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NOTICE TO READERS

The *Journal* of the BSCE Section, ASCE, has been published for many years as a quarterly - four issues per calendar year - identified in the last few years by seasons: Spring, Summer, Autumn and Winter. Volume 67, Number 1 was the Spring 1980 issue. For reasons outside of the control of the Publications Committee and the editors, there were no issues for Summer or Autumn, 1980. The current issue is designated as Volume 67, Number 2, Winter 1981. Numbers 3 and 4 of Volume 67 are being planned for later in 1981 to complete the four-issue set for that volume.

JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS SECTION

Professional Papers

AMERICAN SOCIETY OF CIVIL ENGINEERS

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GEOHYDROLOGIC ASPECTS OF AQUIFER THERMAL ENERGY STORAGE

J. R. Raymond

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Civil Engineers

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Pacific Northwest Laboratory
Richland, Washington 99352

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The data provided by these publications are greatly appreciated.

INTRODUCTION

During the last decade, the storage of thermal energy in aquifers has received considerable attention. The motivations for storing large quantities of thermal energy on a long-term basis have been numerous, including: a) the need to store solar heat that is collected in the summer for use in the winter months, b) the cost effectiveness of utilizing heat now wasted in electrical generation plants, c) the need to profitably use industrial waste heat, and d) the need to more economically provide summer cooling for buildings. The end objective, of course, is the conservation or displacement of costly and scarce petroleum fuels. Seasonal aquifer storage should contribute significantly to satisfy the above needs. Most geologists and ground-water hydrologists agree that heated and chilled water can be injected, stored, and recovered from aquifers. Geologic materials are good thermal insulators; and potentially suitable aquifers are distributed throughout the United States. Recent studies and small-scale field experiments have reported energy recovery rates above 70% for seasonal storage. The U.S. Department of Energy predicts that, by the year 2000, seasonal aquifer storage could replace or conserve up to 350 million barrels of oil per year. However, successful demonstration of large-scale aquifer thermal energy storage has not yet been attempted and the concept's economic feasibility and institutional acceptability have yet to be established.

Many potential energy sources exist for use in an aquifer thermal energy storage system. These include solar heat, power plant cogeneration, winter chill, and industrial waste heat sources such as aluminum plants, paper and pulp mills, food processing plants, garbage incineration units, cement plants, and iron and steel mills. For heating, energy sources ranging from 50 to over 250^{o}C are available. Potential energy uses include space heating on an individual or district scale, heating for industrial or institutional plants and heat for processing/manufacturing.

Investigation of Aquifer Thermal Energy Storage (ATES) is a major part of the Seasonal Thermal Energy Storage (STES) Program, managed by the Pacific Northwest Laboratory (PNL) for the U.S. Department of Energy, Office of Advanced Conservation Technologies (OACT). The STES Program is one element of OACT's Thermal Energy Storage Program.

AQUIFER THERMAL ENERGY STORAGE DESCRIPTION

An ATES installation in its simplest form is composed of a pair (doublet) of fairly conventional water supply wells drilled into an aquifer. During operation, the ground water is withdrawn from one well, heated (or chilled) in a heat exchanger, and then returned to the same aquifer through the second well (Figure 1). The thermal energy is stored in the aquifer until needed. At recovery, the second well is pumped, and the hot (or chilled) water circulated through a heat exchanger to recapture the stored energy and then returned to the aquifer through the first well (Figure 2). The thermal energy can then be employed for space or process heating (or cooling), thus reducing the need for generation of primary energy. The cycle is repeated on a seasonal or other temporal basis (Figure 3). The concept is simple, inexpensive, and relatively efficient.

Aquifers are good heat capacitors. Consequently, under favorable conditions, a large amount of heat (or chill) can be stored in a relatively small aquifer volume. At a typical aquifer thermal capacity of 0.2 cal/g/^{o}C, a ground-water system has capability of storing up to 30 Btu's per degree (F) temperature change per cubic foot of aquifer volume. As a practical example, an aquifer volume of 1.73×10^{7} ft^{3} (a cylinder with a radius of 235 ft and height of 100 ft--assuming "plug" flow and negligible thermal loss) could store 3.1×10^{10} Btu of heat (9070 MW-hr) assuming a water injection rate of 200 gpm at a temperature rise of 144^{o}F (4.2 MW) over a 90 day period.

When heated water is injected into the receiving well of an ATES doublet system which fully penetrates an idealized porous media aquifer (uniform permeability, porosity, thickness, thermal properties and no regional ground-water flow), the water moves away from the injection well in cylindrical form (radial symmetry) with a temperature gradient (thermocline) that separates the heated water from the ambient-temperature ground water. The injection process (because of the fluid pressure increase) establishes a higher than ambient potentiometric surface and resultant streamlines adjacent to the injection well. In the idealized case, the lines of equipotential inscribe circles around the injection well, with potential gradient and flow velocity being greatest near the well and decreasing inversely with distance from the well.

Evaluation of the thermal interface between the injected hot water and the colder aquifer solely by classical molecular and thermal diffusion analysis would show that the thermocline in the idealized case is extremely sharp (high heat gradient) and essentially vertical in attitude. Analsyis by the same methods also would show that heat recovery (pumping from the heat injection well) would be very high (more than 95%). However, in the "real world" there are a number of other factors that greatly modify the gradient and form of the thermocline and generally combine to reduce recovery efficiency.

Hydrodynamic dispersion acts to modify the thermocline gradient to a much greater extent than thermal diffusion. Hydrodynamic dispersion is a complex function (in porous media) of media grain size, shape and porosity and results from stream line "tortuosity." Ground water flows through irregular pore spaces and paths of different length in the media which result in varying local water velocities. The paths are interconnected, and as they diverge and rejoin, waters of different temperature are comingled. This results in a spreading or blurring (reduced gradient) in the thermocline.

The heated water within the thermocline is less dense and less viscous than the ground water outside of the thermocline. The pressure gradient within the thermocline will be less than the gradient in the surrounding aquifer, resulting in a greater horizontal pressure gradient at the top of the aquifer than at the bottom. Therefore, the thermocline will advance more rapidly at the top than at the bottom, producing a tilted interface. In other words, the body of heated water within the thermocline has the shape of an inverted truncated cone rather than a cylinder. The tilting is aided by the buoyancy of the less dense hot water which tends to float to the top of the aquifer. The viscosity/density effects are amplified by hydrodynamic dispersion. During the thermal energy recovery cycle, the viscosity effect will cause the thermocline to move inward more rapidly at the top of the aquifer than at the bottom; thus partially reducing the thermocline tilt. However, the buoyancy effect will continue to act in increasing tilt during the heat recovery cycle.

Figures 4a and 4b are sections through a confined aquifer (one-half of a storage zone) which shows an analytical synthesis of an ATES system which incorporates the factors discussed above.(1)

Shown in Figure 4a is the situation after 90 days of injection of 1 MGD of 350°F water into an aquifer 100 ft thick. Each of the effects was analyzed in closed form separately, to better understand the nature and importance of the effect. They were then combined by superposition, with suitable approximations in non-linear overlap areas. Isotherms are shown at 80°, 200°, and 320°F. Hydrodynamic and thermal dispersion dominates the thermocline spread. Also shown are the isotherm contours in the confining cap and confining bottom showing more penetration near the well where exposure to heat has been longest. The dashed line shows the location of the thermocline if no loss had occurred from hydrodynamic/thermal dispersion.

Figure 4b shows the approximate location of the isotherms after a period of withdrawal of less than 90 days. Withdrawal was stopped when the temperature of water withdrawn dropped to 320°F, a mixture of 350°F water over most of the well depth with colder water near the bottom of the well. During withdrawal the radial separation between isotherms expands greatly as expected from the preceding discussion. The retreating hot water leads to the confining cap and bottom being hotter than the adjacent aquifer, so some heat lost to these layers is returned to the aquifer as indicated by the isotherms. The continuing buoyancy of the hot water leads to first the 320°F contour, then the 200°F contour reaching the bottom of the well, so the average well temperature, with mixing, decreases. Again, the dashed line shows the thermocline location had no loss occurred from dispersion.

Numerical integration of the volume within each isotherm contour indicates that about 31% (recovery of 69°) of the injected energy remains in the aquifer and confining layer after one cycle. More heat could be withdrawn if the application is not penalized by temperatures below 320°F.

Each cycle leaves energy behind, as an increasing buffer reducing the thermal gradients outside of the stored energy zone, hence reducing the rate of heat loss and increasing the recovery efficiency in succeeding cycles.

The doublet configuration averts many potential operational and environmental problems. Since the in-situ ground water is used as the storage medium (rather than a newly introduced, chemically different water), the potential for chemical or physical reactions of the water with the aquifer matrix is reduced, and thus a major cause of clogging of the aquifer can be minimized. The doublet concept also precludes any problems with ground-water depletion, since virtually all of the water withdrawn is immediately returned to the aquifer. There are numerous possible ATES well configurations in addition to the basic doublet. For larger sized systems, either a number of separate doublets, rows of doublets, concentric rings of injection and withdrawal wells, or other multiwell patterns probably will be required.

The key to ATES's effectiveness is that the recovered energy is energy that would have been wasted without seasonal storage, generally because no demand existed at the time of availability. This mismatch of energy supply and demand over time is the common occurrence that makes ATES attractive.

Available energy in this category includes cogeneration, climate-related energy, and industrial waste heat.

Aquifer Thermal Energy Storage Projects

Storage of thermal energy in aquifers has received widespread attention only within the last decade since the onset of the "energy crisis." This new interest in ATES is international in scope, with considerable effort being made in the United States and Scandanavian countries to implement demonstration projects.

The United States' effort in ATES is centered in the Seasonal Thermal Energy Storage (STES) Program, managed by the Pacific Northwest Laboratory (operated by Battelle Memorial Institute) for the U.S. Department of Energy (DOE), Office of Advanced Conservation Technologies (OACT).

Under the STES Program, three projects are presently being implemented under DOE funding to demonstrate the commercialization potential of ATES technology. These projects are in aquifer characterization/conceptual design status (Phase I). Project Phase I is scheduled for completion in mid-1982. If these demonstrations are determined to be feasible, some or all of the projects will proceed to final design, construction and operation (Phase II) under cost sharing between the DOE and the operating entity. Phase II will be completed in 1985. Table 1 gives information on the contractor, location, type, energy source and energy use for the three demonstration projects.

TABLE 1. ATES Demonstration Projects (Phase I)

Contractor	TRW Incorporated	Dames & Moore	Univ. of Minnesota
Location	Bethel, Alaska	Stony Brook, New York	Minneapolis, Minnesota
Type	Heat 95°C	Chill	Heat 150°C
Energy of Source	Diesel Exhaust and Cooling Water	Cooling Tower	Cogeneration Steam
Energy Use	District Heating	Building Air Conditioning	Campus Heating

In addition, institutional environmental and technical issues affecting commercialization of ATES are being evaluated in the STES Program, and field tests are in progress to provide technical information, and operational experience in support of the demonstration projects.

Aquifer Thermal Energy Storage Evaluation Factors

In addition to surface facility engineering (heat exchangers, piping, pumps and valves), which seems to be straightforward, there are a number of factors that must be considered in development of ATES Systems. These factors are: 1) legal/institutional, 2) environmental, 3) economic, 4) chemical, 5) biologic, and 6) geologic/hydrologic. Each of these factors are extremely important in analysis and design of ATES systems; and failing to consider and evaluate any one of the areas could prevent or complicate system implementation. However, the purpose of this paper is to discuss, in some detail, the various geohydrologic factors that are important to ATES and some of their interrelationships.

Geohydrologic Factors

Table 2 shows the geologic factors or parameters that are important and require measurement and evaluation for implementation of ATES systems.

TABLE 2. Geohydrologic Parameters Important to ATES

Aquifer Factors

- Permeability (Vertical and Horizontal)
- Porosity
- Thickness
- Gradient
- Regional Flow
- Thermal Conductivity
- Specific Heat (Thermal Capacity)
- Boundaries

Aquiclude/Aquitard Factors

- Permeability
- Boundaries
- Thermal Conductivity

Permeability, a measure of the relative ability of a porous medium to transmit water, is of first-order importance in design and evaluation of ATES systems. Permeability is a property of the porous medium that is dependent upon the size and shape of the pores. Media permeability (k) multiplied by aquifer thickness (m) equals aquifer transmissivity, which is a measure of the rate at which water moves through a unit width of the aquifer under a unit hydraulic gradient.

A high permeability (and transmissivity) is desired to produce the largest volume of water from a well with the least drawdown. As an example, Figure 5 shows well drawdown (s) plotted against permeability (k) from solution of the steady-state Thiem equation (an approximation of maximum well drawdown) for a 33 meter (100 ft) thick aquifer at a pumping rate of 45 m^3/hr (200 gpm). Forty-five m^3/hr probably is a lower water injection/withdrawal rate at reasonable temperature differentials for pratical commercial ATES heat or chill storage systems. Permeability is in "darcys." The darcy is defined by the volume of water in cubic centimeters flowing in 1 sec through a 1 cm^2 area of porous medium under a pressure gradient of 1 atm/cm. The darcy is equal (at 60^oC) to 18.2 gal/day/ft^2 (gal/day/ft^2 is the "Meinzer" unit coefficient of permeability formerly widely used to define permeability). Figure 5 shows, for the given conditions, that a well water level decrease (drawdown) of about 30 meters occurs if the permeability is approximately 2 darcys. A drawdown of 30$\pm$ meters would be unacceptable for the given system under water table (unconfined) conditions, but may be marginally acceptable for some artesian aquifer systems. In any case, it would be preferable to limit the drawdown to a few meters. In this situation, a well drawdown of about 10 meters would result at a permeability of 5 darcys and a drawdown of 3.5 meters at 15 darcys.

Conversely, particularly for higher temperature ATES systems, low permeability is desirable to prevent excessive tilting of the thermocline from viscosity/buoyancy effects. Figure 6 shows upper limit permeability values required to prevent excessive tilting plotted against aquifer thickness for three injection temperatures. Combinations of permeability and aquifer thickness that would fall above the respective injection temperature curves would result in inefficient heat recovery. Thus, for a reference case aquifer thickness of 33 meters, permeability should be less than 2.7 darcys for an injection temperature of 120^oC. The resultant well drawdown in this case at a water injection/withdrawal rate of 45 m^3/hr would probably be unacceptable, and the injection temperature would have to be reduced; or multiple injection/recovery wells would be required. As shown in Figure 6, upper limit permeabilities (for a 33 meter thick aquifer) are 4 darcys for a 90^oC injection temperature and 10.3 darcys for a 60^oC injection temperature. The data shown in Figure 6 were derived by Hellstrom, Tsang and Claesson[(2)] from operation of a numerical model[(3)] which computes heat and mass flow in water-saturated porous media.

