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Adaptability and Cost-Effectiveness of Inlet Control Alternatives for Urban Flood and CSO Control

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Abstract: An effective technology to control urban flooding and combined sewer overflow (CSO) is inlet control. The inlet control technology is usually combined with other technologies such as storage and relief sewers to become a control plan. This combination is developed in such a way that use of the existing system is maximized and construction of new facilities is minimized, using site-specific conditions of the sewer systems including topography, time of concentration, conveyance capacities, land development, available depth and public preference. Such site-specific combinations are a key to the successful development of an inlet control alternative (ICA) which is highly implementable and cost effective. Two real world projects are illustrated and compared for discussion on the adaptability and cost-effectiveness of ICA. In summary, general guidelines for development of ICA are developed.

Key Words: Inlet Control, Inlet Control Alternative, Combined Sewer Overflow, CSO, Urban Flooding

WHY INLET CONTROL

In order to preserve water environment in the U.S.A, the National Combined Sewer Overflow (CSO) Policy was finalized by USEPA on April 11, 1994. The policy requires that affected communities undertake nine minimum controls; remove or relocate CSO's that discharge to sensitive areas such as beaches and water supply sources; evaluate CSO control alternatives ; and develop and eventually implement a long-term CSO control plan. The policy is expected to affect approximately 1,100 communities with combined sewer (CS) systems, including many small communities, that serve a total population of 43,000,000[1]. These communities will need to spend as much as $150 billion in total or approximately $4.6 to $14 million per CSO site to bring these systems into compliance with the new rules[2]. These compliance costs are high and perhaps even prohibitive for the small communities. At the same time, CS communities also suffer from urban flooding problems such as street flooding and basement backup which are caused by the restricted capacities of the existing CS systems. Since residents are often more sensitive to those problems than to CSO's, most communities are forced to include flood mitigation considerations in all possible CSO control plans, thereby increasing implementation costs of the project. As a result, CSO communities eagerly look for cost-effective CSO control plans.

Among many new and conventional CSO control technologies[3], inlet control is known better designed to reduce costs and to provide significant flexibility to design and implementation. The village of Skokie developed a runoff control system using inlet control and could reduce two thirds the cost of a conventional relief sewer system with similar level of protection[4].

Such results were also observed in a number of projects performed in the U.S.A.[5]. In a number of urban flood mitigation projects done by the authors for a number of communities in Illinois and California in the

United States, moreover, alternatives using inlet control (hereafter, called Inlet Control Alternative, ICA) were the least cost solution with total costs up to approximately 50% less than the costs of other mitigation alternatives. However, these papers were successful in introducing just the concept of inlet control and illustrating their own projects and lack of discussing the adaptability of the ICA via site-specific arrangements of complimentary technologies to inlet control tailored based on site-specific conditions of local drainage systems.

The previous works mentioned above successfully introduced the concept of inlet control and demonstrated their applications. It seems however that they lacked of in-depth discussion about how adaptively ICA can be formulated by utilizing site-specific conditions of local drainage systems. This paper discusses with focus on the adaptability of ICA, resulting in reduction of implementation cost, especially in mitigating urban flood and CSO problems. Details and examples are drawn from two ICA projects which were site-specifically developed and applied. Finally, for future applications, this paper summarizes general guidelines on utilizing site-specific conditions for development of an ICA which is cost-effective and highly implementable for different locations.

DEVELOPMENT OF THE INLET CONTROL ALTERNATIVE

ICA consists of two major components: inlet control and a complementary relief technology. The core concept of inlet control is to limit storm runoff entering the existing CS systems (inflows) up to the maximum allowable rate, which is designed to reduce or eliminate CSO's and/or to prevent surcharge, coupled with outflows of combined sewage. During large storms, limiting inflows may also yield excess storm runoff which is prevented from entering the existing systems and which may accumulate or pond on streets. Improper handling of these excess flows can aggravate street and backyard flooding. Therefore, complementary relief component (such as storage or relief sewers) should be included to achieve the desired overall project objectives.

