing procedures of commercial products for urban stormwater treatment. The major challenges in developing the protocol include: 1) producing scientifically valid results economically; 2) adapting the protocol to be applicable to the various product designs, and 3) fitting the protocol to meet the variety of climatic conditions in the United States. The key monitoring issues standardized by the protocol are: 1) establishment of sampling locations relative to the product's treatment system, 2) constituents to be analyzed and the analytical methodology, 3) number of events to be sampled, 4) definition of events to be sampled, 5) QA/QC procedures, 6) sampling methods (automatic, flow-composited), 7) the analysis of data, and 8) the reporting format (Bachuber 2000). The California Department of Transportation (Caltrans) constructs, operates, and maintains the state highway system in California, runoff from which is subject to the federal Clean Water Act and its associated NPDES permit program.. New permit requirements will require methods that achieve higher levels of pollutant control than are achieved by conventional BMPs. As a result, Caltrans has initiated an extensive research and pilot-testing program to identify new technologies that can be used to meet water quality standards (Krieger 2000). Under the assumption that street drainage will be designed to collect stormwater as fast as possible, the street stormwater capacity has been defined as its hydraulic conveyance, estimated by Manning's formula. Guo (2000) found that the street stormwater capacity at a sump is in fact dictated by the storage capacity rather than the conveyance capacity, and developed a new design methodology to consider the street depression storage as a criterion when sizing a sump inlet. In 1999, a project was instituted to replace two oil-water separators at Mobil de Colombia's terminal facilities in Cartagena, Colombia to bring the facility into compliance with environmental law. Using a proprietary computer program it was determined that the existing pits were large enough to meet the national environmental regulations for effluent oil content if fitted with multiple-angle coalescing plates. Gutierrez et al. (2000) present information on legal requirements, a discussion of how the operating conditions were determined, the new internals designed, and a discussion of how the new internals will affect the quality of the water exiting the facility. Patwardhan et al. (2000) briefly outline the Best Management Practices (BMPs) and reporting modules of the Hydrological Simulation Program – FORTRAN (HSPF) model (Bicknell et al., 1993) with its application to the Camp Creek and Little River Watershed Assessment Project located in Fulton County, Georgia. Stovin and Saul (2000) describe an extensive laboratory and computational fluid dynamics study into the hydraulic performance and sediment retention efficiency of tanks. The work has shown that (i) it is possible to predict the flow field which is measured in the laboratory using computational fluid dynamics, and (ii) a critical bed shear stress may be used to determine the extent of sediment deposition. The study also showed that the length to breadth ratio of the chamber was the most important parameter to influence sediment deposition, and that changes to the benching and longitudinal gradient of the tank had minimal effect. Intensity/duration/frequency (IDF)-relationships of extreme precipitation are widely used for design of stormwater facilities. Because the properties of extreme precipitation may be very different for different storm types and different seasons, IDF-relationships which permit decomposition into different components were established by Willems (2000). This study brings new elements in our current understanding of what determines the IDF curves and their scaling properties. Low Impact Development (LID) is an innovative micro-scale runoff control strategy for WWF based on a combined strategy of conservation to reduce hydrologic impacts and the incorporation of distributed micro-scale BMP's throughout the subcatchment. In order to fully understand the effects of reduced runoff volume and timing, as well as the full implementation of LID technology, modifications to existing models and new models must be developed. Wright et al. (2000) explore the potential and limitations of existing models to evaluate the effectiveness of this design approach. Hydrologically functional landscapes integrate principles of maximizing infiltration, contouring the landscape to encourage temporary detention, and the use of stormwater to reduce demand for irrigation water. Wright and Heaney (2000) report on the design and monitoring of a hydrologically functional landscape in Boulder, Colorado, and present a simulation model that evaluates the performance of the system. An extensive review of some 50 designs for litter traps which can be incorporated into urban drainage designs indicated that only seven showed much promise for South African conditions, A preliminary assessment of the seven most promising trapping structures concludes that three designs - two utilizing declined self-cleaning screens and the other utilizing suspended screens in tandem with a hydraulically actuated sluice gate - are likely to be the optimal choice in the majority of urban drainage situations in South Africa (Armitage and Rooseboom 2000). Alum stormwater treatment (the flow-weighted injection of liquid aluminum sulfate, Al2(SO4)3 . 18 H2O) combines an extremely cost-effective method of retrofitting nonpoint source discharges in urban areas with high removal rates of nutrients, heavy metals, and bacteria. This method of stormwater treatment is applicable to any area needing stormwater treatment and surface water quality improvement. Herr and Harper (2000) discuss two case studies using alum injection in Florida. A project described by Stein et al. (2000), which is funded by the National Cooperative Highway Research Program, includes both a synthesis of current information and a plan to guide future research on management of runoff from surface transportation facilities. The issues to be studied include regulations and permitting, runoff water quality characteristics, best management practices, receiving water impacts, and habitat impacts. Insufficient space, high land values, topography, maintenance, aesthetics and liability issues are reasons why underground detention is being considered more frequently. Finlay (2000) presents the development of a computer program for designing underground stormwater detention tanks. The program has four main functions: (1) develop or allow the direct input of an inflow hydrograph, (2) size the structure and develop a stage-storage relationship, (3) design the release structure and develop the stage-discharge relationship, and (4) route the inflow hydrograph through the structure. Boyd (2000) presents a collection of pre-programmed hydraulic and hydrology-related functions that have been compiled as an add-on module for use in computer spread sheets to aid in BMP and urban drainage design. Results from the modules are similar to results given by widely-used modeling software.

BMP performance can be verified only through expensive field testing, making published testing results a valuable resource for planners and engineers. Strecker et al. (2000) report on a research program funded by USEPA and ASCE to develop a more useful set of data on the effectiveness of BMPs used to reduce pollutant discharges from urban development. They describe some of the comparability problems encountered between different BMP effectiveness studies, considerations that affect data transferability, such as methods used for determining efficiency and statistical significance, efforts used to establish and analyze the currently available data and proposes protocols for future analyses, and recommend that effluent quality is probability a much more robust measure of BMP effectiveness and performance than the currently used “percent removal” metrics. Ball et al. (2000) evaluated the effectiveness of stormwater treatment devices installed on a roadway in Australia, including detention tanks, a CDS GPT, and a sand filter. It was concluded that the devices installed were improving the quality of stormwater flowing from the road drainage system into the general catchment stormwater system. Greb et al. (2000) evaluated the water-quality benefits of a new urban best management practice design called the multichambered treatment train. High reduction efficiencies were found for all particulate-associated constituents, such as total suspended solids (98%), total phosphorus (88%), and total recoverable zinc (91%). Dissolved fractions had substantial but somewhat lesser removal rates (dissolved phosphorus, 78%; dissolved zinc, 68%). Total dissolved solids loading which originated from road salt storage, yielded 4 times the total suspended solids load. The Washington State Department of Ecology's efforts to reduce the flow of pollution to Commencement Bay sediments, a federal Superfund site, caused metals concentrations in the bay to decrease by a factor of 10 between 1984 and 1997. This accomplishment demonstrates that major water quality improvements are possible in a heavily industrialized area, by focusing intensively on pollution problems one property at a time (Smith et al. 2000a, 2000b). Wang et al. (2000) sampled stream physical habitat, water temperature, and fish and macroinvertebrate communities at multiple paired watersheds in Wisconsin before and after BMP installation from 1993 to 1999 to examine the responses of stream quality to watershed-scale BMP implementation. Results clearly demonstrated that watershed and riparian BMP implementation improve overall stream quality and the investigative approach, studying multiple paired watersheds with before- and after-treatment data, proved effective in detecting the response of stream quality to BMP implementation. Continuous Deflective Separation (CDS) is an innovative technology capable of separating solids from liquids. In general a CDS unit could separate the followings loads from a storm-water system: suspended solids, bed loads, floating solids, free oil & grease. Field studies have verified removal efficiencies for gross solids to be greater than 95%, with particulate phosphorous removal of greater than 30%, and TSS removals greater than 70% (Kohzad 2000).