Isotropic media (the same permeability in all directions) is desirable to obtain maximum water supply from a well with minimum drawdown. Conversely, anisotropic conditions with vertical permeability being much less than horizontal permeability is desirable for ATES systems to resist tilting of the thermocline. Sedimentary earth materials generally have horizontal permeabilities from 5 to 10 times greater than the vertical permeability--a definite benefit for high-temperature ATES systems.

Porosity of a rock or soil is its property of containing interstices or voids (pores). Porosity is expressed as the ratio of the pore volume to the total volume of the rock (a decimal fraction or percentage). With regard to the storage and movement of water in a porous medium, only the system of interconnected interstices (effective porosity) is significant. It is obvious that the porosity of the aquifer matrix is an important consideration in ATES systems, because it determines the amount of water (and the heat or chill) that can be stored per unit volume of the aquifer. Most aquifers suitable for ATES will be in clastic sediments with effective porosities of 10% to 20%. Most aquifers that occur in consolidated igneous and metamorphic rocks which have secondary (fracture) porosities of less than 5% will not be satisfactory for ATES. Applicability of aquifers in carbonates and evaporites for ATES is also limited.

Porosity is also important because it is one factor which controls ground-water velocity. Fluid flow velocity in a porous medium is proportional to the permeability and gradient and inversely proportional to the porosity: $v = kI/p$ where v is the interstitial fluid velocity, k is the media permeability and I is the hydraulic gradient. For ATES considerations in this aspect also, a high porosity is desirable to reduce the fluid velocity and hydrodynamic dispersion.

Figure 7 shows the results of a computer model study[4,5] to evaluate regional ground-water flow considerations in thermal front breakthrough for an ATES doublet well system. Location of the thermal fronts are shown for several time invervals. Figure 7a shows that under the assumed conditions (well spacing of 500 meters, steady-state water injection/withdrawal rate of 7 m^3/min, and a porosity of 20%), thermal breakthrough occurs after 2.1 years of operation with no regional ground-water flow. Figure 7b shows that breakthrough occurs in 1.8 years if a required ground-water flow velocity of 100 m/yr is imposed on the system (flow is from left to right, as indicated by the arrow). It is evident that ground-water velocities in this order will not materially effect ATES systems. Regional velocities in confined (artesian) hydrologic systems are usually very low. Ground-water movement in unconfined aquifers can be much greater (up to tens of meters per day) and would have to be considered in ATES system selection and design.

Aquifer gradient was considered in the discussion of porosity and permeability as one element that controls velocity, and this is the main interest in gradient. Gradients in natural aquifers are in the order of 0.1% or less, and thus are unlikely to directly influence the stored thermal water from upgradient movement due to buoyancy of the heated water.

The thermal characteristics of the aquifer are important in determining the heat capacity of the system and conduction of heat out of the storage volume. Thermal conductivity is the quantity of heat conducted in unit time across an element of surface under a given thermal gradient--units of cal/cm sec ^{o}C. Porous geologic materials, saturated with water, do not vary widely in thermal conductivity values.(6) Sands, silts and clays (saturated) have thermal conductivities on the order of 1×10^{-2} cal/cm sec ^{o}C. Thermal conductivity of these materials drops to about 30 to 50% of the saturated value under unsaturated conditions. Compressing the rock increases thermal conductivity slightly, and thermal conductivity decreases slightly with increased temperature. Water has a thermal conductivity of 1.5×10^{-3} cal/cm sec ^{o}C at 30^{o}C. Basically, earth materials are good insulators as considered for ATES conditions, and differences in their thermal conductivities are relatively small; their changes in thermal conductivity are of second-order importance.

Thermal capacity (specific heat) of a material is the quantity of heat required to produce unit change of temperature in unit mass (units of cal/g/^{o}C). Thermal capacity of sandstone is about 0.2 cal/g/^{o}C. Variation in thermal capacity of earth materials, as with thermal conductivity, is expected to be small, thus changes in thermal capacity will be of second-order importance. Earth materials and the contained water are basically good heat capacitors.

Areal aquifer boundaries (together with aquifer thickness) will determine the volume available for storage of heat or chill. Aquifer volume generally will be much greater than the required storage volume, but boundary location may be of interest if the proposed ATES storage site is near zones of recharge or discharge, or on the periphery of a ground-water system.

Characteristics of aquicludes/aquitards are of interest and importance in evaluating heat storage in confined aquifers. It is important that permeability of the confining bed is low and that the bed has areal continuity to prevent convective loss of water and heat. It is desirable that the confining bed have a low thermal conductivity, but this will be of second-order importance since the geologic units involved probably will vary by only a factor of two or three in thermal conductivity.

Characteristics of the unsaturated zone overlying the thermal storage area in an unconfined aquifer is of interest for the same reason. The thermal conductivity value of the unsaturated earth material probably will be satisfactory. However, it is important that the overburden be thick enough to prevent heat loss to the atmosphere and also that it isolates the storage zone from direct access by precipitation and surface water.

Geohydrologic Parameter Measurement

Methods of measuring geohydrologic parameters have been derived from water supply, petroleum production and agricultural technologies. Most of the measurement methods are directly applicable to ATES systems, and provide adequate parameter values for design and engineering purposes. Many of the measurement techniques require access to the subsurface aquifer or formation under investigation. This access is usually provided by wells, which makes extensive field investigations a costly procedure. There is a continuing search for more cost-effective, methods for in situ measurement of geohydrologic characteristics.

Aquifer permeability/transmissivity is generally determined by well pumping tests and application of various graphical, analytical or numerical techniques for analysis of the resultant water level drawdown data. Aquifer transmissivity is the characteristic actually determined from the test, and an average permeability derived by dividing the transmissivity value by aquifer thickness. The derived permeability/transmissivity is generally the horizontal value (or in some cases a composite horizontal-vertical value). Pumping tests can be designed to skew the measurement toward vertical components. Field determination of aquifer permeability/transmissivity has generally been adequate for analysis of ground-water supply, and probably provides the best means of obtaining permeability/transmissivity data for ATES.

Permeability can also be determined in the laboratory by measuring fluid flow-through and pressure drop across a core sample of geologic media. The test is more applicable to consolidated porous media than unconsolidated material or rock with secondary (fracture porosity). Both horizontal and vertical permeability can be determined by proper orientation of the core. Laboratory permeability tests are generally less reliable than the field tests due to the small core size and possible disturbance of the sample, although the tests may provide information on comparative permeability and may provide the only available information on vertical (or other oriented) permeability.

Porosity of geologic material can be determined by either field or laboratory tests. Well pumping test analysis yield "effective" porosity data for unconfined aquifers. Geophysical well logging (neutron-neutron) can measure the "total" porosity of geologic formations adjacent to the well bore. Porosity can be determined from fluid displacement tests on core samples in the laboratory. Both the field and laboratory methods of determining porosity seem adequate for ATES analysis.

Vertical and horizontal boundaries and stratigraphy of earth materials are determined from field studies. Well evaluation, geologic mapping, geophysical logging and surface geophysics, individually or in concert can be applied to resolve these parameters. If there are adequate time and funds available, these methods are fully adequate for ATES analysis.

Measurement of ground-water gradient can only be determined from well measurements (and from surface geophysics in some special cases). Thus, adequate definition of the ground-water surface is dependent on the number and location of wells. Again, if time and funds are available for test/observation wells, the gradient measurement method is adequate.

Ground-water velocity can be measured from field tracer tests, well dilution tests and calculated from porosity/permeability/gradient relationships. Measurements generally will be average or order-of-magnitude values, but probably adequate for ATES assessment. The related hydrodynamic dispersion can be measured by field tracer tests. The test methods give order-of-magnitude values. Better methods of measuring hydrodynamic dispersion are needed.

Thermal characteristics of earth materials (thermal conductivity and heat capacity) can be determined in the field or laboratory by application of heat across a section of the material and measuring temperature change in the media with time. The field methods (subsurface) are costly and time consuming. Laboratory core or sample analysis for thermal characterization appears adequate.

Aquifer Thermal Energy Storage System Simulation and Optimization

It is obvious that design and operation of complex ATES geohydrologic systems will require simulation of the system to provide predictive and optimization capabilities. The examples of geohydrologic parameter relationships discussed above were derived by simple analytical methods or somewhat more complex numerical models.

Technology development in simulation of complex hydrothermal systems has evolved to numerical computer codes that solve the applicable heat and fluid flow equations. The codes can handle most of the parameters involved in the physical system, thus numerical models of the systems can be developed. The present codes are adequate for prediction of ATES system response, given a specific system design. They also can assist in system design through iterative selection. Their shortcomings, in general, are in areas of optimization and system size. The existing codes do not operate with adequate speed or efficiency to provide true system optimization; and optimization of ATES system design and operation is required for cost-effective development of the technology. Most of the codes can either model a small ATES geohydrologic area/volume in considerable detail or model a large area in broad detail.

Much effort is being made in refining the codes applicable to ATES modeling, and these problems are expected to be resolved in the near term.

CONCLUSIONS

Investigation of ATES technology indicates that it is a cost-effective, fuel-conserving technique for provisions of thermal energy for residential, commercial and industrial uses. Most of the existing methods and techniques for measuring geohydrologic elements important to ATES are satisfactory. Small scale field tests have been successfully demonstrated, and larger scale demonstration projects are in progress.

With a suitable institutional framework, ATES promises to provide a significant portion of the nation's future thermal energy.

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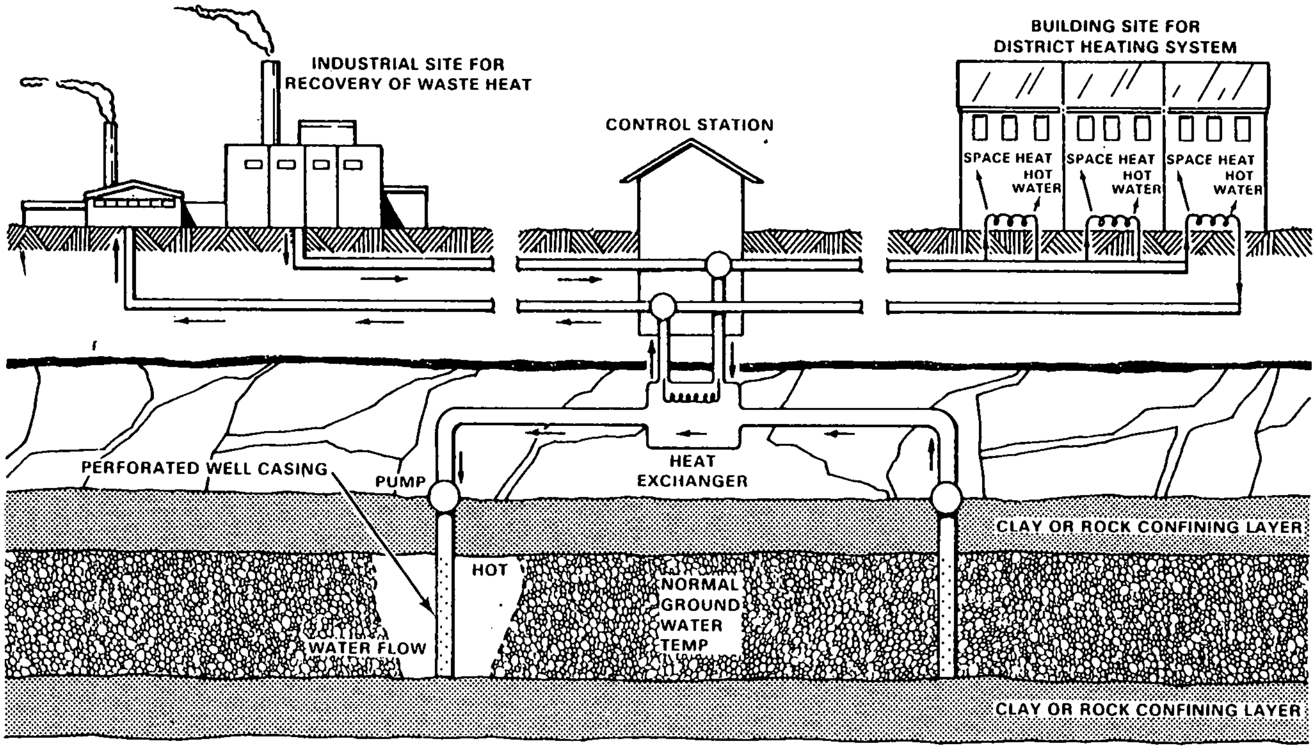
HEAT INJECTION (INITIAL)