For inlet control function, inlet restrictors can be placed in catch basins and drainage inlets (Figure 1) or at other locations such as inside of sewers and manholes[6]. Restrictors should be adequate to limit flows to the proposed design rates which are established based on sewer capacities and the maximum capacity of the end of pipe treatment and disposal facilities. In some systems, inflow rates may vary, whereas in others very rigid control is required leading to possible use of different types of restrictors. At locations where flow variation is tolerable, an orifice or weir can be used for inflow control. In this case, the inflow rate will vary with the depth of water. At other locations, where greater inflow control is required, vortex type flow restrictors may be used as these show little variation in flows within specified depth ranges[7].

To go with the inlet restrictors, there are a number of complementary components for the excess flows which include Induced Overland Flow (IOF); On-Street Storage; Upstream Distributed/Understreet Storage (UDUS); In-line Storage; and Relief Sewers[5]. To be more effective, they can be used in combinations. The selection of complementary relief components for a project depends to a great extent on site-specific conditions including physical characteristics such as topography and soils; hydraulics in and inadequacy of the existing systems; end-of-pipe treatment facilities; and even public preferences.

For example, an ICA can be developed as follows, using such components (Figure 1): The inlet restrictor in Catch Basin (I) limits storm runoff to a predetermined rate. The excess flows from Catch Basin (I) drain along street gutters to a downstream catch basin and are referred to as Induced Overland Flow (IOF). The IOF concept utilizes existing gutters, with some regrading if necessary to maximize flow conveyance. IOF will increase time of concentration and in consequence be able to shave off peaks of storm runoff. IOF works well at the most upstream blocks. If a berm is built