Non-structural BMPs, such a reduction in the use of pesticides and fertilizers, are often suggested for WWF control. However it is ofter difficult to assess the impact of such BMPs. A project underway in Sydney, Australia assesses the effectiveness of a directed community education program aimed at non-structural management of stormwater at source, through detailed monitoring of both the community knowledge and the stormwater volume and contamination. Ball et al. (2000) outline how the community education program was developed to focus on issues of concern to the local community and those issues that the local community could influence by changing their practices. Also outlined are the monitoring program developed to evaluate the effectiveness of the program and the availability of stormwater contaminants (Ball et al. (2000). The pollutant loads conveyed by street cleaning waters, by street runoff and the maximum pollutant load that can be removed from a street surface by water were measured for three streets in central Paris, France. The pollutant load removed on a daily basis from street surfaces by street cleaning waters was found to be similar to that removed during one rainfall event, for SS and organic matter. However, it was five times lower for heavy metals. This load is nevertheless far inferior to the total mass of pollutants stored on the street surface. Thus, the effect of street cleaning on abating runoff pollution seems limited. An unexpected effect of street cleaning is that it induces sediment erosion inside the sewer during dry weather periods, thus reducing the stock of pollutants available for wet weather flow (Gromaire et al. 2000). The key to a clean-water future will be voluntary participation by residents to protect water before it's polluted, primarily by changing household behaviors such as water usage, lawn care practices and proper disposal of household hazardous waste. That, in a nutshell, provided the genesis for "WaterShed Partners," a coalition that grew from a half-dozen founding members in 1993, to over 40 public, private and non-profit organizations working collaboratively in 2000, to develop and implement educational programs to reduce non-point source pollution in the Minneapolis/St. Paul, Minnesota metropolitan area (Henning 2000). Current turfgrass management practices in the U.S. contribute to a number of environmental problems, generate large amounts of solid and hazardous waste, and use (often waste) large amounts of water during the summer months when supplies are lowest. Typical lawncare practices also include intensive use of synthetic chemicals including water-soluble fertilizers, herbicides, insecticides, and fungicides, which may be harmful to human health and to aquatic ecosystems, including threatened salmonid populations and also negatively impact the turfgrass ecosystem. McDonald (2000) presents a proven alternative approach based on observation of the entire soil and grass ecosystem, appreciation that turfgrasses are sustained by the activities of soil-dwelling organisms, and understanding that this grass community is a dynamic equilibrium among many plants, invertebrates, and microbial organisms. Pauleit and Duhme (2000) developed a method to delineate urban land cover units to establish the relationship between the socio-economic performance of the urban system and its different sub-units (i.e. housing schemes, commercial and industrial developments, services) on the one hand and the environmental impacts of these sub-units on the other. A case study on urban hydrology is presented to characterize aspects of the metabolism of the urban system (Pualiet and Duhme 2000). A multi-stakeholder group, was formed to address and to remediate nonpoint sources of bacteriological pollution threatening the economic and environmental health of Baynes Sound, Vancouver Island, Canada. This work demonstrates that partnerships among government, the shellfish industry, community groups, and citizens can create a powerful means for improving water quality (Pinho 2000). The University of Connecticut Nonpoint Education for Municipal Officials (NEMO) Project is an educational program targeted at land use decision-makers. The project emphasizes natural resource-based planning, a planning approach that prioritizes local natural resources and finds a rational balance between development and conservation. Four simple elements are shared by projects in the Network: (1) an educational approach, (2) an emphasis on land use education, (3) a focus on land use decision makers as the target audience, and (4) the use of geospatial technology in the service of education (Rozum et al. 2000).

Stormwater Infiltration

Ellis (2000) addressed the potential conflict between the benefits of groundwater recharge of stormwater runoff versus the risks of long-term groundwater pollution in this paper. The long-term performance of a number of infiltration systems was reported in terms of their pollutant removal efficiencies, and the usefulness of an infiltration acceptability matrix approach was reviewed. Pitt et al. (2000a) presented a review of the literature available on the potential for groundwater contamination from the infiltration of stormwater runoff. The results of the literature review on both the frequency and mobility of the potential contaminants has been organized into a methodology that allowed evaluation of the potential contamination based on these two parameters. Part of this analysis included evaluation of the effects of infiltration on pollutant removal from the percolating water.

Morris and Stormont (2000) showed that near-surface processes such as precipitation, runoff, snowmelt and evapotranspiration have a significant impact on moisture movement in soils, and that models must include these near-surface processes. Pitt and Lantrip (2000) examined the effects of urbanization on soil compaction and resulting infiltration capacity through a series of double-ring infiltrometer tests. They found that sand was mostly affected by compaction, with little change due to soil-water content levels. However, the clay sites were affected by a strong interaction of compaction and soil-water content. The fit of the data to the Horton equation was inconclusive, indicating that when modeling runoff from most urban soils, assuming relatively constant infiltration rates throughout an event, and using Monte Carlo procedures to describe the observed random variations about the predicted mean value may provide the best results. Pitt, et al. (2000b) argued that if the traditional design equations are going to be used to predict infiltration, local data must be obtained and used.

Reemtsma et al. (2000a), in their study on the infiltration of combined sewer overflows versus tertiary-treated municipal wastewater found that, when looking dissolved organic compounds, the groundwater quality that results from infiltration of CSOs is comparable to or better than the quality after infiltration of tertiary-treated municipal wastewater. However, the nutrient quality of the CSO water was worse compared to the tertiary-treated municipal wastewater after infiltration of both. Desorption of both nutrients and organics previously adsorbed was seen to be a potential problem of long-term infiltration. They also investigated the metals content of infiltration water from these two sources and the retention of these metals in the soil profile (Reemtsma et al. 2000b). They found that the metals are effectively retained during passage through the soil; however, additional alkalinity is needed to buffer the acidity caused by bacterial nitrification and mineralization, since soil acidification likely would result in both a reduction in efficiency of metals removal and a potential release of previously-trapped metals. Singh et al. (2000) investigated the potential for metals release from dredged-sediment-derived surface soils in the Netherlands. They found that runoff rates and sediment yields were highest for a silt loam sediment. The metals content of both the runoff and percolating water was greater than the standards for groundwater quality and very high metal fluxes were observed for the recently-oxidized dredged sediment. Metals transport per unit surface area was found to be two to twenty times greater for the percolating water when compared to the runoff water.

Backstrom and Bergstrom (2000) investigated the impact that snowmelt and temporary freezing conditions would have on the infiltration capacity of porous asphalts. Their results showed that alternate freezing and thawing conditions (similar to times of snowmelt) would reduce the infiltration capacity of the asphalt by 90% to a level of approximately 1 - 5 mm/min. Westerstrom and Singh (2000) investigated the infiltration of snowmelt runoff in Lulea, Sweden, and found that unlike rainfall infiltration, the snowmelt infiltration resembled a flow hydrograph, i.e., there was a distinctive rise, peak and recession to the graph. Unlike the relationship for rainfall and infiltration where the relationship is decidedly non-linear, a strong linear relationship between the snowmelt runoff hydrograph peak and the amount of snowmelt was found.

The use of filtration media for stormwater runoff treatment was investigated by several groups of authors. Brown (2000) investigated the potential for using kudzu to remove heavy metals from dilute aqueous streams, such as stormwater runoff. Kudzu was found to be an effective adsorber for heavy metals, and while its capacity was lower than that of commercial-grade resins, it was also cheaper than the resins. The application of kudzu to stormwater runoff was found to be particularly attractive both because of the cost and because of the potential problem of premature fouling of an expensive resin by interfering contaminants typically found in stormwater runoff. Clark et al. (2000) investigated the potential of using low-cost adsorbents, such as peat moss and municipal leaf compost, to treat dilute aqueous wastestreams of copper such as stormwater runoff. The capacity of these adsorbents was compared to the capacities of other well-known adsorbents, such as activated carbon, bone char and cation-exchange resins. The low-cost adsorbents had removal capacities of approximately 20 - 30 mg Cu/g media. While these capacities are less than those of the bone char and resin (approximately 90 mg Cu/g), their cost is significantly less, and they demonstrate a robustness for dealing with the intermittent flow and potential interferences of stormwater runoff.

Sansalone and Hird (2000) reported the results of a prototype partial exfiltration reactor (PER) to remove metals such as lead, cadmium, copper, nickel, zinc and chromium from stormwater runoff. The PER proved effective at removing these metals from the runoff influent. Clark (2000) conducted a pilot-scale study on the ability of several potential filtration media for treating pre-settled urban stormwater runoff. The results of the study showed that modeling pollutant removal in traditional pre-settled stormwater runoff will be difficult because the low concentrations of many pollutants are near the removal limit of many of the filters. Clark also investigated modeling equations for the removal of solids by filtration from stormwater runoff. The model equations that fit the data were similar to the power loading equation proposed for the sand filters in Lakewood, Colorado. This project also investigated the effects of anaerobic conditions on pollutant removal by four of the media: activated carbon, sand, compost and peat moss. The results were that most of the previously-sorbed metals would not be released if the water in the filter turned anaerobic; however, many of the nutrients would be released and washed off the filter during the next storm event.