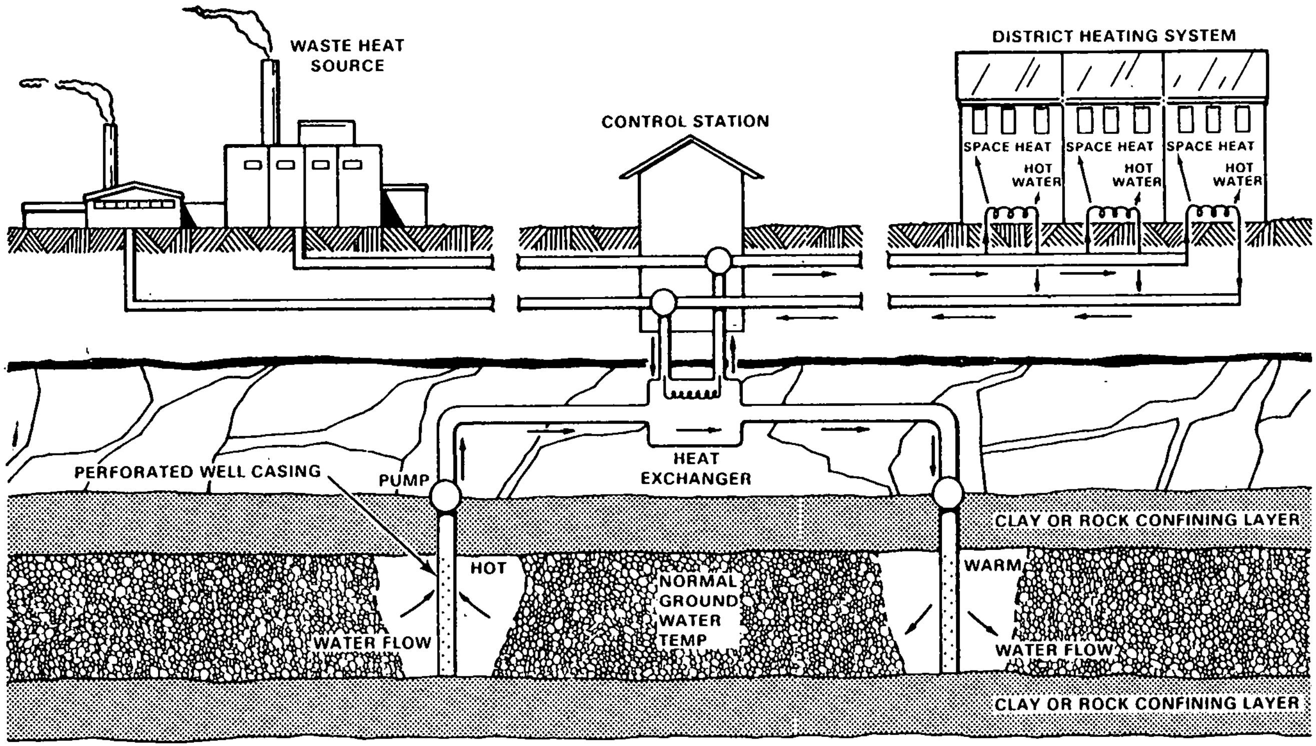


DOUBLET WELL AQUIFER STORAGE SYSTEM

FIGURE 1

SEASONAL THERMAL ENERGY STORAGE

HEAT RECOVERY CYCLE

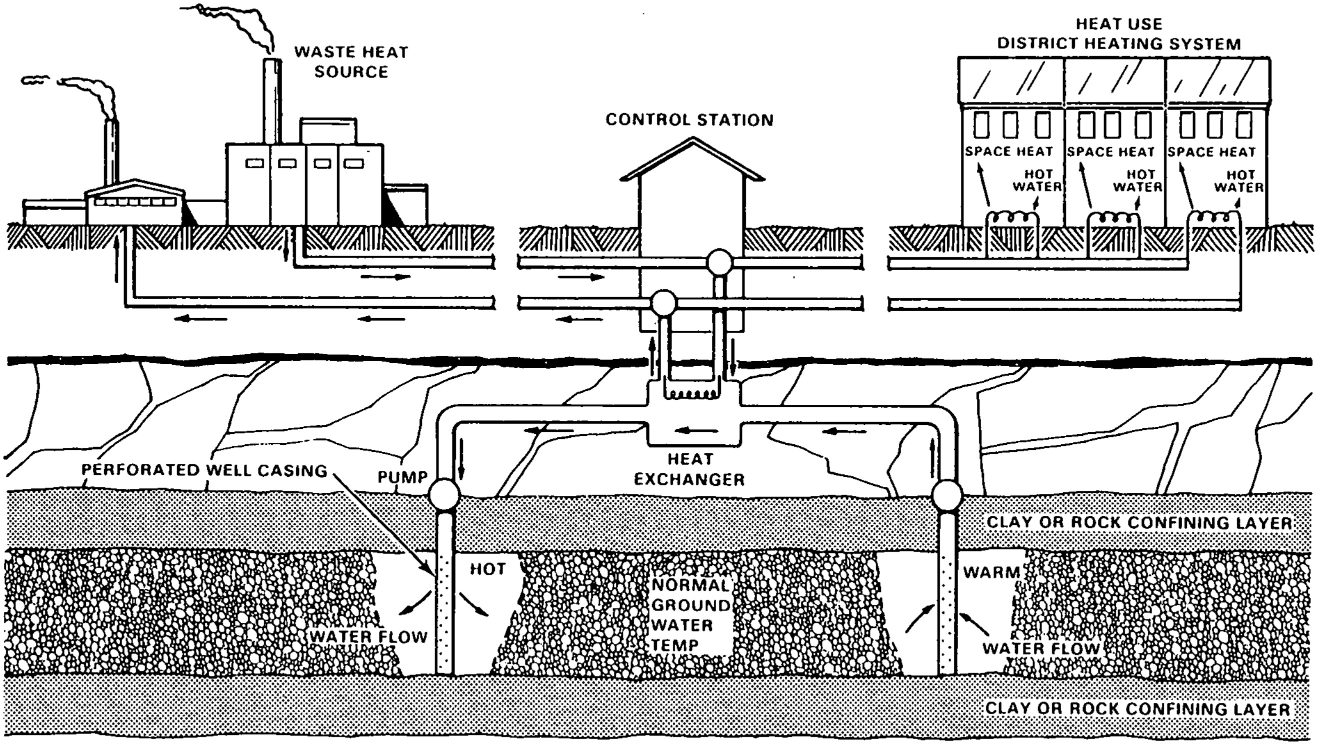


DOUBLET WELL AQUIFER STORAGE SYSTEM

FIGURE 2

SEASONAL THERMAL ENERGY STORAGE

HEAT INJECTION CYCLE (CONTINUED)



DOUBLET WELL AQUIFER STORAGE SYSTEM

FIGURE 3

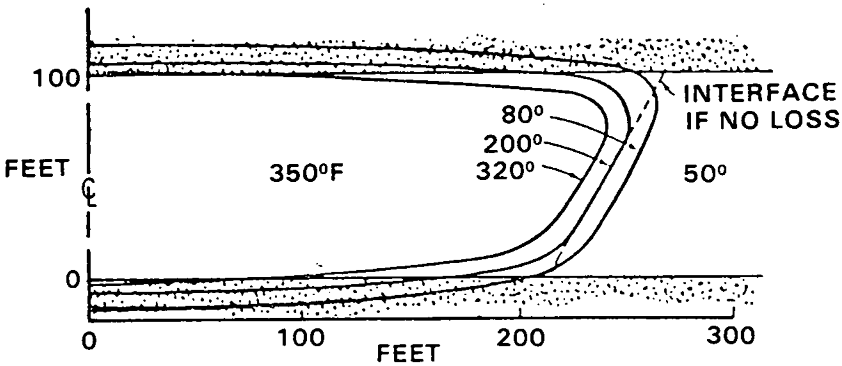


FIGURE 4a. ATES Isotherms-Injection Cycle
(Meyer, 1980)

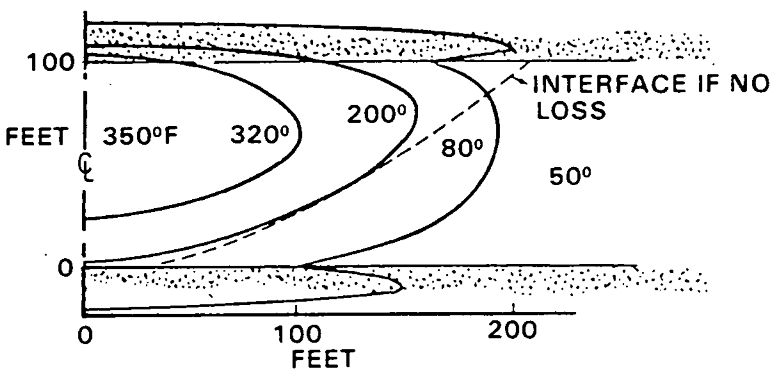


FIGURE 4b. ATES Isotherms-Recovery Cycle
(Meyer, 1980)

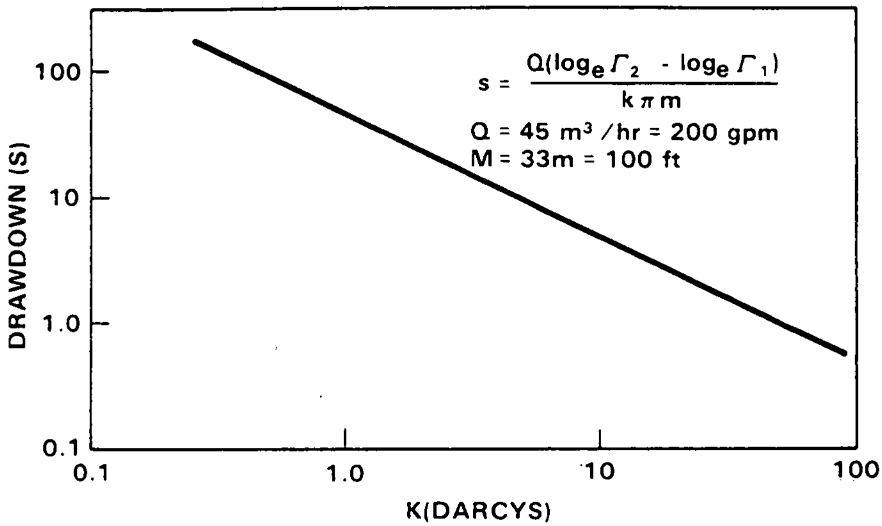


FIGURE 5. Water Levêl Drawdown

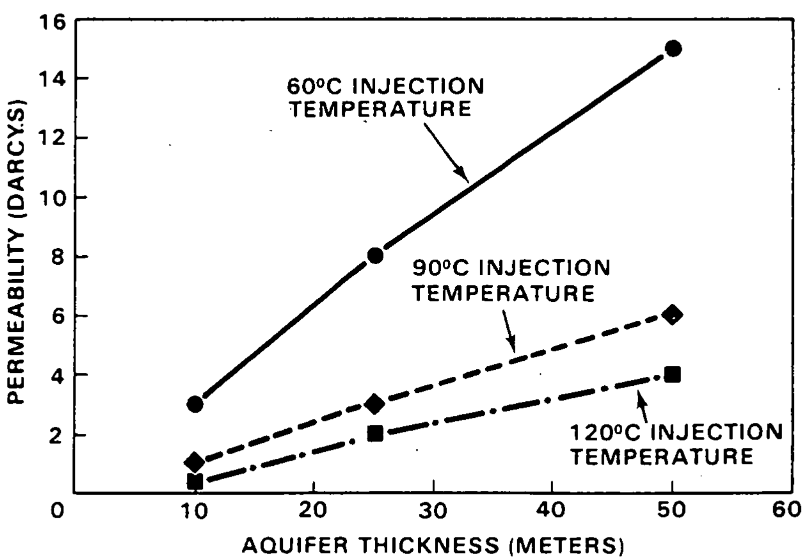


FIGURE 6. Upper Limit Permeability (After Hellstrom, 1979)

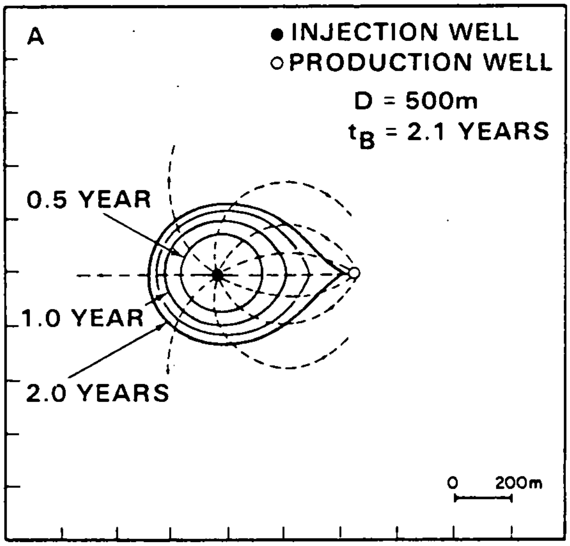


FIGURE 7a. Thermal Breakthrough Without Regional Ground-Water Flow (Lippman, 1978)

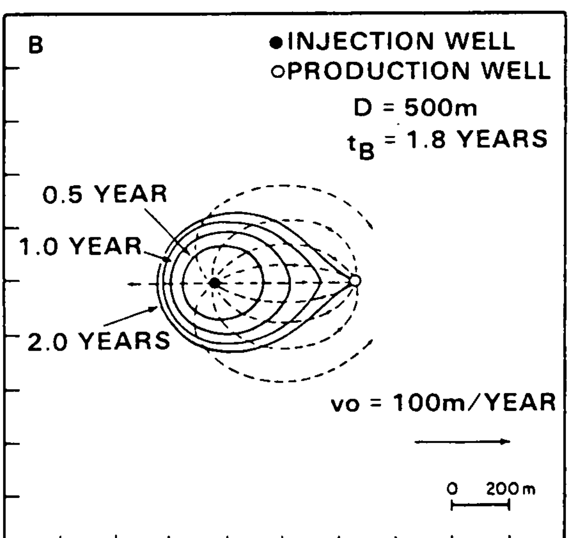


FIGURE 7b. Thermal Breakthrough With Regional Ground-Water Flow (Lippman, 1978)

OVERVIEW OF URBAN RUNOFF MODELS

by M. B. McPherson,* F.ASCE

Introduction

It has been estimated that approximately one-sixth of the "Urbanized Areas" of the United States fall within natural 100-year flood plains,(1) whereas well over half of such areas are drained by systems of underground conduits. Further, national investment for storm drainage conduit facilities appears to be more than four times as great as that for flood plain protection works benefiting urban areas.

There is widespread interest in multi-purpose drainage facilities that exploit opportunities for water-based recreation, provide more effective protection of buildings from flooding, and allow for the use and re-use of storm water for water supply. In addition, the 1972 Amendments to the Federal Water Pollution Control Act have led to considerable interest in reducing the entry of pollutants into receiving waters from combined sewer overflows and storm sewer discharges. Over the last few years urban runoff model development and usage has greatly intensified. Because of this and of the tendency to use tailor-made or custom-adapted models for urban streamflow discharge-quality, discussion of models for simulation of underground conduit system performance will predominate in the overview that follows.

Why Simulation?(2)

All but a small fraction of storm and combined sewers around the world have been sized by means of wholly empirical methods. Given a lack of evidence of superior methods, these overly simplistic procedures proved adequate when the primary purpose of storm sewers was to drain the land and express the accelerated convergence of surface runoff to receiving waters. Out of sight, out of mind. Once restrainment or containment of flows and their pollutant burdens become added primary objectives, traditional procedures of analysis are no longer adequate because of added system complexities.

Why not use observed discharge variations as a guide? There are several compelling reasons precluding this possibility: (1), very few urban catchments, particularly sewered ones, have been gaged; (2), a statistical approach requires a

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period of record spanning at least ten years, substantial physical changes commonly take place on most urban catchments over this long a time, and the mixed statistical series that results is not interpretable; (3), while such a statistical series would characterize the existing situation, there would be substantial uncertainty over its extension to differing future situations; and (4), the clinching reason, in the usual case where no field measurements have been made, is that it would be necessary to postpone planning and analysis until new long-term field records were accumulated, an unacceptable option under contemporary imperatives. An even less acceptable alternative would be to rely solely on empirical tools and determine prototype system performance after system changes had been instituted, a procedure that would indicate the overall errors implicit in the tools used, but would be very expensive experimentation. Thus, in order to anticipate future system performance under changed conditions, because these changes can very rarely be simulated by manipulating prototype systems, recourse must be made to performance simulation by calculation or analogy using tools of analysis such as mathematical models.

Categories of Model Applications

Mathematical models used for the simulation of urban rainfall-runoff or rainfall-runoff-quality can be divided into three different application categories: planning, analysis/design and operations. Some particular models have been employed in both planning and analysis/design, and a few models have been applied in analysis/design and operations applications, making it difficult to allocate them to a single category. Additionally, the reader is cautioned that on no account should the models to be mentioned be regarded as typical tools. Rather, common practice still favors rudimentary techniques, although the use of new tools of analysis seems to be growing rather rapidly around the world.

Planning applications are at a macro-scale, such as for comprehensive metropolitan or municipal plans. Model requirements for planning are less rigorous and require and permit less detail than for analysis/design because investigation of a range of broad alternatives is at issue. What are sought for planning tools are general parameters or indicators for large-scale evaluation of various alternative schemes. Hence, the degree of model detail required in jurisdictional planning is generally less than in analysis/design.