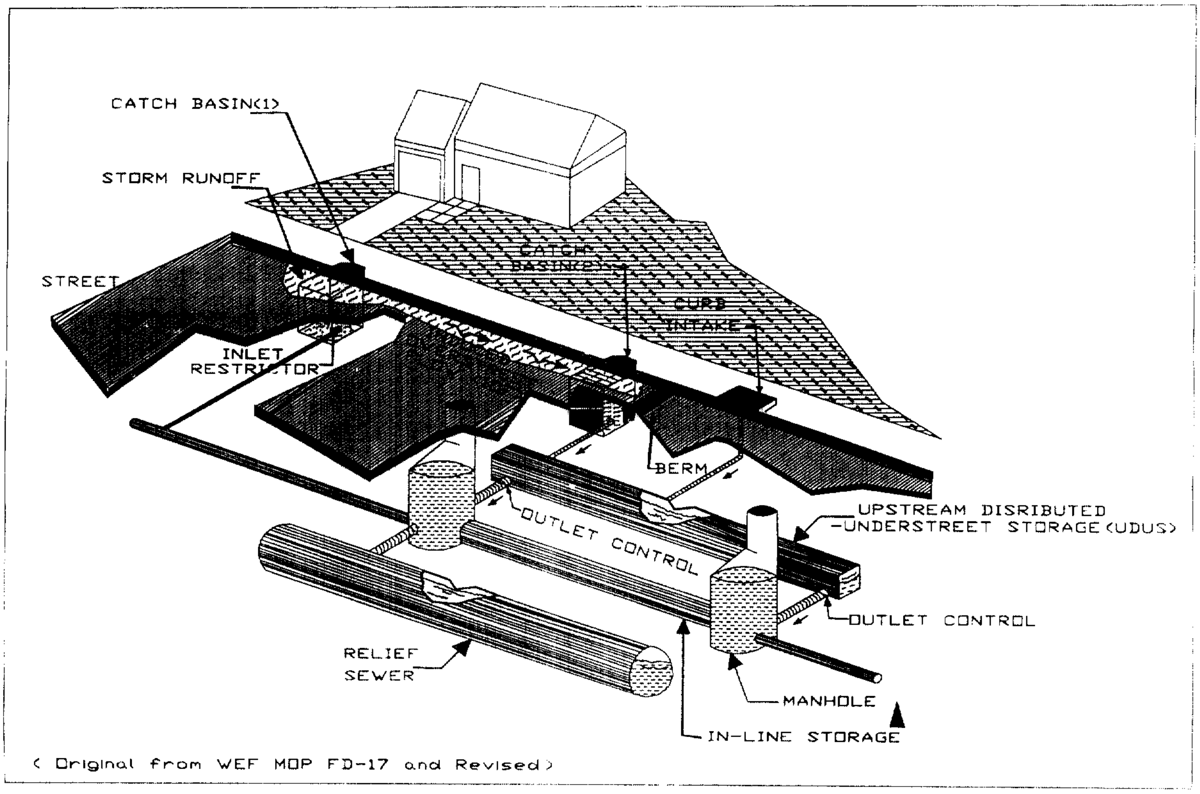

Figure 1. Major components of inlet control alternative.

downstream of Catch Basin (II), excess flows can be stored on the street, On-Street Storage. On-Street Storage volumes at individual locations are small, but this storage will reduce peak flows and if implemented throughout a large watershed, their impact may be significant.

Special storage facilities such as UDUS and in-line storage systems can store flows coming at the unrestricted Catch Basin (II). The objective of UDUS, which can utilize small, shallow boxes, is to utilize available sub-surface space in open areas and along streets for storage. To keep gravity- flow and get more cost-effective, UDUS can be generally placed between ground and invert of existing sewers. Existing sewers can also be upsized to provide in-line storage. Relief sewers can also be provided for the control of the excess flows.

ADAPTABILITY AND COST EFFECTIVENESS OF INLET CONTROL - CASE STUDIES

It is the site-specific selection and arrangement of complementary control components to inlet control, tailored to best fit the individual existing system that keeps the costs of ICA low and competitive and results in a project that is less disruptive. Two projects which utilized ICA's for CSO and urban flood control are studied in this section. These are real- world projects that the authors developed and implemented for the City of Evanston in Illinois and the City of Sacramento in California in the United States. The Evanston case is reviewed in detail to illustrate how adaptable and cost-effective the ICA plans are. On the other hand, the Sacramento case is briefly introduced just to point out important features of its ICA plan which are in contrast with those of the former in utilizing the complimentary components. The two ICA plans are summarized for comparison and eventually developing general guidelines for formulating ICA's which are site-specific and cost-effective.

However, it should be noted that the authors' experiences with other ICA plans not introduced in this paper contributed to developing the guidelines.

CASE A - CITY OF EVANSTON, ILLINOIS, U.S.A

Development and Comparison of Alternatives

The City of Evanston, which is an older, densely developed community immediately north of Chicago, has a CS system that discharges to interceptors and overflows to the North Shore Channel which itself flows to the Chicago River. The CS system serves approximately 1,890 hectares(ha) and a population of about 75,000. The central problem of the Evanston CS system is limited conveyance capacity of sewers, which results in frequent sewer backups. Based on hydrologic and hydraulic analyses conducted with the USEPA SWMM model[8], it was determined that most sewers are only able to convey storm runoff with a 2 month recurrence interval, which is equivalent to approximately 1.65 cm/hour. For larger storms, therefore sewers surcharge causing basement backup and CSO's.

With the help of consultants, the City has developed and evaluated a number of alternatives, based on the following two major technical criteria: (1) basement backup must not occur for up to at least the City's 10 year design rainfall; (2) no street flooding will be allowed during at least the 5 year design storm. Alternatives considered are as follows:

Runoff Control coupled with Storage (RCS): This concept is to reduce inflow to the sewers, by disconnection of downspouts, installation of inlet restrictors, and use of off-line surface/subsurface storage for excess runoff. Because of restrictive sewers, consequent significant storage required throughout the City and little opportunity for such storage, this alternative was rejected in the early stage of development.

Total Sewer Separation (TSS): The total sewer separation alternative includes construction of a separate stormwater system, using the existing system to convey sanitary sewage only. This alternative has been estimated to cost approximately $170,000 per hectare or some $320 million (1990 dollars) for a city-wide program (Table 1). This alternative was rejected because of high cost and because it will result in tremendous disruption to activities in the City. Disruption will be due to the extensive construction required throughout the City.