Sala and Hensch (2000) tested the ability of silica micro encapsulation (SME) for the treatment metals-contaminated wastewater. They found that the technology has potential and they proposed that it could be used to treat stormwater runoff such as by injecting it into a runoff flow stream. The end result was that the metals were permanently stabilized and the SME material could be disposed of properly once its capacity was exhausted. Wigginton and Lenhart (2000) reported the results of using an iron-infused resin for the removal of phosphorus from stormwater runoff. Testing of the iron-infused resin in the Stormfilter™ cartridge showed 38.6% removal of dissolved phosphorus, 44.9% for total phosphorus and 78.6% for total suspended solids. Increased removals were observed between test cycles, indicating that increased oxidation of the iron occurred which provided additional sites for phosphorus adsorption.

In their paper, Cairo and Pujol (2000) advocatde the use of membranes and biofilters for urban wastewater treatment. They demonstrated that the membrane and bio-filters produce a high quality effluent during both dry- and wet-weather flows. Lau et al. (2000) demonstrated that biofilters, even with a biofilm as young as three days, is capable of providing good removal efficiencies for both dissolved and sediment-adsorbed metals. During the nine-week operating of a laboratory-scale biofilter, 90% of the total Cu and Zn were removed. Field-testing of a submerged, aerobic biofilter for the treatment of stormwater runoff was reported by Mothersill et al. (2000). They found that the biofilter removed 97% of the suspended solids in the runoff; however, the suspended solids accumulation interfered with the nutrient removal through bacterial assimilation. Removal efficiencies of 64% for ammonia nitrogen were seen throughout the life of the filter. Backwashing to remove sediment was found not to be sufficient to maintain optimal biological filtration conditions.

James and James (2000) advocate the use of permeable pavement to reduce the impacts of the thermal pollution of receiving waters associated with urban stormwater runoff. They discuss the required design criteria for an acceptable permeable pavement, including long-term performance. Laboratory studies indicated that infiltrating pavements reduced both the flow and contaminant load of runoff to the greatest degree, although asphalt provided the least buffering capacity for acid rainwater and also the least contaminant removal.

Combined Sewer Overflow/Sanitary Sewer Overflow Control

Combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) continue to be an important source of water pollution throughout the world. The approaches used by others offer important insight into CSO, SSO, and wet weather flow (WWF) control planning. The analysis of CSO abatement alternatives often proceeds in an evolving manner. Landside models are generally used to determine which outfalls need CSO abatement, sometimes in conjunction with receiving water quality models. Once CSO outfalls in need of abatement are identified, an optimal level of abatement needed to achieve water quality standards can be determined. With the required abatement level determined, various methods of achieving that level can be explored. Many small-to-medium-sized communities with combined sewer systems are faced with regulatory mandates to prepare long-term CSO control plans. Brilhante et al. (2000) describe the use of USEPA's Storm Water Management Model (SWMM) in CSO analysis. As a project proceeds through planning and design of CSO abatement, the model is refined to test alternatives and set the detailed specifications required. By examining wastewater treatment plant flows during dry and wet weather periods, the effectiveness of your CSO control system in capturing base sanitary flows can be measured. Before embarking on an expensive sewer system modeling project, it is important to examine all of your available data to determine how your system is affected by wet weather events and the probable relative magnitudes of CSO loadings to area receiving streams. This approach was successfully used in Charleston, West Virginia, to identify a low-cost solution to minimize CSO loadings to the Kanawha River (Lyon 2000). With any large project, breaking the problem down into more manageable subtasks staged over a period of time can simplify the effort and make it more practical to undertake. The City of Niagara Falls, New York is taking such an approach in dealing with levels of infiltration and inflow in its collection system that are creating service problems for residents, and impacting its ability to redevelop the eastern portion of the city. The understanding and cooperation of the state environmental regulatory agency has proven vital to undertaking the program and achieving significant progress, without imposing undue financial hardship upon the residents and ratepayers (Roll and Benson 2000). Gomis et al. (2000) present an analysis of the factors involved in the response of an urbanized drainage basin with a combined sewer system to a rainfall event. In the case of moderate and heavy rainfall, the coefficient of flow is independent of the characteristics of the rain, being close to the imperviousness coefficient. For lighter rainfall, flow is above all determined by the initial surface state of the drainage basin (Gomis et al. 2000). Lindholm and Nordeide (2000) evaluate the relevance of different methods and criteria for choosing the best technical system to solve a CSO problem in Oslo, Norway. A simple EIA analysis with a pragmatic choice of criteria was found most suitable for choosing between conventional or nature-based solution. Marsalek and Giulianelli (2000) present a comparative analysis of urban drainage challenges in Italy and Canada. Each country has knowledge to share; Canada can offer stormwater management practices and satellite CSO treatment; Italian contributions include effective layouts of distributed CSO storage and operation of such systems in real time. The City of Livonia, Michigan is using Geographic Information Systems (GIS) technology to enhance the implementation of its illicit discharge elimination program. As a result of the GIS integration, record keeping is improved, problem areas are identified earlier, and joint efforts with surrounding communities and other agencies with storm drainage jurisdictions in Livonia are simplified (Rohrer and Beckley 2000). Smith et al. (2000) present observations and causes of increased odor production and release in recently separated collection systems and present corrective actions which have been shown to reduce these odor effects. Hydraulic/hydrologic modeling was conducted using the EPA Stormwater Management Model (SWMM) in support of the design of a CSO consolidation/relocation project in South Boston. For design, the SWMM model used in facilities planning was refined and recalibrated to provide greater confidence in the design flows. A 50-year storm that occurred during the flow monitoring period provided confidence that the recalibrated flows were appropriate for use as design criteria for the CSO consolidation/relocation conduit (Walker et al. 2000). A detailed hydraulic model was used to simulate alternative flows scenarios to and through the treatment plant as part of a city-wide CSO Strategy in Edmonton, Alberta, Canada (Ward et al. 2000).

Regulatory requirements drive CSO control in most cases. Buchholz et al. (2000) used a computer model to evaluate the performance of a CSO retention treatment facility in Michigan. In an effort to comply with the requirements of the Federal Clean Water Act (PL 92-500 of 1972) improvements to the system were accomplished by additional storage of CSO, removal of storm water inputs to the RTF, and improvements to maximize the use of the existing interceptor system. The (U.S.) State of Michigan's CSO Policy, developed prior to the USEPA policy, says that CSOs must be eliminated or controlled to protect designated uses at times of discharge. The level of control may be determined by either a water quality based demonstration or by accepting a presumptive level of treatment described in terms of a retention/treatment structure (Cowles 2000). Six years after the EPA's 1994 CSO Policy was issued, only two of the 30 States with CSO municipalities have taken actions to facilitate the implementation of the water quality provision of the CSO policy. Human-induced conditions in urban areas and other point and non-point sources of pollution may make current water quality standards in some urban waters no longer appropriate or unable to be met, regardless of CSO controls that are implemented. A proper review and revision of existing water quality standards can save unnecessary expenditures, ensure that proper water uses are maintained, and significantly facilitate the implementation of water quality-based provision of the CSO policy (Dwyer and Huang 2000). The expectation of the CSO Control Policy was that long-term control plans (LTCPs) would be developed to meet water quality standards (WQS) and, where appropriate, States would revise their WQS to reflect the difficulty in achieving compliance with current bacterial standards in urban areas during wet weather events. Slack and Nemura (2000) discuss the difficulties CSO communities face in obtaining revisions to WQS to support the development of LTCPs that are cost-effective and protective of water quality and human health. The Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program was established to overcome the numerous impediments to commercialization experienced by developers of innovative environmental technologies, particularly the lack of credible performance data. Stevens and Frederick (2000) describe the ETV approach and two recently initiated pilot programs for verification testing of source water protection technologies and wet-weather flow technologies. Rowe (2000) presented an overview of SSO control strategies to management and engineering staff who represent a National Pollution Discharge Elimination System (NPDES) permittee. USEPA is in the final stage of preparing and issuing a SSO Rule that will add control of SSO to the NPDES permit requirements. Lai et al. (2000) provide a preview of the rule and describe the advantages of employing a collection system modeling approach for capacity assurance of various components of a collection system and development of SSO mitigation plan. Historically, EPA and the States have allowed municipal facilities to route peak wet weather flows around the secondary treatment process, to disinfect the rerouted flows, and then blend the peak flow with the other, more highly treated, effluent. In a reinterpretation of the federal "bypass" rule, some at EPA have taken the position that if rerouting causes any of the waste stream to skip a treatment process, such action is illegal. Unless resolved, this issue will have an enormous impact on the way municipal facilities deal with extreme wet weather events, whether the excessive flows are associated with combined sewers or separate sanitary sewers (Hall et al. 2000).