Analysis/design applications generally require more sophisticated, more detailed tools, for the analysis of individual catchments and subcatchments where the simulation of detailed performance of discrete elements within a subcatchment must be achieved.

Operations applications are likely to be more use-specific because of wide diversities in management practices, operating problems and individual service-system configurations.

Taxonomy of Urban Runoff Models

The structural characteristics of urban runoff models can be segregated into two broad categories, "lumped" and "distributed". In a lumped model, rainfall is transformed into the runoff at a given point without any hydraulic routing through the tributary area. An example is the conventional unit hydrograph, a tool in widespread use in river basin hydrological analysis and applied occasionally to urban drainage. A distributed model is characterized by a capability for the hydraulic routing of flows in addition to the hydrologic transformation of rainfall into runoff, such as through all or part of the underground conduit system within the tributary area being modeled. Because many more catchment details are accounted for, distributed models are considerably more complex than lumped models.

Another characteristic of urban runoff models deals with the time scale of their representation. Some models can accommodate only one individual rainfall event at a time and hence are commonly termed "event models". Other models that can handle a long series of events, ranging from a season to a decade or more, are commonly called "continuous models". Most urban runoff models were developed within about the last thirteen years. Event models are usually tied to synthetic hyetographs. As the limitations in the use of synthetic hyetographs became more evident, continuous versions of event models were developed to the point where continuous simulation options are now available for nearly all of the former event models that had received user acceptance.

A few years ago, urban runoff models could be additionally segregated by whether or not they could accommodate water quality parameters. The recent trend has been to add such a capability where it did not exist before, and thus this distinction is rapidly fading.

The most widely used models are in the public domain. Versions of nearly all formerly proprietary models have very recently been placed or are in process of being placed in the public domain. Conversion has been predominantly by the U.S. Environmental Protection Agency and the Hydrologic Engineering Center of the Corps of Engineers.

In sum, the recent trend has been to expand the repertoire of the formerly less complete models to include: their applicability to both analysis/design and planning; continuous simulation; and water quality characterization. Distributed features are being added to formerly lumped models, and lumped features are being added to otherwise distributed models, in an effort to extend them all to a combined analysis/design and planning capability. The result of all this is a homogenization of capabilities in a group of models all of which are in the public domain. It is particularly important to realize that practically all urban runoff models are being continually upgraded and improved. As a result, it is not possible to keep up with every new development, and the remarks about specific models in this paper are applicable only contemporaneously.

Components of Urban Runoff Models

Discussion of selected available models will start with total system simulation models and then take up the less complete cases. The principal functional components of the most comprehensive, distributed models are depicted in Figure 1.[3] Because pollutants are physically dissolved within and suspended by the flow of water, the runoff behaves as a pollutant carrier. Thus, pollutant routing (the two lower steps in the column to the right) is performed as an adjunct to hydraulic routing of flow (the two lower steps in the column to the left). "Surface Runoff" refers to the above-ground flow of water from the time rainfall lands until it enters the underground conduit system; and the underground conduit system is termed "Sewerage Transport" in Figure 1. Routing in "Receiving Water" can accept the outflow from one or more sources of contributary combined or separate storm sewers.

Three models deserve mention because they have all the capabilities indicated in Figure 1. All three of these models, in one variant or another, are programmed for routing flows using fundamental hydrodynamic equations of motion (after Barré de Saint-Venant). Late in 1975 it was reported that publicly available documentation

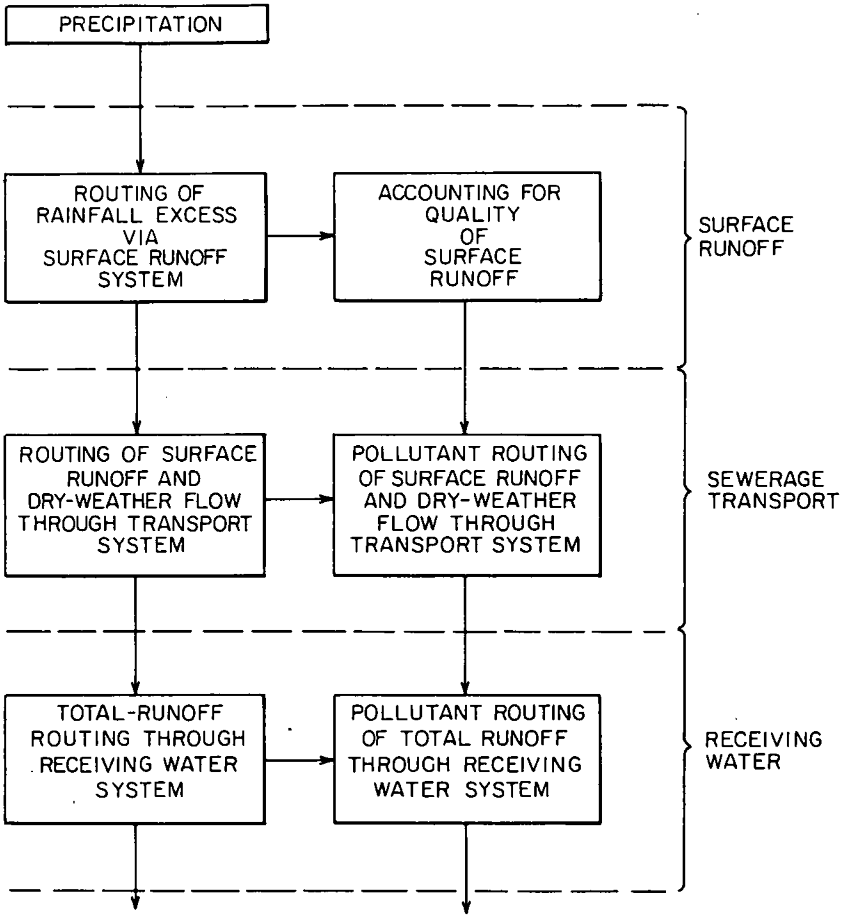

FIGURE 1 - COMPONENTS OF URBAN RUNOFF MODELS[3]

existed on the testing of variants of the Stormwater Management Model (SWMM) using data from 28 catchments (with water quality included for 18) in the U.S.,[4,5] its country of origin; and SWMM has also been tested and applied elsewhere. The QQS model has been tested and applied in the Federal Republic of Germany,[3] its country of origin, and elsewhere.[6] The CAREDAS Program (perhaps better known as the SOGREAH model) has been tested and applied in France,[7] its country of origin, and elsewhere. All three models have been used in both planning and design applications. Features of SWMM and QQS will be described later.

Some of the Models

The last few years have seen an explosion in the applications of urban runoff models, much of which was in conjunction with or as a result of the areawide planning for water pollution abatement mangement that has taken place in most metropolitan areas. Any discussion of urban runoff models is necessarily discretionary and somewhat subjective. To be cited here are only those models that are being used the most. The only exceptions will be formerly proprietary models that have recently passed into the public domain or for which a version is in process of being so transferred.

In a 1975 U.S. national report on urban hydrological modeling and catchment research,(4,5) 64 urban catchments were identified from which data had been used to test some 16 urban runoff models. Citations were restricted to cases that were publicly documented. Since 1975, the number of such catchments may well have doubled, mostly as a result of PL 92-500 (Federal Water Pollution Control Act of 1972) Section 208 planning and jurisdictional master planning activities, but it will be some time before the new ones can be collectively documented because a number are components of on-going planning. In a continuing project for the EPA,(8) urban catchment rainfall, runoff and quality data are being placed on magnetic tapes in a common format and are being entered in the EPA STORET data retrieval system.

SWMM. Subroutines for the EPA Storm Water Management Model are represented symbolically in Figure 2.(9) SWMM, the most widely used system analysis model in North America, is continually upgraded.(10) A user's manual,(11) its substantial updates and the computer program, are available to the public. The latest additions are to be included in a revised user's manual late in 1980. The earlier versions were restricted to a kinematic wave approach for stormwater transport, but a solution to the St. Venant equations is included as an option in the latest version of the model under the acronym EXTRAN. Another new feature is a detailed analysis option for detention storage and treatment.(12a) A conversational version of the Runoff block in SWMM is being used in a course on modeling in Ontario.(12c) Twice per year U.S. and Canadian users meet to review experiences with all types of models.(13) The SWMM Users' Group has become an informal U.S.-Canadian cooperative venture, and participation is open to all interested persons. While SWMM was originally an event model, continuous simulation capability has since been added. A user's experience

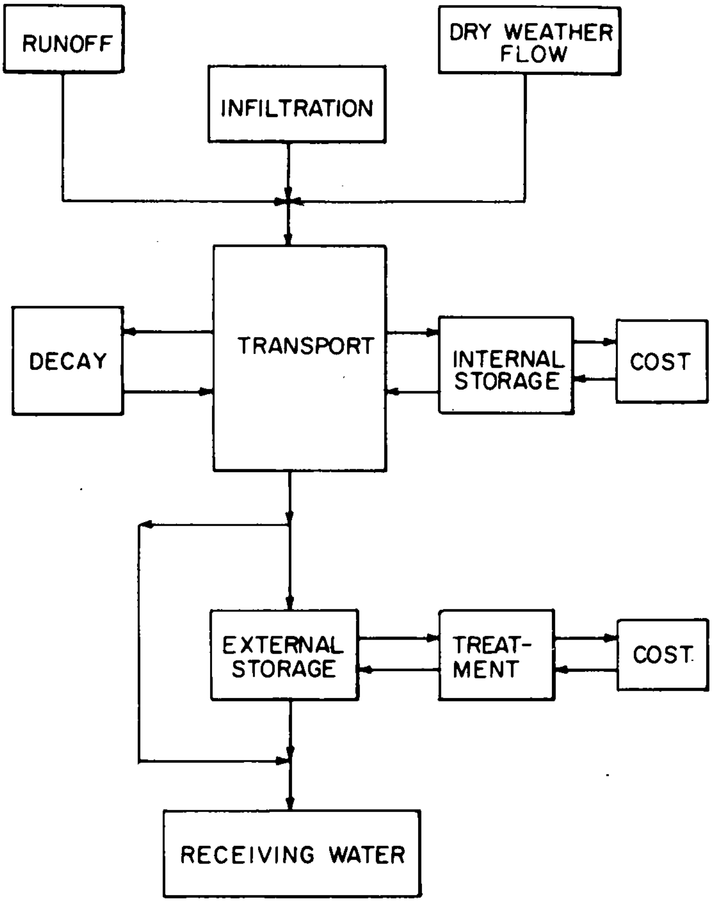

FIGURE 2 - SUBROUTINES OF STORMWATER MANAGEMENT MODEL[9]

with continuous simulation has been reported.[14]

QQS. Figure 3[3] is an overall flow chart for the Quantity-Quality-Simulation Model. Its North American applications have been in Rochester, N.Y., Toronto, Ontario, and Vancouver, B.C.[6] The QQS Model uses a solution to the St. Venant equations for stormwater transport and is a continuous model that can be run for single events. Developed in the Federal Republic of Germany, the model is available to the public from EPA.[6]

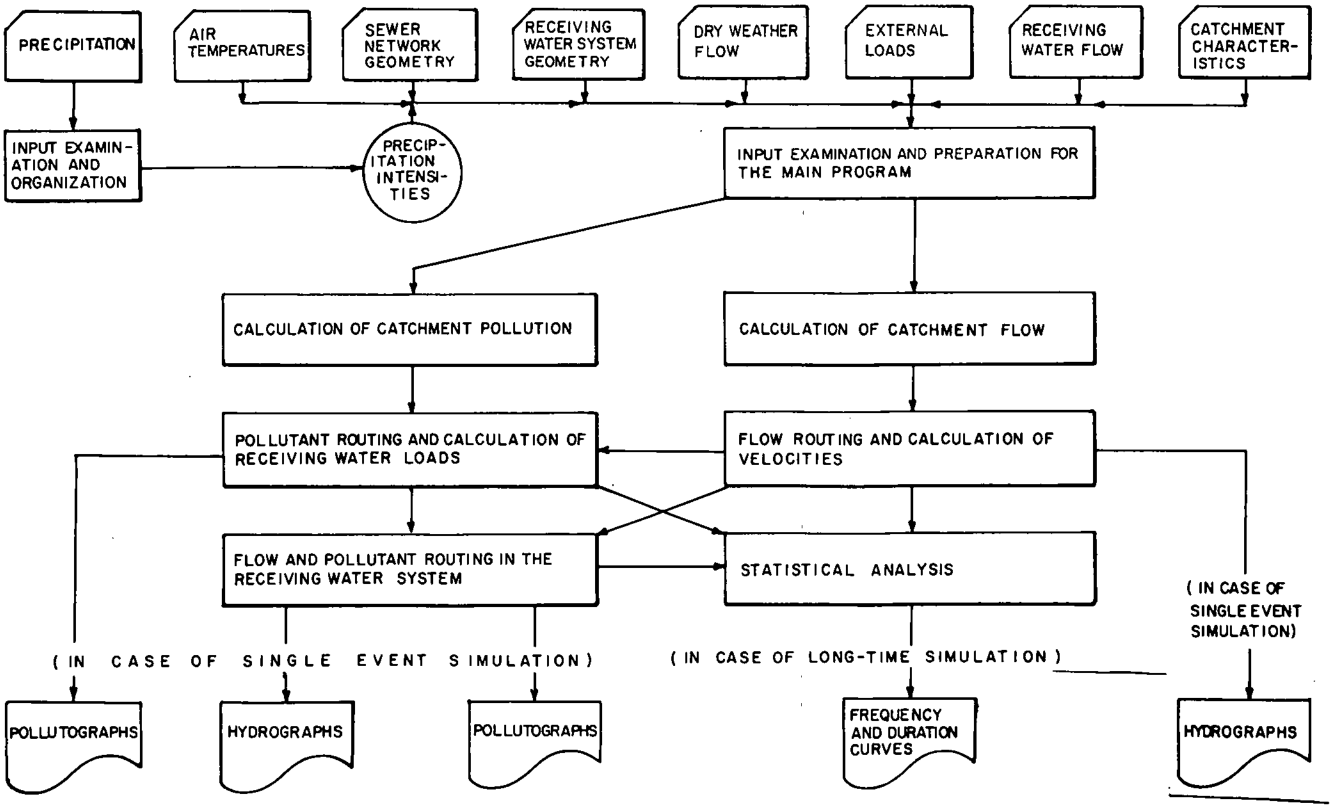

FIGURE 3 - OVERALL FLOW CHART FOR QQS MODEL (3)

Both SWMM and QQS were developed as urban land drainage models that included some receiving water simulation capability. The next model to be discussed was first developed as a streamflow simulator that was later refined to include detailed modeling of urban land drainage.