Combined Sewer Relief (CSR): This alternative involves installation of new combined relief sewers, to increase the capacity of the existing combined sewers such that they are capable of conveying the runoff from the City' 10 year design storm with minimum sewer

Table 1. Comparison of alternatives considered, City of Evanston, Illinois, U.S.A

Alternatives	Estimated Cost($ Million)	Level of Protection	
		To Basement	To Streets
No Action	-	2 month	6 month - 1 year
Runoff Control with Storage (RCS)	infeasible	-	-
Total Sewer Separation(TSS)	320	100 year	10 year
Combined Sewer Relief(CSR)	290	10 year	10 year
ICA With Partial Sewer Separation & IOF(ICPSSI)	125	100 year	5 - 10 year
ICA Without IOF	210	100 year	5 - 10 year

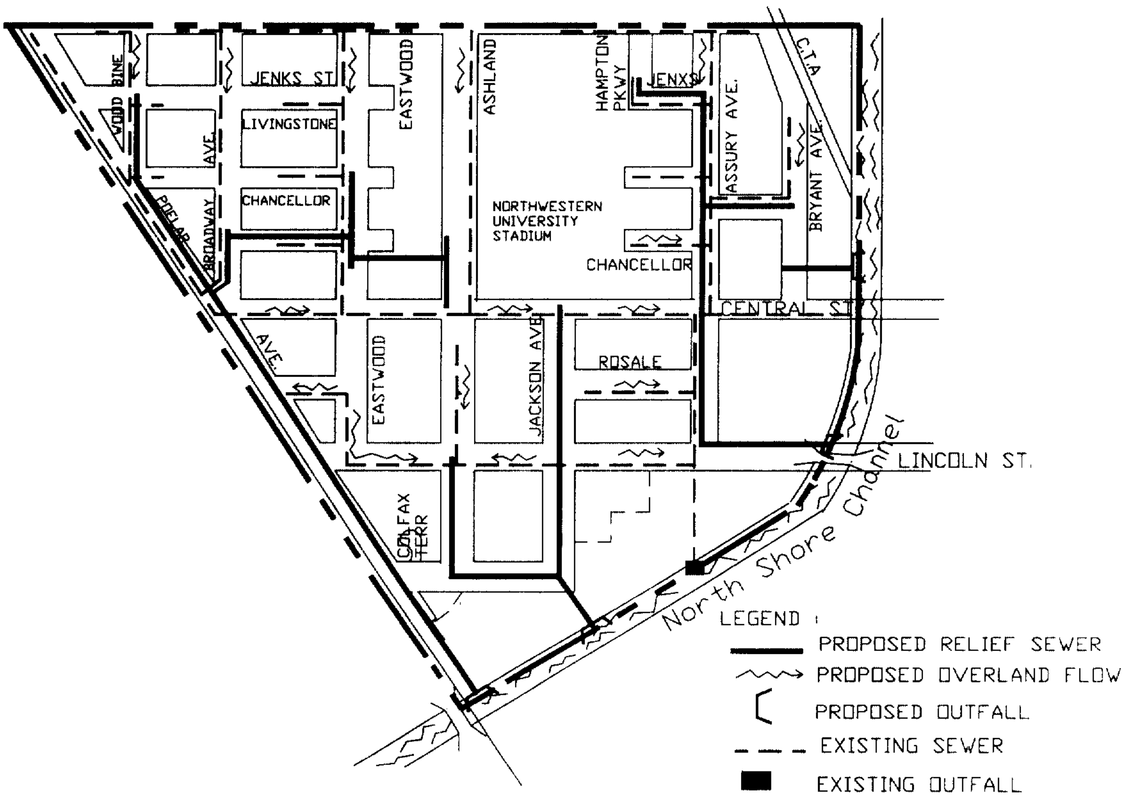

Figure 2. Layout of proposed ICA facilities in Phase I.

surcharging. It was indicated that sewers throughout the City are in need of being replaced or augmented and that the alternative will cost approximately $290 (1990 dollars) million. This alternative is also rejected because of high cost and the level of disruption it will cause to City activities.