Many large-scale SSO, CSO and WWF control programs are underway worldwide. The city of Evanston, Illinois, USA has undertaken a large-scale project to control basement flooding from combined sewer backup by limiting the entry of wastewater to the sewer system to just that quantity that matches the conveyance capacity of the system. Figurelli et al. (2000) evaluated the performance of the program against the following evaluation criteria: technical hydraulic performance (basement backup and street ponding performance), citizen perception of performance (based on postcard surveys and complaint calls), maintenance concerns and costs, project capital costs, level of construction disruption, and public acceptance. Based on the success in Evanston, it is believed that the concept has great potential to be extended to many cities with a combined sewer system and extensive basement backup problems (Figurelli et al. 2000). The City of Saginaw, Michigan is nearing completion of the second phase of a comprehensive CSO control project required to meet NPDES Permit requirements. Hubbell and Phillips (2000) provide information on the historical background and existing sewer system, NPDES permit issues and requirements of project planning, design considerations, construction, operations, and performance. A multifaceted project including highway improvements, development of waterfront parks, and water quality improvements resulting from CSO abatement was undertaken in the New York, New York. The project serves as an example of how inter-agency cooperation can serve to benefit the community and environment (Kloman et al. 2000). Since 1990, Canada's Great Lakes 2000 Cleanup Fund, which is administered by Environment Canada, has been supporting the development and implementation of cleanup technologies to control municipal pollution sources, to clean up contaminated sediments, and to rehabilitate fish and wildlife habitats. Impairments in beneficial uses have been, in part, caused by discharges from CSOs, stormwater, and sewage treatment plants. The Urban Drainage Program has been instrumental in advancing the state of the art in CSO and stormwater management in Ontario, and the lessons learned there can easily be applied to communities in other parts of the country and around the world (Kok et al. 2000). The fundamental goal of the Philadelphia Water Department's (PWD's) CSO program is to improve and preserve the water environment in the Philadelphia area and to fulfill PWD's obligations under the Clean Water Act and the Pennsylvania Clean Streams Law by implementing technically viable, cost-effective improvements and operational changes. The PWD's strategy to attain these goals has three primary phases which are being implemented concurrently over a 5 year time frame: 1. Continued implementation of a comprehensive program for Nine Minimum Controls; 2. Planning, design, and construction of 17 capital projects that further enhance system performance and reduce CSO volume and frequency; and, 3. a commitment to complete comprehensive watershed-based planning and analyses that will identify additional, priority actions to further improve water quality and quantity dynamics in the Philadelphia area water bodies (Marengo 2000). In 1998 the City of Rockland, Maine began a major capital improvement program aimed at its aging wastewater collection and treatment system which included provisions for high-rate treatment of CSO flows (Freedman et al. 2000). Clifforde (2000) discusses efforts by the water industry of England and Wales to solve urban CSO pollution problems and planning guidance on dealing with stormwater in an integrated manner. The Northeast Ohio Regional Sewer District is undertaking the lead role in CSO management in the metropolitan Cleveland area. Following a rigorous study and characterization of Cleveland's complex collection system, a CSO control plan has been recommended. The plan includes several technologies to maximize use of the existing system as well as new facilities, which will control CSOs to the desired level (Matthews et al. 2000). Various public utilities in Broward County, Florida are implementing sanitary sewer rehabilitation programs which are expected to include a total of at least 7,796 repairs (Larsen and Garcia-Marquez 2000). Seigle et al. (2000) reported on the negotiated long-term CSO control plan for Manchester, NH. An inventory and structural evaluation of CSOs in towns in Slovakia with more than 30,000 inhabitants was carried out during a three-year joint research project of the Water Research Institute and the Department of Sanitary Engineering of the Slovak Technical University in Bratislava (Sztruhar et al. 2000).

In many cases, CSO is treated at the point of overflow. Nine facilities for storing and treating CSOs are in operation on the Rouge River in metropolitan Detroit, Michigan. Overall, the operating experience with the Rouge River CSO control facilities is providing valuable information for designing future phases of CSO control on the Rouge and for communities engaged in CSO control in other watersheds (Johnson et al. 2000). Andoh and Saul (2000) outline recent developments in CSO technologies, particularly screening devices for the control of aesthetic pollutants and describe the characteristics of the ideal intermittent wet-weather screening system. The authors then describe the development and evaluation of a novel self-cleansing CSO device - The Hydro-Jet Screen™. Intermittent and highly variable wastewater and stormwater flows created by rainfall events create new challenges in the field of pollution control. Averill and Gall (2000) examine the implications of intermittent loadings and operation, and outline a strategy for the planning and design of treatment systems designed for the treatment of CSO, SSO or stormwater. In the City of Niagara Falls, NY, USA, a feasibility study initially recommended a storage facility for a major CSO. Alternative CSO control options were evaluated because of the high cost of constructing a storage facility. High rate treatment by means of vortex separators was considered an attractive option after preliminary settling column tests showed that the settling characteristics of the CSO were amenable to high rate treatment (Cheung 2000). Underflow baffles have gained in popularity over the years as a viable mean to intercept floatables in CSOs, but have been largely untested. Cigana et al. (2000) report the results of a study of floatables capture performed in a 17 meters long basin at various flowrates. Their data suggests that capture efficiency of existing underflow baffles in overflow chambers can be, at best, very low whenever the horizontal velocity increases above 0.30 m/s or 1ft/s. Clegg et al. (2000) discuss projects related to removal of rainwater inflow sources on private property from combined and sanitary sewer systems in Lansing and Port Huron, Michigan. Keys to success for these programs include: property owner understanding, city identification of inflow sources, free advice and site visits, tracking and follow-up, flexibility on removal method, and ordinances to help enforce inflow removal on all private properties. The city of Detroit, Michigan has planned the Conner Creek Pilot CSO Control Facility, which will provide skimming, settling, and disinfection to meet the daily and monthly fecal coliform limits of 400 and 200 colony forming units (cfu) per 100 milliliters (ml), respectively (Fujita et al. 2000a). If this 30-million gallon "pilot facility" can meet the fecal coliform limits, it may allow for significant cost savings in CSO treatment (Fujita et al. 2000b). Continuous Deflective Separation (CDS) is a unique method of liquid/solid separation consisting of a stainless steel perforated and deformed separation plate placed in a hydraulically balanced separation chamber. Louisville and Jefferson County MSD (Kentucky) currently has a full scale demonstration project that is one of the first CSO applications of CDS technology in the world (Gratzer 2000). The Detroit (Michigan)Water and Sewerage Department, in developing the Long Term CSO Control Plan, is recommending an innovative screening and disinfection approach to reduce the impacts of CSOs on the Detroit River. Underground structures were designed for two pilot facilities to convey the CSO flows through 4mm raked bar screens, which direct the solids to the wastewater treatment plant through a side stream and thus eliminate the need for residuals to be collected and transported from these remote facilities (Rabbaig and Neibert 2000). Zaccagnino et al. (2000) reported on a plan by the New York City Department of Environmental Protection to reduce CSO impacts on Flushing Bay; the plan includes several end-of-pipe CSO controls.

Real Time Control (RTC) of wastewater systems involves using automatically adjusting weirs, flow separators, and similar devices to divert flow to unfilled portions of the system before overflow is allowed to occur. RTC may be useful if both operational problems exist and idle capacity is available. One of the more frequently applied RTC techniques in combined sewer systems (CSS) is the activation of in-line storage capacities by positioning regulators such as moveable weirs and gates into the collectors. Campisano et al. (2000) present the results of the application of RTC to the Roma Cecchignola CSS by using an advanced hydraulic model. Comparison of the results obtained with the tested strategies has shown that a global control strategy allows for reducing overflows considerably more than a local control strategy (Campisano et al. 2000). Charron et al. (2000) present the results of a study of RTC to reduce CSO in and around Louisville, KY. The results from this first study show that a global RTC strategy could enable a more efficient use of the existing system capacity and reduce the overall cost of the CSO control. Cigana (2000) introduces the use of linear overflow devices that can help municipal managers in achieving increased retention of sewage in a sanitary or combined sewer while protecting against flooding. In some example applications, the required water head is be lowered by 50% for the same overflow rate (Cigana 2000). Jain (2000) summarized the hydraulic characteristics of a two-ramp drop structure used for diverting flows from near-surface storm-sewer systems to underground storage tunnels. This drop structure can be constructed by a tunneling technique that can be more suitable in urban areas where an open-cut construction may be expensive and infeasible. Lavallée et al. (2000) review the lessons learned from the implementation and the performance of the RTC system installed for the Quebec Urban Community (QUC), Canada. Thus far in QUC, the implementation of a Global Predictive Real Time Control (GP-RTC) strategy on the Westerly Sewer Network has been a success in terms of proven efficiency. GP-RTC will permit construction of only 4 storage facilities instead of the 7 needed without GP-RTC, resulting in savings of approximately 22% of the cost of the plan without GP-RTC (Pleau et al. 2000). Pollution-based RTC, or PBRTC, is designed to reduce the potential pollutant load on receiving waters during wet weather without having to expand transport or storage capacity. The basis for PBRTC is to give priority for most of the polluted wastewater for transport to treatment and storage. In branched interceptor systems PBRTC can reduce CSO pollutant loads by more than 20% compared to volume-based RTC (Risholt 2000). Stinson et al. (2000) present results of two case studies of RTC that were conducted at real-scale demonstration sites on portions of sewerage systems near Paris, France and in Quebec City, Canada. Villeneuve et al. (2000) compared three RTC strategies used to operate a collection system in order to optimize use of system capacity and to reduce the cost of long-term CSO control. The Philadelphia Water Department used the SWMM EXTRAN model and SewerCAT modeling framework to investigate the application of RTC in its Southwest Drainage District (Vitasovic et al. 2000). A 100-year old brick interceptor sewer ruptured in the exclusive Sea Cliff area of San Francisco during an intense, but not extraordinary, rainstorm. Water was constricted by a partly-lowered gate in an overflow structure that had recently been constructed some 1400 feet downstream of the failure (Medley 2000).