HSP. The earlier Hydrocomp Simulation Program, as outlined in Figure 4,[15] fundamentally simulated watershed hydrology and flow routing. The HSP was the commercial successor to the Stanford Watershed Model, first reported in 1960. An entirely new version using the same basic equations but in FORTRAN, (HSP-F), is available to the public from the EPA Environmental Research Laboratory, Athens, Georgia 30601. HSP is strictly a continuous simulation model.

EPA's Nonpoint Source Pollutant Loading Model[16,17] (NPS Model) incorporates the LANDS subprogram of the HSP. While the original testing of NPS was on urban watershed data, the methodology is said to be sufficiently flexible for other land use applications. NPS is a continuous model but has yet to be interfaced with a receiving water model. The reference report[16] is actually a user's manual.

MITCAT. The general structure of the proprietary MIT Catchment Model is shown in Figure 5.[18] A water quality handling capability has yet to be added formally. Its experimental use by the USGS and the Corps of Engineers will be mentioned subsequently.

ILLUDAS. Figure 6[19] is a flow chart for the Illinois Urban Drainage Area Simulator. It is an offshoot of the empirical British Road Research Laboratory (RRL) method,[20,21] and is the only widely used model that has determination of pipe sizes as a modeling objective. The water quality algorithms of SWMM have been adapted in a version known as QUAL-ILLUDAS, an event model.[22] The parent RRL method was reported in 1962, which made it one of the first distributed-type design models on the scene. ILLUDAS is predominantly a hydrologic model. Uses of various modifications of the RRL method for design have also been reported in Australia, Canada, the United Kingdom, Norway and India.

The USGS has modified the MITCAT and ILLUDAS models for continuous simulation, detention-storage accommodation and water quality simulation.[25] From its experiences with MITCAT, the USGS has evolved its own urban rainfall-runoff model.[26]

Through the use of greatly simplified hydrologic considerations, a computer

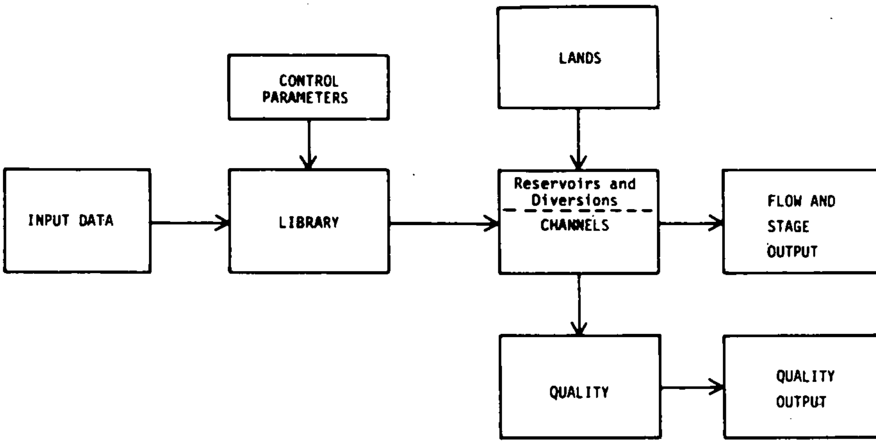

FIGURE 4 – THE HYDROCOMP SIMULATION PROGRAM SYSTEM[15]

program has been developed for the optimal deployment and sizing of separate storm sewers for altogether new developments.[23] A newer optimal layout model[24] incorporates STORM (cited later herein) and includes sizing of storage and treatment facilities for pollution abatement.

Unit Hydrograph. This relatively simple tool has been used in the hydrologic analysis of streamflows for quite some time. An excellent manual on urban unit hydrograph analysis is readily available.[27] The Corps of Engineers has developed a computer program user's manual for its Flood Hydrograph Package (HEC-1),[28] which develops unit hydrographs from field data and routes flows from one point to another. HEC-1 has been used extensively in urban projects by the Corps of Engineers and others. While HEC-1 is a single event simulator, a version known as HEC-1C has been developed for continuous simulation.[29]

The only interpretive tool for urban runoff that incorporates regionally specific parameters on a national scale has been developed by the Soil Conservation Service.[30] Its underlying hydrological element is a triangular unit hydrograph.

Synthetic unit hydrograph parameters derived from a number of field measurements in several States[2,31] offer a means for extrapolating findings from local field observations to local ungaged catchments in a given metropolitan area. A user can calculate synthetic unit hydrograph parameters directly from the equations given

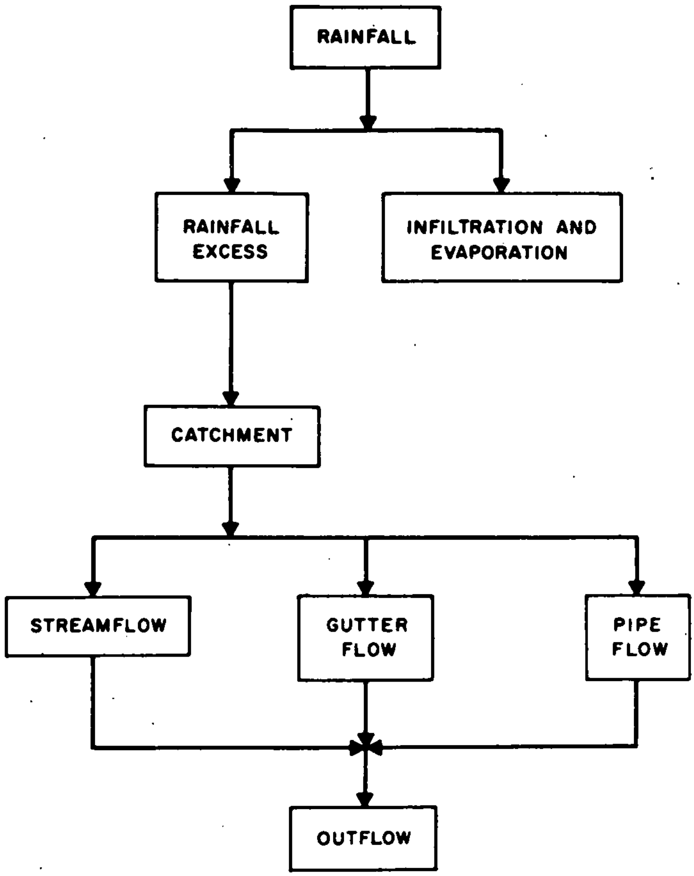

FIGURE 5 - GENERAL STRUCTURE OF MIT CATCHMENT MODEL (18)

with a pocket calculator of modest capability or simply use the nomographs provided.

Water quality considerations have not been included with any of the unit hydrograph formulations mentioned above. However, the QQS Model, noted earlier, employs unit hydrographs as the inputs to the routing module for underground conduit transport, and these inputs are accompanied with what might be termed "unit pollutographs" for water quality simulation.

STORM. The Storage, Treatment and Overflow Model was designed specifically for urban runoff and quality evaluation for total jurisdiction and metropolitan master

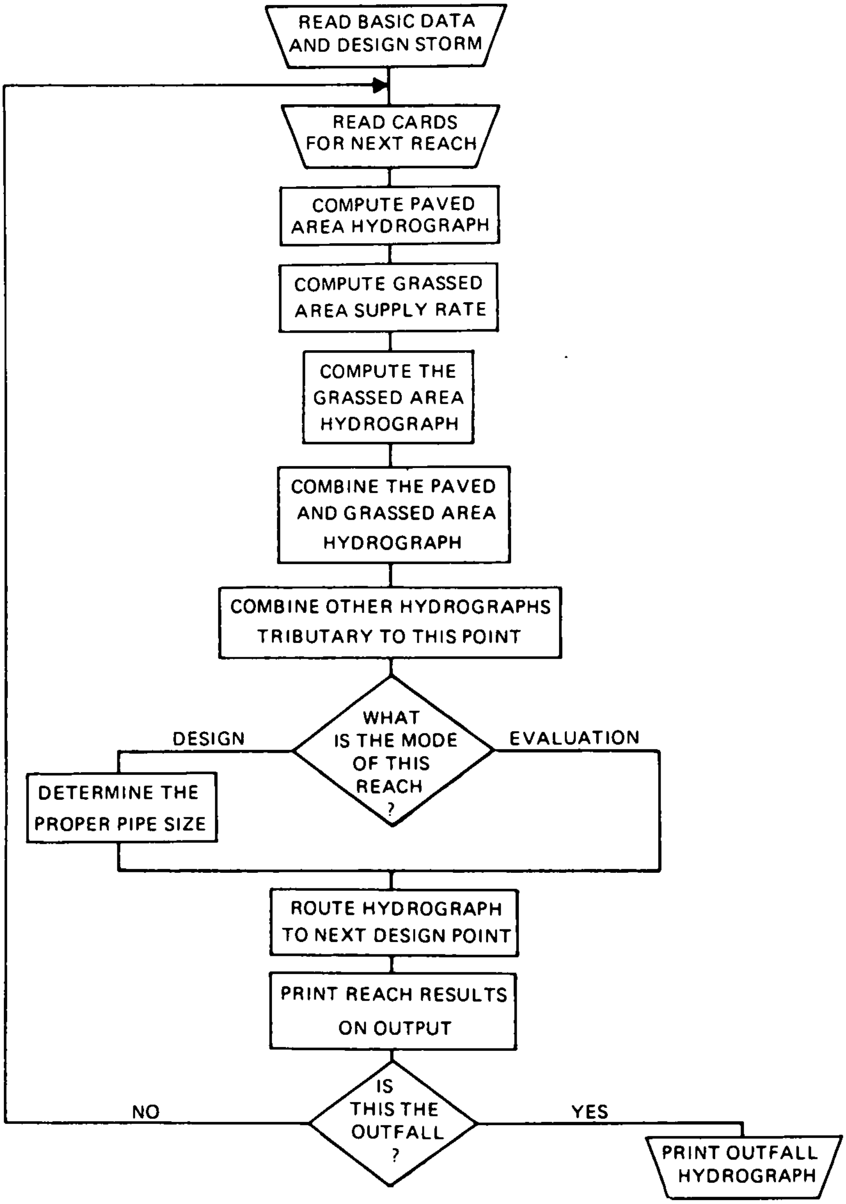

FIGURE 6 – FLOW CHART FOR ILLUDAS[19]

planning. It is eminently suited for that purpose and it currently enjoys, in one version or another, the most extensive use of any urban drainage simulation planning model. The computer program, model documentation,(32) user's manual(33) and guidelines(34) are available to the public. A simplified logic diagram for STORM is presented in Figure 7.(35) Note that this model focuses on structural means for flow and pollutant containment (storage and treatment). It is designed for use with many years of continuous hourly precipitation records (but can be used for individual storm events). Essentially, the model employs an accounting scheme that, for each storm event, allocates runoff volumes to storage and treatment, noting volumes exceeding storage or treatment capacities (overflows, in the case of combined sewer systems) as these capacities are exercised from one event to the next. Water quality is handled as a function of hourly runoff rates, with generated quantities of constituents allocated to storage, treatment and non-capture as for runoff volumes. Statistics are generated for each event and collectively for all events processed, including average annual values. STORM accommodates non-urban catchments and snowpack accumulation and snowmelt, and land surface erosion for urban and non-urban areas can be computed in addition to basic water quality parameters. Until recently, hydraulic simulation or flow routing was not incorporated in STORM. The latest Corps of Engineers' version includes a capability for routing to the outlet of each sub-basin through the use of triangular unit hydrographs based on the Soil Conservation Service procedure.(33) Capabilities of STORM and HEC-1 have been described in a symposium paper.(36)

A modification of STORM has been linked with the receiving water module of SWMM for continuous simulation of receiving water quality.(37,38) The Hydrologic Engineering Center has added a receiving water module to its STORM computer package.

As part of a nationwide assessment of stormwater pollution control costs, a "desktop" procedure was developed, by streamlining the STORM model, that can be used to estimate the quantity and quality of urban runoff in combined sewer and storm sewer areas and unsewered portions of a jurisdiction. Combinations of storage and treatment for pollution abatement and their costs can be estimated taking advantage of generalized results from the nationwide assessment.(39)

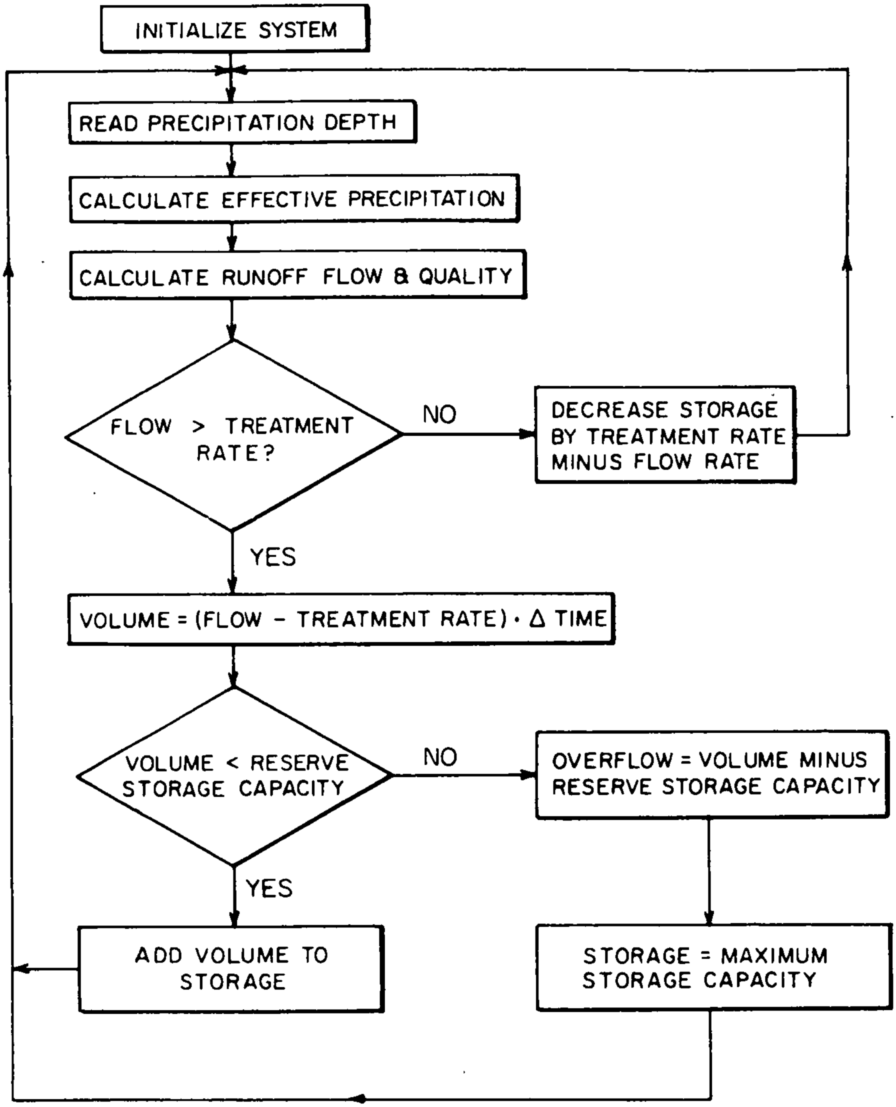

FIGURE 7 – "STORM" SIMPLIFIED LOGIC DIAGRAM[35]

Model Comparisons

From 1973 to 1976 there was a rash of projects comparing the merits of various models on the basis of a variety of criteria.(40-48) More recently, reliabilities of some of the simpler models (three versions of STORM and HEC-1 and HEC-1C) have been compared with those of some of the more complex models (SWMM, MITCAT and HSP) using data for a particular catchment.(29) Instances where tests had been published of the performance of various types of models against field data were reported in 1975.(4) Advances in modeling capability occur almost too rapidly to keep track, and in 1975 it could be said that mathematical model development for sewered system applications had already seemingly greatly outpaced the data base for model validation.(4)

Results of the various tests are mixed, mostly because there is no acceptable basis for multiple-objective comparison. Peak flow is the major consideration in sizing conduits, volume and hydrograph shape are critical for sizing storage, and concentrations and loadings of pollutant emissions are essential for evaluation of receiving water impacts and helpful in sizing treatment facilities. Each model has its strengths, weaknesses and outright faults for a given application. Over and above the problem with multiple-objective comparisions is the inherent difficulty with any runoff model in the necessarily subjective separation of abstractions (infiltration, depression storage, etc.) from total rainfall to resolve rainfall excess (amount and pattern), which is the input from which an equal volume of direct runoff is generated by models of one kind or another. After analyzing the performance of a variety of models, it was concluded that the weakest link is the proper estimation of rainfall excess.(49) All this is to emphasize that urban hydrology is still, in the absence of an adequate body of field data, more of an art than a science, and that under this circumstance the choice of a model for a given application is largely a matter of taste.