Inlet Control with Partial Sewer Separation and IOF (ICPSSI): This ICA includes installation of inlet restrictors in catchbasins and construction of new relief sewers. By allowing IOF along street gutters for up to 2 blocks, this plan reduces the length of new relief sewers required. On streets without new relief sewers, where IOF will take place, the plan limits flow to the gutters and requires that a center lane be free of water at all times. To facilitate IOF, the plan includes street regrading where necessary, with the installation of relief sewers at the downstream ends of the streets with IOF. As shown in Table 1, the estimated costs was $125 million which is the lowest and 39% and 43% of the TSS and CSR alternatives, respectively. The ICPSSI is designed to utilize the specific drainage conditions to a great extent, which results in reducing costs and minimizing disruption while still satisfying the given design criteria. (Just for information, a variation of ICPSSI where new relief sewers extend to most upstreams by not utilizing IOF was developed. The estimated costs was $210 million.)

Adaptability and Cost-effectiveness of the ICPSSI

The ICPSSI is to fully utilize the existing combined sewer capacity to convey sanitary sewage plus a portion of stormwater flows up to the capacity of the most restrictive sewer. For this, inlet flow restrictors are placed in all inlets that are tributary to the existing combined sewer system. Excess flows are to be conveyed along streets as overland flow for at least two blocks and then captured by new relief sewers in the downstream sections of the City through high capacity inlets (Figure 2). The envisioned impact of the placement of the restrictors is to prevent CS surcharge regardless of the intensity of the rainfall event. If the concept works, it would translate into protection against basement backup for the 100+ year rain event.

As explained, major components of the ICPSSI plan include vortex inlet restrictors, IOF, relief sewers and high capacity inlets. Adaptability of those components critical to the development of ICPSSI are as follows:

Vortex Inlet Restrictors: Since the existing sewers in Evanston are so restrictive, the restrictors should be capable of restricting flows to a very low rate to be placed in as many existing catchbasins as possible and in turn to minimize modification. After an intensive testing program with three types of inlet restrictors; the Reg-u-flow vortex restrictor; the Vortechnics Fluidic Amp Hydrobrake and the Geiger Plate, it was decided to use vortex restrictors capable of restricting flows to 4.25 liter per second[9]. This small rate limited the size of the vortex outlet to 10 cm in diameter, which may be easily clogged. For easy maintenance, therefore, the restrictor was made of two portions: an inlet portion with vortex and a sleeve portion. The two portions are designed to separate such that the latter will be fixed into sewers and the former just attached to it. Whenever the vortex portion is clogged, it can be separated out to be put back into after being cleaned.

IOF in Upstream Areas: This was introduced to convey excess flows to the downstream relief sewers, which reduces the lengths of new relief sewers to be installed and in turn the construction costs. Each street was thoroughly surveyed to get information regarding longitudinal slope, width, cross section and eventually to estimate conveyance capacities for IOF.

It was determined after field testing that acceptable IOF could be obtained for one or two blocks if the ground elevation dropped by more than 0.3 m per block. Since the length of a typical upstream block is about 100 m, the longitudinal slope of the streets with IOF is at least 0.003. A width of the streets with triangular-shaped gutters on both sides is 7.3 m, which is typical in the upstream areas of Evanston. A maximum flow in the triangular gutter sections is obtained 0.18 cubic meter per second (cms) at a curb depth of 10.2 cm which allows a center lane free of water[10]. The computer simulation with the SWMM models and the flow monitoring results estimated that a typical upstream block in Evanston discharge 0.085 cms from the 10 year design rainfall, resulting in a total discharge of about 0.17 cms from two upstream blocks. These numbers of 0.18 and 0.17 cms indicated that the upstream streets can accommodate IOF from up to two blocks. This specific street conditions of Evanston enabled the concept of IOF to be a major component of the ICA.