Public involvement and education play a role in WWF control programs. Little Rock Wastewater Utility’s Captain Sewer Water Conservation Education Program began in October, 1988, with the costumed superhero’s appearance at the annual Utility Halloween costume contest and a subsequent visit to his son’s elementary school to discuss water conservation. Captain Sewer now visits at least twenty-four schools each year and has appeared in 24 states and two foreign countries (Barger 2000). A campaign to involve the public in developing a control plan for CSOs in Edmonton (Alberta, Canada) has evolved into a program with broader implications. “Towards a Cleaner River” has raised public awareness of the condition of the North Saskatchewan River, the general functioning of the drainage and sewerage systems, and how people can help improve the river’s water quality (Barth et al. 2000a). The Project Working Committee, the City and their consultant team collaborated to develop a long term CSO Control Strategy that will mitigate the environmental impacts of Edmonton’s combined sewer system. The comprehensive, 16 year, $150 million strategy strikes a balance with stakeholders by providing significant environmental benefit while being flexible, cost-effective and affordable. (Barth et al. 2000b). Water quality in Pogues Run and the West Fork White River, near downtown Indianapolis, Indiana, has seriously deteriorated as a result of 23 CSO outfalls along Pogues Run. To address the problems facing Pogues Run, a multi-million dollar comprehensive plan has been formulated. Due to the multiobjective nature of the project and its funding needs, many agencies and neighborhood groups with varied, and sometimes conflicting, interests were involved. Issues such as short-term funding, handling special waste, compensatory wetland creation, allowance for dam overtopping, and even the project's name and purpose had to be resolved (Kirk and Beik 2000).

One widely used approach to CSO and SSO control is to improve the ability of wastewater treatment plants (WWTP) to adequately treat high volume wet weather flows. The Binghamton-Johnson City Joint Sewage Treatment Plant, New York, is under state consent order to expand its wastewater treatment facilities to meet effluent limits for discharge to the Susquehanna River, to increase the primary treatment capacity to treat peak storm weather flows up to 60 mgd, and to increase the secondary treatment capacity to a minimum of 35 mgd. Arbridges et al. (2000) designed and conducted a pilot-scale evaluation of a system of biological filters that would fit within the existing site limits and allow elimination of the peak wet weather bypassing associated with activated sludge (Arbridges et al. 2000). In order to minimize CSOs to local receiving waters, the Philadelphia Water Department has initiated a program to maximize flow to be treated by the existing WWTPs during periods of wet weather. As part of this effort, Ferguson et al. (2000) documented the effect of variations in influent characteristics, operational procedures, and minor physical modifications on clarifier performance. In the City of Edmonton, Alberta, Canada's CSO Strategy, a preferred method of control was to convey more flow to the WWTP for treatment and expand treatment capacity To understand and evaluate the hydraulic relationship between the upstream collection system and the WWTP a detailed hydraulic model was developed and included as part of the collection system hydraulic model (Gray et al. 2000). Kurtz et al. (2000) present the results of pilot testing of high rate physical chemical treatment technologies in a New York City WWTP. All units performed well when operating correctly, removing between 69% and 84% of TSS on average (Kurtz et al. 2000). When King County Washington elected to modify the continuously operated Alki Treatment Plant to an intermittently operated wet weather facility, they demonstrated that treatment of wet weather flows is possible with modifications to existing primary treatment facilities in a cost-effective manner (Maday et al. 2000). An analysis by Moffa et al. (2000) demonstrated that retrofitting existing wet-weather flow facilities can be technically feasible in most cases and may be more cost effective than construction of new conventional control and treatment facilities. The feasibility and cost effectiveness of retrofitting was found to be a function of site-specific conditions and treatment requirements. A related paper by O'Connor and Goebel (2000) indicated that retrofitting processes will better enable communities to meet the U.S. EPA's National CSO Policy and stormwater permitting program requirements. The Arlington County (Virginia) WWTP is undergoing a retrofit to meet a proposed mandatory ammonia and voluntary total nitrogen standard and reduce plant bypasses which occur during wet weather conditions. The main components of the wet weather management plan are the new flow equalization basin, operational flexibility in terms of PE feed to the individual aeration tank passes, flexible aerobic/anoxic swing zones and retrofitting of the secondary clarifiers (Pitt et al. 2000). Camp Dresser & McKee Inc. has developed a wet weather flow strategy for the wastewater collection and treatment system that represents the first use of microsand-ballasted high-rate clarification in WWF treatment (Vick 2000). Chemically enhanced high rate separation offers a robust treatment alternative for application to CSO, SSO and excess WWF at WWTPs, and will be evaluated by USEPA's ETV Program (Zukoys et al. 2000).

The condition of a combined or sanitary sewer influences overflows from the system, and sewer inspection and prioritization of repair efforts are important parts of overflow control. Continual improvement and streamlining of a comprehensive program of inspection and evaluation to assess the condition of a system of interceptor sewers and CSO facilities in the Cleveland (Ohio) metropolitan area resulted in an innovative and widely applicable approach to locating, identifying, and inspecting interceptor and CSO facilities that significantly reduced field time and greatly increased the accuracy of the data collected (Krizmanich et al. 2000). Hahn et al. (2000) describe an expert system, Sewer Cataloging, Retrieval and Prioritization System (SCRAPS), that prioritizes sewer inspections to target the collection of information from critical portions of a sewer network. Kelley et al. (2000) reported on a process to quickly and effectively address manhole rehabilitation needs. This process consists of standardized data collection, computerized decision-making and implementation of appropriate rehabilitation methods, and has made tackling the rehabilitation of New Orleans' 28,000 sanitary sewer manholes an attainable and feasible task. Merrill et al. (2000) present a tool to help utilities prioritize inspection of sanitary sewers to overcome limits of available data and limited ability to inspect and repair or replace sewer infrastructure. In validation exercises using case studies supplied by the experts, the tool was shown to outperform a group of experts in quantifying the need to inspect (Merrill et al. 2000). In 1995, the Washington Suburban Sanitary Commission, which is located in Montgomery County and Prince George's County, Maryland and is the sixth largest wastewater agency in the country, launched a 4.5-year, multimillion-dollar I/I analysis and sewer system evaluation survey in a high profile, critical drainage basin. A paper by Nguyen et al. (2000) summarizes the results of the Rock Creek I/I Analysis project, describes the tools that were developed to analyze the voluminous amount of data, and discusses the method that was used to prioritize and choose the most cost-effective solutions to repair all defective manholes and pipelines that were identified. A statistical condition model was used to forecast the future condition of selected small-diameter (4- inch to 10-inch) sewer pipes and to estimate necessary rehabilitation capital costs in the Central Contra Costa (California) Sanitary District. A condition model uses detailed knowledge of a small portion of a system to predict the condition of the entire system. Pomroy et al. (2000) reported that condition modeling provides an efficient means to plan future expenditures and staffing requirements. An important part of assessing the performance of a sewer is monitoring flow in the sewer. A highly accurate dye dilution testing protocol was developed and used to quantify flow meter accuracy in the Greater Detroit Regional Sewer System. Many meters that are typically considered to be accurate had errors of more than 30%. Some meters had errors that exceeded 70%. Overall, the average initial system accuracy for system meters was observed to be ±15.0% of measurement with an overall bias of 6.1% (under-predicting flow). It is concluded that: 1) there are observable accuracy differences between flow meter technologies, 2) objective standards like dye dilution testing are critical to good metering, 3) verifying installed accuracy is important, even for technologies considered to be highly accurate, and 4) the simplest technology that can be used is often the best (Stonehouse et al. 2000).