Some Simpler Planning Models

A Simplified Stormwater Management Model has been developed that is an inexpensive, flexible tool for planning and preliminary sizing of stormwater facilities.(50,51) Time and probability considerations are incorporated in the model. Joint usage of a complex model and a simplified planning model, such as this one, is said to be not only compatible but also complementary.

A very simple methodology has been advanced for preliminary screening of stormwater pollution abatement alternatives.[52,53] While the method was conceived for combined sewer system applications, it could as easily be applied to stormwater systems. Developed for use at the national or State decision-making level for early identification of poor candidates for abatement project funding, it might as readily be applied for rough, early assessment of the maximum pollutional impacts of storms at the metropolitan level.

Reported verifications of simple process planning models, including STORM, have been limited, although hearsay indicates that the number of verifications is growing. Because suggested magnitudes of model coefficients are based on the sparse amount of field data available nationally, it is very important that local rainfall-runoff-quality field data be used to calibrate such models for the sake of enhanced reliability of results. Too many planning exercises have proceeded without benefit of local field data, using one model or another.

Receiving Water Modeling

Receiving streams and lakes are the common repository of effluents from just about every community and self-supplied industry in a metropolis, constituting perhaps the most shared aspect of urban water resources. Impressive advances have been made in receiving water modeling. Initial attention was on hydrology and hydraulics in support of flood control objectives. Water quality modeling capability has evolved more recently, with a tendency to use tailor-made models for discharge-quality simulation in planning applications. Earlier development was focused on estuaries. The choice of a model or models to be used in any given planning effort therefore requires careful and discriminating study. Consequently, it is appropriate to cite recent capability summaries. Reference has been made earlier to capabilities of SWMM and other models for simulating receiving water impacts.

A compendium,[44] two companion reports,[54,55] a North American summary,[56] and a text,[57] survey features of large-scale water quality models; and an annotated bibliography of models for tidal rivers, estuaries and coastal waters is available.[58] Tidal water models have been comprehensively classified,[59,60] and capabilities for modeling estuary and streamflow water quality have been assessed.[61]

Aquatic ecosystem submodels have been delineated for process analysis.[62]

Aquatic ecosystem models were surveyed in 1974 for the National Commission on Water Quality via a questionnaire,(63) and while several of the models reported upon therein are more generally applicable, nearly all have been developed or tested on a specific water body and only a fraction of the applications have urban implications.

Water quality modeling for systems containing rivers and reservoirs has been advanced through the issuance of a description of a combination of models.(64) The Hydrologic Engineering Center has since added dynamic flow routing routines.(65) Dynamic or unsteady-flow water quality modeling is particularly important in the case of significant pulse loadings from urban runoff or when man-made controls such as dams are involved.

Although receiving waters represent only a part of the total urban water resource, they commonly traverse entire metropolitan areas and are affected by the actions of a multitude of local jurisdictions. Recent emphasis on regionalized wastewater treatment and disposal has resulted in some receiving water simulation studies on a grand scale.

Role of Models in Operations

Models used for analysis/design applications are more sophisticated than those for planning and thus are more detailed tools. They are used for analyzing individual catchments and subcatchments where the simulation of detailed performance of discrete elements within a subcatchment must be achieved. Whereas hourly rainfall data is an appropriate input for planning models and for simulating flows in larger urban streams, 5-minute interval rainfall data (the shortest duration reported by the National Weather Service) is the appropriate input for simulating flows in sewers and small urban streams for design applications. That is, the level of sophistication of hydrological process modeling for analysis/design becomes a much more important practical consideration than data processing, just the opposite of the emphasis imposed by planning requirements.

Models used for operations applications are likely to be more use-specific because of wide diversities in management practices, operating problems and individual service-system configurations. However, the most potentially transferable technology will be for automatic operational control of total community runoff, a capability that has received intensive development attention. The mathematical models required feature control algorithms that have to be painstakingly derived from numerous indicator applications of both detailed analysis/design models (for generalization of the performance of individual process components by simulation) and planning models (for generalization of community-wide system performance by simulation). Here also, analysis/design models are used as tactical tools and planning models are used as tools of strategy.

A computer model has been developed at the University of Toronto for exploring possibilities in the automatic control of existing combined sewer systems.[12b] Extensive research has been carried out at Colorado State University on a planned City-wide automatic control scheme for new storage and conveyance facilities in San Francisco's combined sewer system.[66-68] Metropolitan flood warning systems[69] require incorporation of some sort of hydrologic model. Development of a storm tracking capability is considered to be a necessary adjunct for automation of flood warning systems for combined sewer systems and urban streams.[70] Very little attention has been given to separate storm sewer system modeling for operations because there are normally very few existing components of such systems that can be manipulated.

Role of Simulation in Planning

A special session at the 1976 annual meeting of the American Geophysical Union[71] attempted to define appropriate rationales and incentives for the more extensive use of urban runoff mathematical models for planning, analysis/design and operations. Among the advantages cited for the use of such models for planning were that: tests can be made of alternative future levels of development and their impact on facilities needed in the future; several models well-suited to master planning are in the public domain and are regularly upgraded and made readily available by the Federal agencies that supported their development; when detailed models are used in advanced stages of planning the user is able to understand better the physical performance of a system; the interrelation between land-use projections and planned mitigative programs and their costs can be made more apparent; revisiting plan assumptions to update projects can be done with consistency and relative ease; joint consideration of quantity and quality of runoff in sewered catchments and in streams can be accommodated;

hydrologic-hydraulic effects of future urbanization can be explored; and deficiencies in existing facilities and prevailing management programs can be identified.

The most significant liability in the development of more acceptable measures of reliability of all types of models is the dearth of field data on rainfall-runoff-quality, particularly for sewered catchments. A workshop conducted by the ASCE Urban Water Resources Research Council resolved guidelines for the acquisition of such data by local governments.(72) The spectrum of investigative stages utilizing field data for the sewered areas and receiving waters of a metropolitan area include the following:

- Identification and evaluation of quantity and quality problems.
- Exploration of alternatives for pollution and flooding abatement.
- Analysis of the most attractive alternatives.
- Preliminary design of adopted alternatives.
- Detailed design of adopted alternatives and their implementation.
- Post-implementation operation via a range of possibilities extending from simple monitoring to automatic control.

Total lengths of underground drainage conduits dwarf those of open watercourses in major cities. For example, total lengths in the 97-square miles of the City of Milwaukee as of the beginning of 1970 were as follows:(73)

Lakefront length	-	8-miles
River lengths	-	37-miles
Combined sewers	-	550-miles
Storm sewers	-	820-miles.

These combined and storm sewers are distributed over 465 drainage catchments having a maximum size of 1,820-acres and a median size of 25-acres.(74) When dealing with so many components the model used must be as simple and as flexible as possible. That is, data processing for planning applications becomes a much more important practical consideration than the level of sophistication of detailed hydrological and hydraulic processes modeling. While not shown above, there were also 685-miles of wastewater sewers.

Some Reservations

Because complex processes, such as in the hydrological response of a sewered catchment to a precipitation occurrence, can never be fully replicated in a computation due to incomplete technical understanding of the processes and the infeasibility of detailing the literally myriad pieces involved, resort is made to simulation of response of a conceptually equivalent system. The simulation package is commonly called a "model". Reality dictates that a model should be selected on the bases of the type of application involved, how it is to be used, how much can be invested in its use, how often it would be used, what levels of precision are required or desired, what kinds of outputs are wanted, how much time can be spent to get the model to work, and how much can be committed to verify and calibrate the model. Calibration is the process of varying model parameters to minimize the difference between observed and simulated records.

We have been reminded that until each internal module of an overall catchment model can be independently verified, the model remains strictly a hypothesis with respect to its internal locations and transformations.(75) Because of the very limited amount and kind of field data available, just about all sewer applications model validation has been for total catchment response, at outfalls. That is, under contemporary conditions a distributed system model deteriorates into a lumped system model for all practical purposes. It should therefore be evident that validation using transferred data by the model's developer is not nearly enough. Credibility requires at least token calibration using some local rainfall-runoff-quality data. Unfortunately, the acquisition of such data is commonly regarded as the exclusive problem of local governments, and too many planning and analysis exercises have proceeded without benefit of local field data using one model or another.

Calibration and validation is further confused by the fact that much more field data are available for partially sewered catchments, where flow is measured in receiving watercourses, than for totally sewered catchments. (That water quality samples have been taken for only a fraction of these gaging sites does not help). Adding streamflow hydraulics to sewer hydraulics hardly simplifies the lumped system dilemma alluded to above, yet much of the data used to verify various models has been from such mixed catchments. This should add additional incentive for calibration with local data.

Concluded in a comprehensive Canadian study was that sufficient information is not available on relationships between street surface contaminants, their pollutional characteristics, and the manner in which they are transported during storm runoff periods. Also concluded was that basically only one type of model exists for analysis of urban runoff quality, and that the accuracy of the water quality computations using models extant has not been sufficiently established to be used with confidence for prediction purposes, in particular the formulation relating water quality with land use.[40]

Because relatively few runoff-quality field gagings in sewered catchments have been made, and these have been mostly at outfalls, source quality has been investigated principally as a function of street surface pollutants accumulated between rainfalls. In order to accommodate cause-effect relationships required for modeling, it is current practice to estimate potential street loadings, separately for individual parameters, on the basis of the few documented solids-accumulation histories. Arbitrary allowances are then added to account for off-street contaminant accumulations, expressed as multiples of the potential street loadings. Thus, no direct verification of the hypothesized buildup of pollutants and their transport to receiving waters is presently available. It is reasoned that when "pollutographs" generated by models reasonably approximate field observations for a catchment, that the overall accumulation and transport hypothesis is validated. As a result, it might be concluded that model development has already greatly outstripped the data base for model validation, in the sense of bracketing probable reliability.

Against this historical perspective is a viewpoint that deserves quoting: "There does not seem to be a 'perfect' model for analysis of stormwater. The models are either too complicated, do not allow for distributed inputs and parameters, do not simulate continuous streamflow, or have not been tested extensively on hydrologic data. ..... There remains much uncertainty in stormwater modeling. There appear to be enough parametric models available which have been shown to be feasible conceptualizations of the stormwater runoff process. What is needed now is a continued and accelerated verification of the existing models and a follow-up regionalization of the parameters."[76] All this will take some time.

A viewpoint from the United Kingdom is instructive: "Progress in hydrological modeling inevitably appears to involve more complicated procedures for the designer to implement and more information to be gathered. It is vital for the researcher to be aware of this and to ensure that recommended improvements are truly beneficial. For example, the present use of the U.K. RRL method is probabilistically unsound and too simple in terms of scientific hydrology. But unless a new method can be shown to give more accurately sized pipes and less costly protection against surface flooding, no amount of technical elegance will persuade the engineering profession to adopt it. It is this reluctance to accept anything which appears more complicated than is considered necessary that is sometimes responsible for recommendations that we return to simpler techniques. ..... Urban hydrological modeling in the U.K. continues to be geared primarily to the improvement of sewer design methods. The common aim is to seek a compromise between the mainly old, established, easily applied but theoretically unattractive methods, and the highly complex analytical models based on physical laws."[77]

Although the results are hardly universal, limited comparative study of models in Canada gives some indication of levels of reliability currently achievable: "On the average, about 70% of the simulated runoff volumes and peak flows, and 85% of the times to peak, were within $\pm$20% of the observed values".[78,79] The tests were on data from catchments with a single gaging station.

Concluding Remarks

The principal local detrimental effects of flooding are damage to the belowground sections of buildings and hindrance of traffic. Human life is seldom threatened by the flooding of urban drainage facilities. Such facilities are designed so they will be overtaxed infrequently and provision of complete protection from flooding can only rarely be justified. A monumental question in the use of models is the choice of storms to be applied.[80] Storm definitions used for deriving river basin extremes are irrelevant because urban sewer systems are expected to be overtaxed much more frequently than major river structures whose failures could be catastrophic.

In terms of actual objective functions, the mean frequencies of occurrence of flow peaks and volumes and quality constituent amounts are the issue, not the frequencies of the input rainfall. Furthermore, because there are inherent non-linearities in most methods for processing inputs for linear models, and dynamic models are non-linear by definition, the statistics of the rainfall input array may differ appreciably from those of some or all of the arrays for runoff and quality characteristics. Attempting to assign a mean frequency of probable occurrence to a "design storm" can be meaningless because of likely statistical nonhomogeneity of rainfall, runoff and quality, and such an approach neglects the effects of prior storms on the runoff from a given storm. However, once we must extrapolate beyond the period of available rainfall records (50 to 70 years or so) for streamflow simulations, it is obvious that no reasonably reliable storm analysis criteria exist (such as for 100-year streamflow simulations) and in that circumstance there is no valid argument against the use of synthetic storms as inputs to models, as in river basin hydrology. But there are ways to test the validity of rare events by means of simulations using available rainfall records.(81) Even if very simple procedures are used, e.g. to determine only a peak flow rate, the collateral, occasional monitoring of computations by means of one of the more complete models can serve as an auxiliary guide to sharper judgment.