In addition, it was also determined that the major obstacle to IOF under this condition was the street intersections and that IOF could be easily obtained by intersection regrading or by installing swales at street intersections. If a high point exists along gutters, the streets were regraded to facilitate IOF. Since street regrading reduces the total length of relief sewers required and is cheaper than installation of relief sewers, savings are substantial with the citywide application.

On-Street Storage: The concept of on-street storage is to build street berms and store excess flows behind them[4]. This concept was successfully applying to the city of Skokie which is a next door to Evanston. Since the topological conditions of Evanston is very close to those of Skokie, this concept could be considered as another major cost-effective component of the ICA plan. Since Evanston residents found storing water on many streets to be unacceptable, however, this idea was not able to be pursued. A specific lesson we learned from is that public preference must be a factor to consider.

High Capacity Inlets: high capacity inlets are installed at the upstream ends of the new relief sewers, i.e., the downstream ends of the IOF routes. They are designed to intercept all the overland flow from the upstream areas where no relief sewers are placed.

Downstream Relief Sewers: The sewers in Evanston discharge to a tunnel system (i.e., an upstream branch tunnel of the Chicago TARP system). Since the tunnel is deep and large, it provides a free outfall conditions to them. Because of this, utilizing relief sewers turned out cost-effective in the case of Evanston, compared to other options including storage. Enhancement of the existing sewers with improved conveyance capacity to control urban flooding require new end-of-pipe facilities such as pump stations and treatment plants to treat and discharge the additional flows conveyed by the system, which is usually costly. It is utilization of the TARP system that is a major specific condition of Evanston to make relief sewer a cost-reducing complimentary component to inlet control. What was required was only connection structures and dropshafts in order to connect relief sewer to TARP[7]. Construction of those structures is much cheaper than that of other major end-of-pipe facilities.

Another specific condition making relief sewer favorable is that a time of concentration is short. The entire CS basin of 1,890 ha was divided into ten subbasins of which each has its own point of discharge. This makes the time of concentration in a range of 20 to 40 minutes and in turn the length and size of relief sewers required short and small, respectively. Ultimately, construction costs are reduced.

In summary, the site-specific conditions in Evanston which enhances the adaptability and cost-effectiveness of ICA are as follows: use of vortex inlet restrictors capable of handling very low rate, slope of upstream streets to accept IOF, short times of concentration with multiple points of discharge, discharge to the TARP deep tunnel and residents' willingness to accept such innovative concepts. As demonstrated in the test project (discussed below), effective use of such site-specific conditions yielded that the ICA project costs less than 50% of the traditional solutions of either combined sewer relief or complete sewer separation while satisfying all the performance criteria required

Testing the ICPSSI Plan and Evaluation

Since such a combination of the component technologies as for ICPSSI have never been tried (even if they were conceptually and individually introduced earlier), it was necessary to test them before full implementation, especially to convince the city staff and residents of Evanston. The plan was thus phased out to be implemented in ten phases over a twelve year period and the first project phase was designed to test the innovative concepts of ICPSSI and to develop actual cost data. Construction of the Phase I project was initiated in April 1991 and the project was completed in 1993. In 1994 when the facilities had been in operation for approximately one year, data was collected and reviewed for evaluation of the recommended system. The Phase I area of 81 ha was selected because it previously experienced above average urban flooding complaints and the local CS system in the area is isolated from the rest. Thus performance changes could be clearly measured against severe storms after implementation. Figure 2 shows the layout of proposed facilities in the Phase I area.

Extent of Construction and Cost Evaluation: During the test project, 8,380 m of relief sewers ranging from 59 cm (=24 inch) to 274 cm (=108 inch) diameter are placed in the downstream areas. A total 25,000 linear feet of upstream areas where traditional approaches would have required new sewer were converted to function as overland flow areas with inlet restrictors. A total of 88 inlet restrictors were installed. Intersection regrading was required at two locations for overland flow enhancement. The implementation cost of the test project was $5,960,000. The total cost was equivalent to $73,580/ha. The system-wide costs of the recommended ICA is projected $125 million.