Infiltration / Inflow (I/I) is a term that describes groundwater / stormwater inputs to sanitary sewers, and can be a source of unnecessary flows and increased occurrence of SSOs. Forbes (2000) examines the causes, diagnosis, impacts, and treatments for excessive I/I, which is a significant cause of sanitary sewer problems, including SSO. Kurz et al. (2000) report on a program in Nashville, Tennessee to improve system characteristics, recapture capacity, and reduce I/I so the sewers can carry the peak flow from a design storm with a specified recurrence probability, without overflows. I/I removal rates will likely vary in different locations due to groundwater levels, annual rainfall, previous construction techniques, soil types, etc. Accordingly, sewer rehabilitation programs should include procedures to measure I/I removal effectiveness as a program progresses (Kurz et al. 2000). Trenchless technologies are desirable for use in I/I control in sewers because they can be implemented with less traffic control, minimum conflict with other utilities, increased workers and community safety, and minimum dust and noise generation (Garcia-Marquez et al. 2000). In the Village of Beverly Hills, Michigan, I/I into the sanitary system from public and private sources overloads the sewer system and causes basement flooding and SSOs to local surface waters during large rain events. Sump pumps from residences are connected to the sanitary sewer system in many areas of the Village, so a project was undertaken investigate the effectiveness of removing sump pump connections to the sanitary sewer system in an effort to correct this I/I source. All factors suggested a quantifiable decrease in inflow after the sump pump removal (McCormack et al. 2000). Rehabilitation of two basins in the City of Olympia, Washington allowed direct comparison of the effectiveness of rehabilitation of the upper lateral vs. the public sewer and lower laterals to reduce I/I, as well as the total removal that can be achieved when the entire system is rehabilitated (Merrill et al. 2000). The City of North Miami Beach, Florida initiated a system-wide I/I reduction program and selected formed-in-place liner installation to rehabilitate many of the damaged gravity mains. Through 1999, the City has installed liner in 27,500 feet of collection system piping, and is metering a nearly 48 percent reduction in average daily flow from that measured at the start of the I/I reduction program (Rothman and Heijn 2000). A geographic information system (GIS) based system has been developed to manage both sewer maintenance and I/I reduction programs The system is designed to be used primarily by sewer managers as a tool for managing day-to-day activities relating to sewer system tasks such as issuance of work orders and responding to customer complaints, and can also be utilized by engineers in conjunction with sewer line modeling needs (Shaffer and Greiner 2000). In 1992, Springfield, Missouri, began a long-term program of I/I reduction which included a comprehensive sanitary sewer evaluation, development of a hydraulic model, various manhole and pipeline renewal projects, and the addition of strategic relief sewers (Wade 2000).

Sewer solids which are deposited in combined and sanitary sewers during dry weather can make up a significant component of CSO and SSO pollutants. Detailed research investigating all aspects of solids in sewer systems that has been underway in Europe for nearly two decades. Recent research has characterized the nature of the solids getting into sewer systems, how they behave in terms of transport, and some of the main aspects of their effects. In a number of catchments it has been possible to demonstrate that the majority of pollutants found in suspension during storms, and likely to be discharged from overflows, originate from the predominantly organic 'near bed solids' which accumulate in systems during dry weather. New ideas for the way in which the sediments are transported and research which has shown the importance of the transformation processes, are leading toward the development of unified and integrated understanding of the way in which sewer solids and associated processes behave. In turn this is allowing the development of more effective predictive models (Ashley et al. 2000). The USEPA is also investigating the causes of sewer solids deposition and development/evaluation of control methods that can prevent sewer sediment accumulation. Control of sewer sediment not only protects urban receiving water quality but also prevents hazardous conditions in sewers and protects sewer structural integrity (Fan et al. 2000). Chen and Leung (2000) demonstrate that the sediment phase plays a key role in the oxygen utilization in the sanitary gravity sewer. Their study indicates that the sediment phase contains more active biomass than the sewage phase. Del Giudice et al (2000) examined supercritical flow in a bend manhole used in sanitary sewers, and introduce the bend cover, which allows air entrainment into the downstream sewer, may significantly increase performance and capacity of bend flow, may easily be added to existing manholes. A three-dimensional particle settling model has been used to predict the benthic exposure zone to sewage solids for a large marine outfall and diffuser serving Nanaimo, Canada, in an area with large variations in bathymetry. The predicted exposure zone was determined largely by horizontal advection, and to a lesser extent by the relative amounts of floc and non-floc solids settling at two different rates (Hodgins et al. 2000).

Other research investigated various aspects of sanitary sewer systems that impact SSO and CSO control efforts. The decision to build collector, conveyance, and outfall sewer systems by tunneling or conventional cut and cover is based on a myriad of elements. Western Carolina Regional Sewer Authority is completing construction of the largest sewer project in South Carolina to reduce SSOs and to protect water quality. Building 10 miles of deep trunk sewer up to 96 inches in diameter, located 20 to 45 feet deep along the fully developed Reedy River valley required innovative construction methods and meticulous restoration to protect water quality and achieve public partnerships (Hildebrand et al. 2000). Private pump stations (commercial, industrial, institutional, etc.) are typically constructed as an immediate fix when no nearby wastewater facilities exist or to overcome sewer elevation differences. In many cases, insufficient documentation and coordination between the developer, engineer, permitting agency, and sewer system operator renders this component of the collection system seemingly non-existent after installation (Huerkamp et al. 2000). Huisman et al. (2000) studied the propagation of surface waves is on the operation of a novel urine (anthropogenic nutrient solution) separation system. They showed that the wave phenomenon has no adverse effects on the practicability of the urine separation system, but can lead to the release of undiluted wastewater during a rain event. With the increased scrutiny by EPA and other regulatory agencies on prevention of SSO, Jones and Schneider (2000) review the elements that make up a pumping station design, including the results of client-consultant interaction that has resulted in exceptional reliability and reduced operational costs. The North Central Sewer Separation Project will separate storm water and wastewater pipes in a section of downtown Columbus, Ohio, USA (Keefer and Chase 2000). Milwaukee Metropolitan Sewerage District authorized an emergency project to design and construct a new CSO pump station using a fast-track approach. Maurer and Bush (2000) present a discussion of the use of large submersible pumps for CSO service, design considerations, procurement methods, and the challenges of fast-track design and construction. The Vortex Drop Structure is an effective energy dissipater and aerator, which considerably improves the drop structure. It dissipates the flow energy and aerates the wastewater, preventing emission of odorous gases, oxidizing the hydrogen sulfides, and protecting the drop structure from corrosion and abrasive wear. The analysis of multiple wastewater samples taken simultaneously upstream and downstream of the Vortex Drop Structures shows a significant decrease of dissolved hydrogen sulfides and a sharp rise in the dissolved oxygen concentrations downstream of the structures (Moeller 2000). (Stonehouse et al. 2000). Street storage refers to the technology of temporarily storing stormwater in urban areas on the surface (off-street and on-street) and, as needed, below the surface close to the source. A case study approach, based on two largely implemented street storage systems, is used to explain the concept through construction and operation aspects of street storage systems. (Walesh 2000).