This paper has appeared, in a longer version, in a report for Ecole Polytechnique of Montreal.(82)

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CONSULTING ENGINEERING IN THE 1980's: CHANGES, CHALLENGES, OPPORTUNITIES[1]

By Peter J. Gianacakes[2]

My topic today is intentionally broad. Engineers, involved in the challenging day-to-day work of our professional lives, sometimes find it difficult to take the time to stand back a moment and examine the broader view of where we are and, more important, where we are going.

As chief executive officer of one of the nation's leading consulting engineering firms, I can verify that the tendency, even at my level, is to become immersed in pressing short-term concerns. However, it is important for all of us to take time once in a while for a broader look at the business of consulting engineering and our roles in it. Today, I'd like to speak of what I see as the coming changes and challenges for the consulting engineering industry in the 1980's, in the context of my organization - Metcalf & Eddy.

In order to set the stage for the issues that I shall be discussing, let me begin by giving you a brief history of the firm. Metcalf & Eddy was formed in 1907 when Harrison P. Eddy and Leonard Metcalf set up practice at 14 Beacon Street in Boston. By 1927, the partnership had expanded and had outgrown its Beacon Street headquarters, so the firm moved to the Statler Office Building where it remained until the move to our current location on Staniford Street in 1975.

Leonard Metcalf & Harrison Eddy were men of exceptional talent and vision, and their practice, one of the first in America specializing in water supply and sanitary engineering, grew and eventually broadened into other fields of expertise. Both men, by the way, were presidents of the Boston Society of Civil Engineers.

In 1967, Metcalf & Eddy was acquired by Bangor Punta, which in turn sold it to Research-Cottrell in November, 1970. Research-Cottrell has its own 70-year history in the environmental field, primarily as an environmental management company. More recently the company has begun a program of diversification into the energy field to complement its leadership position in environmental management as described in the cover story for the September 4, 1980 edition of *Engineering News Record.*

[1]Presented at a luncheon meeting of the Boston Society of Civil Engineers Section, ASCE, October 16, 1980.
[2]President and Chief Executive Officer, Metcalf & Eddy, Boston, Massachusetts.

At the time of the acquisition Metcalf & Eddy was essentially a Boston firm with a New York office and a smaller operation on the West Coast. Today, the firm works throughout the world. Domestically, it operates through seven regional organizations including one in Hawaii, and 13 domestic offices. Internationally, it has project offices in five nations: Egypt, Saudi Arabia, Qatar, Thailand and Brazil. Billings have grown from about $17 million to over $45 million. The staff has increased from about 550 to around 1,000 today worldwide.

Metcalf & Eddy environmental engineering work has continued to be the firm's major area of activity since its inception in the early 1900's. Today, approximately 65 percent of our work is in the water and water management fields. The mix of other fields shows the firm's diversity: 20 percent of our business is in civil projects; 10 percent in the fields of transportation, land development, architecture and planning; and about 5 percent of our projects relate to the growing energy field.

With that introduction and background, let me turn to a discussion of the changes, opportunities and challenges which I feel consulting firms will face in the 80's. It will become apparent as we go through this review that the greatest single challenge before us is to recognize and adapt to change.

For example, it is doubtful that either Mr. Metcalf or Mr. Eddy would recognize the business environment in which today's engineer works, particularly the changed traditional engineer-client relationship which now is involved with many other parties such as federal and state authorities. The resulting forces, as well as other forces brought to bear on consulting firms, are bringing about change, whether we like it or not. I believe that recognizing and adapting to present and future conditions is something we must do, and do well, in order to succeed in the 1980's.

In taking you through my assessment of the important factors impacting our business, I will, in order, discuss changes, opportunities and challenges. Recognizing that it will be impossible to cover each category in detail, I plan to give you an overview of each with examples, where appropriate, to give you a better feel for the issues.

Change: External Factors

Let us begin with the subject of change in the environment within which we operate: I will discuss changes arising from external sources beyond the control of the firm, and those internal to the firm over which the management has control and responsibility. It is obvious that external events to a large degree influence and dictate the need for internal change, so there is an interrelationship between the two. Some of the key external factors which I will touch upon are shifting national priorities, increasing competition between consulting firms, and the shortage of engineering talent.

One of the important external influences on our business is the shift taking place in our national priorities which has in turn brought about changes in many of the traditional consulting engineering markets. Whereas in the 1970's environmental issues and achievement of a better quality of life received the highest priority, today the emphasis has been and is being shifted to energy, inflation, and national defense.

- In the energy field, a major need exists to move more toward self-sufficiency by extending our present energy supply through conservation and through development of alternate energy sources. We are the only industrialized nation in the world which truly has the opportunity to move toward self-sufficiency.

- On the economic front, the issue is how inflation, which has run in double digits in 1979 and the beginning of 1980, compared to about 6-½ percent in the prior nine years, can be controlled while addressing the priorities of the 1980's.

- In national defense, the perceived need is to enhance our capabilities, not only in equipment but also in facilities, through an expanded and more cost-effective national defense program.

As a result of the shifting priorities, considerable uncertainty has developed in our key markets, many of which form the foundation for our consulting business.

The markets of interest to M&E include those related to the Clean Water Act, where the construction grants program is being questioned by the public and Congress as to its value and future role.

In addition to the prospect of changes in Clean Water Act, an air of uncertainty also pervades the transportation and international markets.

Transportation — In transportation which includes highway, bridges, and street, federal expenditures are being cut back and delayed as costs rise and availability of highway funds on the present basis of accrual is being reduced. The question is: will Congress and the administration come up with a workable solution to put the Highway Trust Fund on a sound financial basis?

International — The international market does not have the same uncertainty of funding or demand and still provides a growth opportunity to U.S. firms. The uncertainty here is one of constraints because of a competitive disadvantage imposed upon us by our own government in the form of personal income taxes. The volatile socio-political conditions with changing governments and the threat of war also represent an uncertainty.

As markets have changed and as the business environment in which we operate has become more difficult, competition between consulting engineers has increased dramatically.

There is a shortage of engineering talent today which is likely to become more severe in the 1980's. Major new programs such as the new synthetic fuels industry and the massive MX missile project will further tax an already short supply of talent. The major design-construct firms are predicting that their technical staff needs will swell from 38,000 in 1980 to over 55,000 in just the next five years. The MX missile project will create 1,200 new engineering positions in the Corps of Engineers alone by that same year. The growth in demand for engineers is exceeding the supply of experienced talent.

Consultants will be faced with competition from industries offering higher salaries, better growth opportunities and greater security.

Change: Internal Factors

Turning to internal factors: a major one which must be faced is the higher cost of doing business. I will touch here on a few of the interrelated factors contributing to higher costs.

- Inflation has an impact on all our costs. Salary costs are escalating, particularly since the wage and price guidelines have, for all practical purposes, been abandoned. Inflation also contributes to the sharp rise in non-salary costs such as travel, insurance, recruiting and relocation, all of which are increasing at more than 20 percent a year.

- Increased government regulations translate into higher costs; for example in project delays, where it is not unusual for an entire year to elapse between the time of selection and project start-up. Regulations on profit guidelines may also be unrealistic; and there is sometimes a lack of full understanding of cost plus fixed fee contracts on the part of the consultant or client.

- Productivity or staff utilization has shown a significant decrease since 1975. At M&E, staff utilization has decreased two points since 1977. This has added over a half million dollars to overhead costs at our level of operation. The higher costs resulting from increased competition, delays, etc., are reflected in higher time commitments by staff to administration, business development, and non-billable time. The result: the rate of increase in overhead costs has doubled in the 1975-80 period compared to the prior five years.

- And the last element, which I have labeled technology, consists of two facets. First, on the project side, there has been pressure to force on clients the use of innovative technologies without fully considering the orientation and needs of those clients. Such projects, which often have not worked, place a burden on the community in construction cost over-runs and higher operating costs. Second, the consulting profession has not adopted new technologies which continually become available and could extend our staff capabilities.

Finally, consulting engineers have been incorrectly lumped together in the public's eyes with the "beltway bandit" consultants in Washington, D.C. who were associated with excessive profits, scandals including payoffs, etc. We are being painted as the guys in the black hats - an image we must change.

Opportunities

Turning to the future, I see the decade of the 80's as one full of opportunities for consulting engineers. In the environmental field, these opportunities range from M&E's present major market, under the Clean Water Program, to integrated waste management, with due regard to hazardous and toxic substances, water and groundwater contamination. Other opportunities will arise from the growing energy field; from the redevelopment of cities and the upgrading and growth of our industrial capacity, from the expansion of defense facilities in addition to military equipment; and from the large and ever changing international market. Let us look at just a few of these opportunities.

Clean Water Program — First and foremost is the Clean Water Program. It is true that if the program does not survive, then Metcalf & Eddy as well as a large number of other firms will be in serious difficulty. The need for clean water has not diminished. It is the results achieved to date which must be improved upon.

Recognizing the major investment that M&E has made in this area, we took the initiative to bring together 17 of the larger consulting firms to discuss and address this matter. This program was not intended to replace and has not replaced the work underway by professional societies including ASCE and the American Consulting Engineers Council. It has supplemented these efforts and involved the leaders of those firms in working more to improve the situation. The program has moved along; the group met with EPA administrator Douglas Costle and his top staff in July 1980. What came out of that meeting in terms of the future market is that the program needs to show progress: it needs to show results. We, the consulting engineers, can and must help make these results happen.

We can strive to design plants which relate directly, possibly more directly than in the past, to the unique requirements of the client. This involves not only meeting effluent guidelines, but making technical design decisions taking into consideration capital and operating costs and their impact on the community.

International — The international field is one which represents a market for our existing expertise, as well as an opportunity to participate more broadly in the future. The international market for A/E services is approaching a billion dollars per year and growing at a rate in excess of 15 percent a year. The exporting of services, including consulting engineering, represents the fastest growing element of U.S. trade.

However, poorly conceived government policies, particularly in the area of personal income taxes, have been weakening our position. The U.S. is the only major nation that taxes the earnings of its citizens working in foreign countries. Other nations encourage and support such efforts as a lead-in to further development of their international trade potential. The impact of U.S. tax policy on engineering and construction companies has been dramatic. Whereas in 1976, the U.S. held 10 percent of the Middle East market, we have only about 1½ percent of that market today. This impact as I see it is mainly in the construction end, but the same could develop for A/E services.

M&E is active in attempting to restore the competitive position of American firms through our participation in the Tax Fairness Committee. We have also testified before Congressional committees on this issue. The outlook for substantive change in the tax situation in 1981 is encouraging.

The 1980's will open up new, expanded opportunities for consultants, particularly in the areas of energy, national defense, and construction management.

Energy — Energy is without a doubt one of the key developing markets for the 1980's. Ours is an energy-based economy which, until recently, was stimulated by the relatively low cost of energy. With the four-fold increase in energy costs, the oil we import has become significant not only as to availability, but also because the cost is a major contributor to inflation.

For some time now Congress and the country have struggled, largely unsuccessfully, to develop a comprehensive energy policy, to promote energy conservation and development of new sources of supply. Legislation has emerged from this Congress, primarily the Energy Security Act of 1980 (synthetic fuels legislation) which addresses parts of the problem. For example, the development of oil shale reserves calls for 40 super projects with production of two million barrels per day by 1991. Estimated cost of that program alone is pegged at over $20 billion. The opportunity for consulting engineers is that this effort will involve work in water and water management; and management programs to assure little or no degradation of the environment.

The 1980's should see major programs designed not only to conserve energy but also to develop alternative energy sources. Both approaches, and I emphasize the word "both", represent significant opportunities for consulting engineers.

National Defense — In the area of national defense, the civil and environmental work associated with the increased expenditures the Administration and Congress have targeted for facilities represent sizable markets for consulting engineers. For example, the MX program which I referred to earlier, is projected as a 10-year $13 billion opportunity.

Construction Management — Another opportunity for the 1980's is the inflation-fueled concept of total project management, which is often identified as construction management. This market, which is estimated at a billion dollars per year, will continue to grow, fueled by the economics of total project cost which favors a fast track approach versus the present segmented approach.

Challenges

Finally and briefly, the challenges we face.

In looking back at those issues I've touched upon today; namely, changing national priorities, uncertainty of present large markets, internal operational factors, and opportunity areas, it becomes apparent that there are key challenges which the consulting engineering profession must address to assure not only its continued viability, but also its growth.

- First, we must become more assertive in the protection and improvement of present markets like the Clean Water Program and the international field.

  In other words, we must get more involved. To do so, the profession must move away from its present position of fragmentation to one of unity. We must speak with a single voice on issues of importance.

- Second, we must develop a management focus which complements and is equal in emphasis to our technical orientation so that we can, in fact, identify with and address the needs of our clients. By doing so we will ensure that they receive the technology which best meets their needs and the economic realities of their situation. Also, improving our management focus will put us in a better position to address the issues of rising costs, increasing competition, and the shortage of engineering talent.

- Third, our staff must be encouraged to identify and respond to changes in the marketplace. Flexibility, particularly in broadening our technical base and adjusting our technical approach to meet varied and broad market opportunities, will be a key to success in the 1980's.

- Fourth, we must invest in the training and development of our staffs, not only in the technological and business aspects of our business but in people management as well, in order to better meet the challenges of the 1980's and create an environment which will permit us to compete with other industries for the engineering talent we will need.

Successfully meeting these challenges, both from a technological and a business point of view, will open up vast opportunities for consulting engineers. At Metcalf & Eddy we are enthusiastic about the 1980's, but we are not underestimating the effort and dedication required to meet those challenges and thereby take advantage of expanding opportunities.

THE DANIEL W. MEAD PRIZE FOR STUDENTS

The Daniel W. Mead Prize for Students was established in 1939 to honor the memory and accomplishments of the 67th President of the American Society of Civil Engineers. The Mead Prize is awarded annually on the basis of papers on professional ethics. Each year, the topic of the contest for the forthcoming year is selected by the National Committee on Student Services. The topic chosen for the 1980 contest was "The Role of ASCE in Influencing Public Policy on Controversial Technical Issues".

One winner was selected from each of the Society's four zones and subsequently the national winner was chosen from among the four zone winners. All four winners presented their papers at the ASCE Spring Convention in Portland, Oregon on April 18, 1980.

The national winner this year was Karen Kirk of the class of 1980, Northeastern University. Her paper is presented on the following pages. It is also being published in *Issues in Engineering, Journal of Professional Activities,* ASCE.

THE ROLE OF ASCE IN INFLUENCING PUBLIC POLICY ON CONTROVERSIAL TECHNICAL ISSUES[1]

By Karen Kirk[2]

The issue of who should be involved in forming public policy is dependent upon the prevailing social and economic climate of the day. It is therefore necessary to bring toegether a variety of viewpoints in order to be qualified to suggest the role of the American Society of Civil Engineers (ASCE) in public policies which concern controversial technical issues.