Performance Against Street Ponding and Basement Backup: In the upstream IOF portion, the criteria was that one traffic lane would be without ponding during the 10 year storm and that localized ponding could be drained off the streets completely within 30 minutes after the 10 year rain event. Although a 10 year rain event had not occurred since during the test period, an intense storm with approximately a 5 year recurrence interval did occur in August 1993. During that and other storm events, the IOF portion of the project has functioned as planed. There had been positive feedback from project area residents on the impact of the project on street ponding. During the same events, even including the intense August 1993 storm that in the pre-project period would have caused many backups, there had been no reported basement backups from the sewer surcharging. In addition, flow monitoring was also conducted to validate the performance of the system.

The actual post-project measured flows during rainstorms were below the design flow and well within the bounds of protecting the sewer from surcharging.

CASE B - CITY OF SACRAMENTO, CALIFORNIA, U.S.A

Development and Comparison of Alternatives

Sections of the City of Sacramento are served by a CS system. The system with two primary outlets encompasses approximately 2,830 ha. The two outlets locate near the Sacramento river which is the west boundary of the CS system. Thus, its drainage pattern is characterized with a long time of concentration of approximately 3 hours. In addition, the system has limited capacity, which during wet weather results in combined sewage outflows from manholes to streets and CSO's to the Sacramento river several times a year. In order to improve the existing system to minimize the outflows and to reduce the CSO's to a level that is consistent with the National and State of California CSO strategies, the City has vigorously evaluated a number of alternatives in detail[11].

Table 2 summarizes some of them. Major components of the alternatives considered include tunnel, regional storage, treatment facilities, total and partial sewer separation and inlet control.

The ICA of Sacramento is developed to continuously utilize the entire existing CS system to convey both sanitary sewage and a portion of stormwater runoff from all tributary areas. Inlet restrictors limit stormwater inflows into sewers to the capacity of the most restrictive sewer in the system, eliminating outflows and CSO's. To handle a large part of the excess storm flows, it utilizes the UDUS storage placed under streets in most areas, which is a major difference from the

Table 2. Comparison of alternatives considered, City of Sacramento, California, U.S.A

Alternatives[1]	Major Components	Estimated Costs ($Million)	
		1/Yr CSO[2]	5/Yr CSO[3]
Tunnel system	· Tunnels (dia.=4.6m) · Large sewers for consolidation	738	834
Storage only	· Large surface regional storages	850	-
Storage with treatment	· Large surface regional storages · Upsizing treatment capacities	827	-
Conveyance & storage	· Large sewers for conveyance · Large surface regional storages	-	865
Total separation	· New storm drain · Use existing system only for sanitary sewage	936	-
Inlet control (ICA)	· Inlet restrictors · Upstream distributed/understreet storage (UDUS)	-	300

[1] Level of Protection against urban flooding is 10 year.
[2] One occurrence of CSO per year.
[3] Five occurrences of CSO per year.

Evanston ICPSSI plan. Stored flows are gradually released by gravity as conveyance capacities in the existing sewers become available. In addition, depending on site-specific conditions of local sewer systems, the UDUS storage is supplemented with other complimentary components such as relief sewers and regional storage.

Adaptability and Cost-effectiveness of the Sacramento ICA

Major components of the plan include inlet restrictors for limiting inflows, UDUS, two large regional storage systems and relief sewers for excess flows. UDUS is the main facility for handling excess flows. The two regional storage systems are off-line storage facilities located close to large trunk sewers and are designed to reduce UDUS volumes in some basins to make the entire plan more cost-effective. As noticed, use of storage is a main feature of the Sacramento ICA, which is not the case with Evanston. Focusing largely on this feature just for comparison to the Evanston ICPSSI, site-specific arrangements of complimentary components are discussed as follows:

IOF & On-Street Storage : Since the residents are sensitive to water on streets which are considered combined sewage, letting water flow and stored on streets is unacceptable. These options are thus not reviewed in detail.

UDUS : The selection of this storage option is largely due to three site- specific conditions of the Sacramento CS system: long conveyance distances from individual drainage basins to the point of discharge (a time of concentration = approximately 3 hours), the need of end-of-pipe facilities of pumping stations and treatment plants and the relatively large conveyance capacity of the existing CS system.