Disinfection of overflows is an attempt to minimize the human health risks of CSO and SSO. Wojtenko and Stinson (2000) provided a state-of-the-art review to examine the performance and effectiveness of ultraviolet (UV) light disinfection for CSO applications, and concluded that UV irradiation has a potential to be used in high-rate processes. In a separate paper Wojtenko et al. (2000) presented a state-of-the-art review of chlorine dioxide (ClO2) used for high-rate disinfection of CSO. Because ClO2 is a more powerful oxidant than Cl2, lower levels of ClO2 can be used to get the same level of inactivation with a reduced formation of halogenated organic compound byproducts, if any, and at a lower cost. In general, ClO2 appears to be effective for high-rate disinfection and a suitable Cl2 replacement (Wojtenko et al. 2000). As part of an innovative expansion of 100 MGD WWTP inWayne County Michigan, a unique UV disinfection system design has been provided which is the largest of its type in the US. The UV system was designed to disinfect the “blended flow” which will have varying concentrations of fecal coliforms from the primary and secondary wastewater, and is expected to provide disinfection that meets permit requirements for wet weather flows up to 175 MGD (Christeson and Fath-Azam 2000). The New Orleans Sewerage and Water Board has taken steps to control the odor and disinfection problems common to SSOs. The Board began the use of Nok-Out, which is a blend of oxidative chlorine compounds and non-charged amines. Since its use, this blend has effectively controlled both odor and disinfection problems (Austin et al. 2000). Safety concerns and more stringent regulations regarding gaseous chlorine use have forced reconsideration of disinfection practices, focused on UV as a most attractive alternative. Varying flows are a particular challenge for UV systems. Faisst et al. (2000) report on implementation of UV disinfection at two coastal communities carried out in response to these challenges. Microbial indicator concentrations, measured before and after treatment, typically are used to evaluate wastewater and CSO disinfection effectiveness. A concern with using the standard methods for measuring microbial indicator concentrations in sewage is that they fail to measure particle-associated microorganisms, underestimating the total concentrations present. A related concern is that particles and other matter in the water interfere with a disinfectant’s ability to contact and, therefore, inactivate microbes. EPA researchers presented the results of two projects which examine the effects of particle association on measurements of microbial indicator concentrations in CSOs, and determine the effectiveness of four treatment trains for CSO disinfection and the effects of removing solids on the disinfection effectiveness of chlorination and ultraviolet (UV) light irradiation Perdek and Borst 2000a, 2000b). The USEPA is advocating that beach managers monitor marine water quality at bathing beaches using counts of the indicator bacterium Enterococcus, rather than the present approach which is usually use of a coliform indicator. Rex (2000) explores the potential impacts of changing from the fecal coliform indicator to the Enterococcus indicator in three areas (1) monitoring disinfection of wastewater, including CSO; (2) monitoring receiving water quality for the relationship between fecal coliform and Enterococcus; and (3) monitoring changes in receiving water over time as improvements in CSO infrastructure are made. The analyses suggest that, while changing to the Enterococcus indicator will not change our overall assessment of receiving water quality, there is a potential impact on the ability of CSO facilities and wastewater treatment plants to meet new water quality standards. The City of Atlanta’s four westside CSO facilities are high-rate treatment facilities that utilize coarse and fine screening followed by sodium hypochlorite disinfection. Optimization studies that were undertaken at these facilities to improve disinfection performance found that the CSOs exhibit a first flush, water quality varies throughout an event and between events, and the CSOs are currently contact time limited during the first flush in regards to the disinfection process (Richards and Gurney 2000). The New York City Department of Environmental Protection performed a field pilot study to evaluate the acute toxicity of CSO treated via ultraviolet irradiation (UV), chlorination/dechlorination, and chlorine dioxide. Toxicity effects observed in the treated effluents were associated with the untreated wastewater rather than the disinfection processes. The results showed poor correlation between Microtox analyses taken in the field versus the off-site laboratory WET analyses (Santos et al. 2000). The Uptown Park CSO facility in Columbus, Georgia is the home of a national demonstration program sponsored through a Congressional appropriation and EPA grant for technology testing with peer review by a team of experts coordinated by the Water Environment Research Foundation (WERF). Four disinfection technologies have been examined in full-scale side-by-side comparisons to evaluate performance and operation criteria under similar CSO quality conditions. Vortex separators were used as contact chambers for three types of chemical disinfection including sodium hypochlorite (with and without sodium bisulfite dechlorination), chlorine dioxide and peracetic acid. A compressed media filter followed by UV disinfection was also evaluated at various vortex pre-treatment levels to provide high quality control for the more frequent, more concentrated events. Turner et al. (2000) describe methods for quantifying the statistical distribution loading on the receiving waters for a given solids removal and disinfection control scheme, and for operation of disinfection process control. Study applications show how the loading and technology performance relationships can be used to formulate a waste load allocation (WLA) for the CSO in comparison with other WLA’s and non-point load allocations for compliance with a TMDL.

Detention/Retention Ponds

A variety of pond-like BMPs are used to treat urban runoff. These BMPs include permanantly-filled ponds (wet ponds or retention basins), ponds that are allowed to go dry between storms (dry ponds or detention basins); detention basins may be lined or unlined, in which case they are usually vegetated. Ponds and basins are used to treat a variety of pollutants. Bhattarai and Griffin (2000) studied the pollutant removal performance of a concrete-lined detention basin that receives runoff from a highway bridge in Louisiana. The basin primarily acted as a settling basin and was most effective in terms of TSS removal. For other constituents, the basin exhibited a somewhat erratic range of removal efficiencies, but it was still able to reduce their concentrations in most cases. The performances of a constructed wetland and a water pollution control pond were compared in terms of their abilities to reduce stormwater bacterial loads to recreational waters by Davies and Bavor (2000). Bacterial removal was significantly less effective in the water pollution control pond than in the constructed wetland. This was attributed to the inability of the pond system to retain the fine clay particles (< 2 mu m) to which the bacteria were predominantly adsorbed. Sediment microcosm survival studies showed that the persistence of thermotolerant coliforms was greater in the pond sediments than in the wetland sediments, and that predation was a major factor influencing bacterial survival. The key to greater bacterial longevity in the pond sediments appeared to be the adsorption of bacteria to fine particles, which protected them from predators. Guo et al. (2000) experimented with modifications to the outlet structure of a dry detention basin to improve pollutant removal performance of the pond., and found no conclusive correlation between the pollutant removal efficiency and the detention time was determined. Rather, it was found that the pollutant removal efficiency in the field was strongly dependent on the inflow concentration. The outflow concentration may be a more reliable and useful criterion for evaluating the water quality performance of a detention basin.

Although stormwater detention ponds are widely used, there is relatively little engineering experience with their design and analysis. Heitz et al. (2000) examined the precipitation and runoff patterns on Guam in order to: (1) characterize the hourly rainfall events with respect to volume, frequency, duration, and the time between storm events; (2) evaluate the rainfall-runoff characteristics with respect to capture volume for water quality treatment; and (3) prepare criteria for sizing and designing of storm water quality management facilities. The resulting design curves could lead to a reduction of non-point source pollution to Guam's streams, estuaries, and coastal environments. Marsalek et al. (2000) examined the hydrodynamics of a frozen in-stream stormwater management pond located in Kingston, Ontario, Canada. Measurements of the velocity field under the ice cover agreed well with that simulated by a CFD model (PHOENICS(TM)). During a snowmelt event, the near-bottom velocities reached up to 0.05 m . s(-1), but were not sufficient to scour the bottom sediment. Van Buren et al. (2000) studied the thermal balance of an on-stream storm-water pond in Kingston, Ontario, Canada. During dry-weather periods, pond temperature increased as a result of solar heating, and thermal energy input exceeded output. Conversely, during wet-weather periods, pond temperature decreased as a result of limited solar radiation and replacement of warm pond water by cool inflow water from the upstream catchment, and thermal energy output exceeded input. Newman et al. (2000) describe the application of the Storage-Treatment (S-T) Block of the EPA Storm Water Management Model (SWMM) to design and/or analyze extended-detention ponds (EDPs) for the reduction of pollutant loads from storm-water runoff. The importance of this refined method for EDP design is emphasized with examples of how the use of common rules of thumb or guidelines from best management practice (BMP) manuals could result in unexpectedly poor EDP performance. Kentucky’s Sanitation District No. 1 worked with a local elementary school to convert a badly eroding stormwater detention basin into an outdoor learning center for the school. Funding for the project came from grants, community donations, PTA fundraisers, and volunteer labor. The project was a cooperative effort from start to finish that offered positive results for everyone involved. The sewer district gained a corrected detention basin. The public gained an education in stormwater management, which laid the groundwork for a pending stormwater utility. The students learned about water pollution and the school gained an educational resource in the Outdoor Learning Center (Proctor et al. 2000). Dewey et al. (2000) adapted a two-dimensional, vertically averaged hydrodynamic model to compute the circulation and sedimentation patterns in stormwater detention ponds or other water impoundment facilities. The Circulation and Water Quality Model (CWQM) can identify areas in the pond where short-circuiting and dead zones occur. Sedimentation, based on first-order decay, can be predicted. The sedimentation model is applied to an existing stormwater pond, and agreement was found between the predicted suspended solids (SS) concentration at the outlet and monitored outlet concentrations.

Despite widespread use, there is little evidence that stormwater ponds adequately protect downstream aquatic systems from the deleterious effects of stormwater runoff. Lieb and Carline (2000) examined the impact of runoff from a stormwater detention pond on the macroinvertebrate community in a small headwater stream downstream of the pond, at a site in central Pennsylvania, USA. Invertebrate communities 98m and 351m downstream of the pond were highly degraded, while a community 798m downstream was markedly less degraded. Despite downstream improvement, all three sites were dominated by Oligochaeta and Chironomidae and impaired relative to a reference community. These results are generally in agreement with those of similar studies in other states and reinforce the need for land-use planning that considers the potential negative effects of urbanization on headwater streams. Based on an investigation into phytoplankton and periphyton algal communities of two recently constructed stormwater management ponds, Olding (2000) ponds suggests that stormwater impacts on biological communities are reduced during passage through the ponds, providing a degree of protection for biological communities in their receiving waters by reducing toxins harmful to algal communities (e.g, heavy metals), and acting to reduce nutrients. The taxonomic composition of the two sites provides an indication of the quality of the incoming stormwater. The lack of blue-green algae can be linked to the hydraulic functioning of the ponds, suggesting that stormwater facilities may be engineered to inhibit undesirable algal communities. Turtle (2000) studied the impacts of road runoff on spotted salamanders breeding in roadside and woodland vernal pools in southeastern New Hampshire. Road deicing salts heavily contaminate roadside vernal pools, Salamander embryonic survivorship was significantly lower in roadside pools for four of five transplants in 1995 and all transplants in 1996; Deicing salts used for highway maintenance contaminated roadside vernal pools, and are a possible factor in the reduced embryonic survival observed in these pools.