While researching this topic, I contacted several civil engineers and other informed individuals, all of whom were very helpful. I should like to thank Mr. Louis L. Meier, Jr., the ASCE Counsel in Washington, who was particularly helpful in answering my many questions and sending me a great deal of literature pertaining to ASCE. I should also like to thank the people who took the time to answer my questions in person or by letter: Mr. Oscar Bray, former ASCE president; Mr. Charles Par-

[1]1980 Daniel W. Mead Prize Paper, ASCE.
[2]Class of 1980, Northeastern University; National Winner, 1980.

thum, Vice-President of Camp Dresser & McKee, Inc.; Mr. Lawrence Bergen, New England Division, U.S. Army Corps of Engineers; Mr. John Sullivan, Chas. T. Main, Inc.; Mr. Michael S. Dukakis, former governor of Massachusetts; Ms. Marcia Rockefeller, Sierra Club; Mr. R. Lawrence Whipple, ASCE; Prof. Saul Namyet, Dr. Kenneth Leet, and Prof. Richard J. Scranton of Northeastern University. The opinions stated in this paper are the opinions that I developed while researching the subject. I alone am responsible for the statements and opinions expressed in this paper.

I shall first state the problem and then pose some questions and finally explain how these questions relate to ASCE and its role in public affairs. Also several suggestions will be offered on how ASCE can fulfill this role.

The role of professional and technical societies in controversial technical issues is becoming increasingly important as our society grows more complex. Every day, decisions are made at the local, state and Federal levels of our government and often the people making these decisions are not aware or do not fully understand all the potential consequences that may be involved with a particular project or policy. Our government leaders find it more and more difficult to make sound decisions involving complex technical issues. As these issues become more complicated, they are also becoming more numerous. The technological advances of the past three decades have brought science and engineering closer to, and more involved in, the every day lives of almost everyone in this country. Legislators are constantly being bombarded with information provided through special interest groups, some of which may not be concerned with what is best for the general public. Can we be sure that the information on which our elected officials base their decisions are sound, dependable facts leading to rational conclusions?

I. Should civil engineers, as individuals, make a conscious effort to inform the public on technical issues concerning the public's safety and well-being?

Yes, civil engineers have a moral and ethical responsibility to serve the needs of the public. The first of the Fundamental Canons in the ASCE Code of Ethics states, "Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties." Many engineers are currently involved in fields concerning air and water pollution, public transportation, water supply and waste disposal. Engineers, in the day-to-day performance of their duties, are becoming increasingly involved in the social and economic affairs of various communities. It is essential that engineers, trained to think and make decisions based on facts, speak out and become involved in the issues and problems facing their community. There are many instances where an engineer's input as a professional and a concerned citizen is not only welcome but also imperative.

II. Should civil engineers seek public office with the purpose of contributing their technical knowledge?

Yes, engineers, through the opportunity they have had in their education and training, are uniquely qualified for many public offices. Our government should be representative of the people it serves and should involve a variety of viewpoints on any current issue. An engineer can, through his/her technical background lend balance to any debate concering public policy.

At the local level there are many areas where an engineering background is needed. Good planning and design can greatly enhance any community. In most cities and towns there are planning boards, zoning committees, public works boards, building code committees, park and recreation commissions, and boards of selectment or city councils. At the county or state level there are building and zoning committees, examining boards and various environmental protection agencies. As congressmen, engineers would have the training and knowledge to be capable of making sound decisions on any type of issue.

The engineer's logical approach to issues and problems can be invaluable in the decision-making and policy-forming stages.

III. What is the Role of ASCE in Influencing Public Policy?

ASCE's role in public policy can be very complex and the extent of the Society's involvement in any issue must be based on the circumstances of each particular situation. However, the type of involvement can be grouped into four comprehensive categories which are described below.

1. The ASCE's most important function is the education of its members. The Society should strive to keep its members informed on current, controversial, technical issues - thereby indirectly informing the general public. The Society, through publications such as "Issues in Engineering" and "Civil Engineering", could present the facts and all aspects of such topics by inviting other professionals, medical doctors, attorneys, and economists, to furnish articles or information pertaining to their field of expertise. Other professionals can be invited to Na-

tional Conventions and Local Section meetings to offer some insight to perspectives to which the engineer is not normally exposed. This will produce engineers who are more cognizant of the social impact of current issues. Issues such as nuclear energy, hazardous waste disposal, and offshore drilling are multifaceted problems. The physiological, environmental and economic, as well as the technical aspects of these issues must be considered. If individual members are involved in public affairs they can contribute the information they have gained through the Society when they participate in discussions or debates concerning these issues.

2. The Society should encourage and assist its members to become more involved in public affairs particuarly in their own communities. The narrowly technical stereotype of the engineer is partly due to the engineer's apparent lack of concern in the social segment of projects, problems or policies. The separation between social and technical issues is becoming less distinct as our society grows more complex. The active involvement of the Society and its members in public affairs will enhance the general public's image of the civil engineering profession. The increased visibility and citizen awareness of the civil engineers in the community will help improve the public's understanding and respect for our profession. Assistance and support for individual members will encourage them to become more involved in civic affairs. By detailing how an engineering background can be applied to particular areas of government and community affairs, the Society will facilitate the engineer's decision of how he can best benefit his community. ASCE, through programs such as Continuing Education courses, could teach engineers to be more effective *public* communicators. Former Governor Michael Dukakis stated, "One of the problems that people like myself have is that we do not have all the necessary technical information. If that information can be translated into terms that we can understand, it would be very helpful." This would be beneficial in both public and private business. Other professionals, such as attorneys, can be invited as guest speakers to discuss how to organize a campaign or be a successful candidate. ASCE could also provide a medium for the exchange of ideas or experiences among engineers currently involved in civic affairs.

Engineers are an untapped resource which could and should be utilized more extensively in the community decision-making process. Many citizen advisory groups and other committees would welcome the assistance of an engineer to help ensure that their information is correct and technically sound. Marcia Rockefeller of the Sierra Club stressed the point that the presence of an engineer will also help ensure the group's credibility. Local sections could compile lists of engineers willing to serve on such committees, endorse their credentials and recommend them to towns and cities or other public interest groups. Engineers have the education and background to ask the right questions and to attack a problem objectively, looking at all sides of the issues before drawing a conclusion.

3. The ASCE Code of Ethics states that engineers shall be involved in community affairs and shall work towards improving our environment. The Society, in addition to encouraging its members in this direction, can also pursue these goals at the National and Local Section level. The Society can increase its involvement in public policy through legislation and by offering information and guidance to legislators to ensure that wise decisions will be made concerning technical issues. But, there is a problem with ASCE advocating a particular piece of legislation. If that legislation is not supported by, or representative of the viewpoints of, the entire membership, can the Society justify spending the necessary time and money involved in promoting it? The way to avoid this conflict is to urge individuals and groups within ASCE to actively support legislation or policy which they deem appropriate. But, these groups must also be extremely cautious not to support a bill which will appear to be self-serving or may involve a conflict of interest.

Providing speakers for civic organizations and public forums and providing facts and explanations of technical aspects of projects or issues for the news media are perhaps better ways in which ASCE can influence public policy nationally and locally.

4. If an ASCE member, through his or her engineering judgment, believes that an existing project or policy, in government or private industry, should be questioned or reevaluated, ASCE should organize a task force or investigative committee which is objective and knowledgeable on the subject to offer guidance on proper conduct. If so, ASCE's duty then is to support and guide the individual in whatever corrective action is necessary. As an example, if an engineer suspected that chemical wastes from the firm employing him were contaminating a water supply and the firm ignored his warning, ASCE would act as an intermediary. ASCE should advise the engineer as to how he should report the problem and what his responsibilities are in that particular situation. The Society should also offer support in the form of a lawsuit to retain his position, economic assistance, or aid in finding a new position, if any of these become necessary as a result of the recommended action.

* * * * * * * * * *

The engineering profession must prove that it is concerned about the problems facing our society and is willing to cooperate with the public in solving these problems effectively. It is essential that in every community the most knowledgeable and most qualified people participate in their government if the democratic system is to function in the way in which it was designed. It is the responsibility of the Society to promote both the fact and the image of the engineer as a socially concerned, technically knowledgeable citizen by urging its members to meet these expectations in their own communities. ASCE does not need to sacrifice any of its traditional professional society activities in becoming a more socially-oriented organization. Through the efforts of its members, ASCE will become an organization that is more conscious of and more concerned about the social problems, in conjunction with the technical problems, of our society.

The role of ASCE is to help its members to be more enlightened about *all* facets of technical issues, and be more involved in public decisions concerning these issues. ASCE should also strive to assist our elected officials in making wise decisions pertaining to technical issues and point out and rectify faulty projects or policies of the past.

JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS SECTION

Proceedings

AMERICAN SOCIETY OF CIVIL ENGINEERS

MEETINGS HELD - TECHNICAL GROUPS

Computer Group

October, 15, 1980 — Dinner meeting at the MIT Faculty Club. Speaker, Professor J. S. Lazarus of Boston University. Subject, Structured Programming; how it improves production by reducing errors, and improves maintainability and understanding. Attendance, 19.

December 10, 1980 - Dinner meeting at the MIT Faculty Club. Speaker, Robert A. Wells, Jr., of Project Software and Development, Inc. Subject, the new Fortran - ANST Fortran 77. This was an official BSCE Section meeting. Attendance, 38.

Construction Group

October 2, 1980 — Dinner meeting at the MIT Faculty Club. Speaker, Peter J. Philliou, Esq., Attorney at Law. Subject, Who's at Fault; a discussion of the principles of liability with respect to construction and engineering. Attendance, 36.

December 4, 1980 — Dinner meeting at Cottage Crest Restaurant, Waltham. Speaker, Richard Reardon of the New England Division, Corps of Engineers. Subject, National Dam Safety Program and Flood Control Projects in New England. Attendance, 32.

Environmental Group

October 8, 1980 — Dinner meeting at Purcell's Restaurant, Boston, held jointly with the Society of Women Engineers. Speaker, Dr. Michael O'Hare, Director, Office of Policy and Management Analysis, Massachusetts Department of Environmental Affairs. Subject, Siting of Hazardous Waste Disposal Sites. This was also an official meeting of the BSCE Section. Attendance, 55.

Geotechnical Group

September 9, 1980 — Dinner meeting at Kennecott Copper Corporation, Lexington, held jointly with the BSCE Section's Ad Hoc Energy Committee and the Association of Engineering Geologists. Speaker, John R. Raymond, Staff Scientist, Battelle Pacific-Northwest Laboratories, Richland, Washington. Subject, Aquifer Thermal Energy Storage. This was also an official meeting of the BSCE Section. Attendance, 74.

October 7, 1980 — Dinner meeting at Mugar Hall, Tufts University. Speaker, Derek Maishmann, freezeWALL, Inc. Subject, Ground Freezing. Attendance, 47.

November 12, 1980 — Dinner meeting at the Engineers Club, held jointly with the Utility Contractors Association of New England. Panel discussion: Francis T. Bergin, Chief Engineer, Construction Division, Metropolitan District Commission; William S. Zoino, Principal, Goldberg Zoino & Associates, Inc.; and Denis M. Foley, Vice President, J. F. White Contracting Company, Inc. Subject, Sewers in Poor Soil Conditions — Improving Practice for the Eighties. Attendance, 110.

Geotechnical Group Lecture Series — The Geotechnical Group, with cooperation of MIT, will sponsor a series of six lectures on ground waste hydrology, beginning on March 10, 1981. The lectures are from universities and from industry.

Hydraulics Group

October 22, 1980 — Evening meeting at the Ralph M. Parsons Water Resources Laboratory, MIT. Speaker, Dr. Peter Larsen, Director, Hydraulics Laboratory, Swedish State Power Board. Subject, Swedish experience in the development of solar energy storage utilizing heated water stored in man-made rock caverns. Attendance, 22.

November 22, 1980 (Saturday) — Site visit to the new hydroelectric station at the Essex Dam on the Merrimack River. Attendance, 36.

December 17, 1980 — Evening meeting at the Ralph M. Parsons Water Resources Laboratory, MIT. Speakers, Dr. E. Eric Adams, Research Engineer and Lecturer, MIT and Dr. Dominique N. Brocard, Research Engineer, Alden Research Laboratory. Subject, Combined Use of Physical and Mathematical Modeling in Evaluating Effects of Pumped Storage Operation on a Reservoir. Attendance, 10.

Hydraulics Group Lecture Series — The Hydraulics Group, with cooperation of MIT, is sponsoring a series of six lectures on small scale hydro power, with lecturers from the U.S. Corps of Engineers, industry and a law school.

Structural Group

October 1, 1980 — Evening meeting at the Center for Advanced Engineering Studies, MIT. Speaker, Prof. Stanley T. Rolfe, Department of Civil Engineering, University of Kansas, recipient of this year's T.R. Higgins Award of the American Institute of Steel Construction. Subject, the T.R. Higgins Lecture entitled Fracture and Fatigue Control in Steel Structures. Attendance, 110.

December 3, 1980 — Evening meeting at Barnum Hall, Tufts University. Speaker, Brice Bender, of BVN/STS Consulting Engineers, Indianapolis, Indiana. Subject, Design and Construction of a concrete segmental bridge, Zilwaukee, Michigan. Attendance, 70.

Transportation Group

September 25, 1980 — Dinner meeting at Nick's Restaurant, Boston. Speakers, Justin Radlo, Chief Engineer, Massachusetts Department of Public Works; Martin Weiss, Chief Engineer, Metropolitan District Commission; Richard Dempsey, Director of Construction, Massachusetts Bay Transportation Authority; and David Weiner, Director of Engineering, Massachusetts Port Authority. Subject, The Consultant Selection Process. Attendance, 120.

November 13, 1980 — At Polcari's Restaurant. Speaker, Joseph Fitzpatrick, Executive Office of Energy Resources. Subject, Current Transportation Strategies in Dealing with the Energy Crisis. This was also part of the Section's Monthly Luncheon Series, and an official Section meeting. Attendance, 51.

MONTHLY LUNCHEONS

October 16, 1980 — The first in this year's monthly luncheon series was held at The Great Hall, Quincy Market, Boston. Speaker, Peter J. Gianacakes, President, Metcalf & Eddy. Subject, Consulting Engineering in the 1980's: Changes, Challenges, Opportunties, Attendance, 58.

November 13, 1980 — See report above of luncheon meeting on this date co-sponsored by the Transportation Group.

December 9, 1980 — The second in the current monthly series was held at The Great Hall, Quincy Market. Speaker, Joseph Ward of Converse, Ward, Davis, Dixon, Inc.; Past President, ASCE. Subject, Professional Societies: Are they Headed in the Right Direction? Attendance, 47.

LECTURE SERIES

Refresher Course — The BSCE Section, with cooperation of MIT, is again sponsoring refresher courses for engineers preparing to take examinations for professional registration. The first of the two sets of lectures in the 1980-1981 season began on September 23, 1980, continuing for twelve weekly sessions. The second set will begin on February 12, 1981.

Geotechnical Group and Hydraulic Group Lecture Series — (See above under respective group headings.)

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PROFESSIONAL AND SOCIETY AFFAIRS DIVISION	Paul J. Trudeau
TECHNICAL DIVISION	Rodney Plourde

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