Wetlands

Constructed wetlands are frequently used to capture, detain, and treat stormwater runoff from urban areas. They have the potential to treat a variety of pollutants. Knight and Kadlec (2000) present an overview of constructed wetlands used for water pollution control. Bachand and Horne (2000) examined the effect of vegetation type on nitrogen removal rate in wetlands used to treat wastewater, including urban runoff. Based on the study and a literature review, in organic carbon-limited free-surface wetlands, a mixture of labile (submergent, floating) and more recalcitrant (emergent, grasses) vegetation is recommended for improving denitrification rates. Carleton et al. (2000) examined the pollutant removal performance of constructed wetlands treating stormwater runoff from a residential townhome complex in northern

Virginia. Median load removals of all constituents were greater for a subset of storms that had inflow volumes less than the maximum volume of the marsh. Estimated removals were positive for most constituents and consistent with expectations based on the relative ratios of wetland area to drainage area at the two sites. Outlet concentrations of oxidized nitrogen were consistently lower in base flow than in storm samples, suggesting that removal of this constituent occurred primarily between, rather than during, storm events. Zhu and Ehrenfeld (2000) compared the ability of sediments from Atlantic cedar wetlands in suburban and undisturbed watersheds to remove added inorganic N in laboratory incubations. Results suggest that wetlands in suburban drainages may have limited ability to retain frequent, pulsed N inputs from runoff, and high intrinsic N mineralization in N-saturated sediments can become a cause of water quality degradation. Graham and Lei (2000) evaluated many aspects of the effective long-term operation of stormwater management ponds/wetlands, including removal, methods of removal and disposal of removed sediments.

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

Wetlands are frequently chosen for use in retrofitting existing developed areas or stormwater detention facilities to improve the treatment of stormwater pollutants. Kerr-Upal et al. (2000) present a conceptual plan to retrofit a wetland component within the a stormwater management facility in Toronto, Canada, using three wetland design options. Traver (2000) converted an existing stormwater detention pond to an extended detention wetland at a site near Philadelphia, Pennsylvania. The project will maintain the original storm water controls and provide proper hydrologic growth and non-point source pollution control. The City of Elkhart, Indiana has constructed an artificial wetland at a CSO outfall to capture and treat overflows prior to discharge into the Elkhart River. The treatment process consists of a) bar screen/sedimentation basin to remove grit and floatables, b) nearly 30 different species of native aquatic and transitional vegetation (all strategically planted for ecological competitive advantage), and c) a downflow drainage and collection system to enhance biological removal of dissolved organics and inorganics, dissolved metals, and suspended particulates (Umble et al. 2000). Bioretention is the use of small, vegetated basins similar to wetlands to capture and treat urban runoff near its source. Davis et al. (2000) reported laboratory and field results of a study of bioretention for treating urban runoff. Kim et al. (2000) evaluated the capacity of bioretention to remove nitrate from urban runoff using a design modification to incorporate a continuously submerged anoxic zone with an overdrain. Work to date has focused on selecting an electron donor and carbon source that will promote significant denitrification and be stable for extended periods of time in the subsurface. Further studies will be performed using the electron donors that gave the best nitrate removal efficiency and effluent quality in the experiments reported here: newspaper, wood chips, and small sulfur particles/limestone.

Design and analysis methods and tools for wetlands are constantly being modified. Since surface flow constructed wetlands (SFCW) are now commonly designed with low aspect ratios to circumvent surfacing problems, plug flow is not ensured; therefore, alternative models which more accurately describe the flow should be considered. However, to solve the alternative models, a value for dispersion is required. The fundamental variables affecting the dispersion number are the interstitial velocity, which is dependent upon flow rate, porosity, and cross-sectional area, and the pore geometry, which is dependent on the media characteristics such as the average grain diameter and permeability. In addition to these fundamental variables, the dispersion number will also fluctuate with a series of uncontrollable variables specific to a particular SFCW situation. Cothren and Daly (2000) have begun research to extend the results of an empirical relationship between the interstitial velocity as a function of flow rate and aspect ratio and the dispersion number developed using a bench-scale model to the field scale application. Larm (2000) presented a methodology for quantifying yearly and monthly material transport into and out of stormwater treatment facilities (STFs) and discussed problems related to monitoring and estimation of reduction efficiency. Standard values of runoff coefficients and pollutant concentrations together with precipitation data and estimated areas of different land uses within sub-watersheds were used to predict loadings to a multiple pond-wetland STF. A comparison of standard concentrations with measurements shows good correlation for nitrogen, but variable correlations for other pollutants. Tucker and Acreman (2000) describe a user-friendly, physically-based model for the estimation of ditch water levels in wet grassland drainage ditches, which can potentially be used to provide a rapid assessment procedure to assess the impacts of different water level management strategies on ecological communities and agricultural practices in wet grassland areas. Simulated rain events and runoff produce a more realistic influent to a stormwater treatment wetland than do an averaged inlet flow and concentration.

Network flow models provide a more realistic prediction of a treatment wetland's internal flows than does a plug flow or complete mixing estimation. Therefore, a combination of simulated rain events and a partial mixing model was chosen by Werner and Kadlec (2000) to produce realistic and descriptive predictions of treatment wetland function. Using the model, an equation was developed to estimate the average conversion provided by a treatment wetland. Moustafa (2000) extended empirical mixed-reactor models governing phosphorus (P) retention and nutrient assimilation in lakes and reservoirs to include free surface water wetland treatment systems. It was found that sedimentation rates, loading rates, and settling velocity in these wetlands, and their typology are comparable to their lake counterparts. Stormwater treatment areas (STAs) are extremely large-scale (several square miles) wetland BMPs being constructed on former agricultural areas of south Florida to provide total effective treatment of stormwater before discharge to the water conservation areas and Everglades National Park. Hyder and Hilton (2000) report on the hydraulic design model that provides a technical basis for management of STAs. Neumeister et al. (2000) present a modeling approach to evaluate design alternatives for STAs. The flexibility of their model allows impacts from alternative design scenarios to be evaluated and incorporated into watershed management projects.

Vegetation plays a key role in many wetland processes, and the establishment of vegetation in newly constructed wetlands is an important aspect of construction. Fassman et al. (2000) examined strategies for planting constructed wetlands to enhance development and survival of constructed wetland systems used for stormwater management and mitigation credit. Galatowitsch et al. (2000) used wetland biomonitoring approaches to determine when changes in response to stressors are occurring and to predict the consequences of proposed land-use changes for 40 wet meadows associated with prairie glacial marshes in Minnesota (U.S.A.). Site impacts (stormwater, cultivation) and landscape disturbance (agriculture and urbanization, combined), coincide with a reduction in native graminoid and herbaceous perennial abundance. This vegetation is replaced with annuals in recently cultivated sites or introduced perennials and floating aquatics in stormwater impacted wetlands.

One often cited advantage of wetlands for stormwater treatment is that wetlands provide habitat for wildlife. A study was performed in 1997 and 1998 of 15 stormwater pond wetlands and one natural wetland varying in age from 3 to 22 years in the Guelph and the Greater Toronto Area (GTA) in Ontario, Canada. Bishop et al. (2000a) concluded that wildlife made use of the ponds, but species richness at almost all sites was low to moderate, indicating that the ponds did not provide high quality habitat for wildlife. Due to concerns that wildlife may be attracted to stormwater detention ponds and would be exposed to contaminants accumulating in these ponds, contaminant levels in ponds, sediments, and wildlife was also conducted (Bishop et al. 2000b). A variety of impacts detected in wildlife species including fish, songbirds, and amphibians led the authors to conclude that stormwater ponds do not offer clean ecosystems for wildlife and the monitoring of contamination and its effects within stormwater ponds is necessary. The Lake County Sanitation District is developing a program to recycle treated wastewater in Lake County, California. The plan includes constructed wetlands to improve water quality, enhance wildlife habitat, offer evapotranspiration of excess water, and provide public benefits by creating settings for passive recreation and wildlife study. Kimmelshue et al. (2000) present a paper which include results from a wetlands screening study, a preliminary design effort and the design and construction of an initial wetland.

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