First, the long distance to convey results in greater cost for options of enhancing conveyance capacity such as use of relief sewers and total separation, since most sewers from the upstream to the point of discharge should be upsized or replaced. Secondly, the water conveyed must be treated before being discharged. In addition, the point of discharge in Sacramento is located on low-lying areas beside the Sacramento river. The conveyed water after treatment must be thus pumped out to the river. As a result, costs for enhancing capacities for treatment and pumping must be counted for, which may escalate total costs of the conveyance options and make them unfavorable. As shown in Table 2, most conveyance alternatives cost more than $800 million.

Last, the relatively large capacity of the existing CS system reduces required volumes to store excess water and in consequence make storage options favorable in cost. Both the SWMM modeling study results and the City records indicated that the existing system is able to handle approximately up to 1.5 year frequency storms without problems. This results in relatively smaller storage volumes required for the 10 year design storm, when compared to the Evanston system which can accommodate only 2 month frequency rainfalls,. The City as developed as Evanston has not, however, much open spaces for storage. Small spaces under streets between inverts of sewers and the ground are selected and utilized for storage. Since the storage volume under a street is limited, it needs to be installed along many streets and thus scattered over the upstream basins.

Regional Storage: In order to effectively utilize available storage potential, the regional storage is introduced. Not all upstream basins have equal potential for UDUS. Specifically, regional storage is to reduce storage requirements of those local basins with limited opportunity for UDUS and is located close to the existing trunk sewers since otherwise extra costs are required to build collection sewers to convey excess water from the local basins to the regional storage.

In summary, effective use of UDUS according to such site-specific conditions as explained above is a key to developing a cost-effective ICA plan for the Sacramento CS system. As shown in Table 2, the ICA plan costs only $300 million which is 30 to 40% of the costs of the other alternatives.

SUMMARY - GENERAL GUIDELINES

Adaptability and cost effectiveness of ICA is largely due to best utilization of site-specific conditions of drainage systems for selection of complimentary components to inlet control, as illustrated in the two case studies. In summary, general guidelines for developing ICA are developed below. The guidelines focus on the selection of complementary components for handling excess flows which is one of most critical factors in developing adaptable and cost-effective ICA's. For this, the two ICA plans introduced above are compared in terms of design parameters and local drainage system characteristics. In addition, the authors' experience with other ICA's that are not discussed in this paper are rendered to make the guidelines more general. The guidelines are as follows:

Area and Time of Concentration: A larger drainage area with a greater time of concentration results in more expensive relief sewer options than storage options. In the Evanston case, a total CS area of 1,890 ha was divided into ten subbasins and each subbasin has a discharge point. On the other hand, the Sacramento CS system serving a total area of 2,830 ha is a single system with two primary outlets. Individual subbasins of Evanston have times of concentration of 20 to 40 minutes and Sacramento, 3 hours. As a result, the Evanston alternative is a relief sewer oriented one whereas storage is a core component of the Sacramento ICA.

Conveyance Capacities of the Existing System: Storage systems prove more effective than relief sewers in systems where conveyance capacity of the existing system is less restrictive. The existing Evanston system has a conveyance capacity that can handle 2 month frequency storms without problems while the existing Sacramento system can accommodate the 1.5 year frequency storm event. Because of the more restricted capacities, the Evanston plan needs greater unit storage, which makes the storage options more expensive. On the other hand, with the Sacramento alternative, the unit storage results in lower costs.

Land Development: The extent of land development also impacts choice of relief option in that storage opportunities are reduced as the level of development increases. The Sacramento CS area can be divided into four quadrants (the NW, NE, SW, and SE subbasins). The NW subbasins includes downtown areas of the City which are the most densely developed. In this subbasin relief sewers proved to be more cost-effective even if storage is favorable in the others.

Available Depth: Upstream Distributed/Understreet Storage (UDUS), which will generally be constructed between ground and invert of existing sewers, is more cost-effective when existing sewers are deep. If the available vertical corridor is large, the UDUS volumes can be accommodated with gravity discharge eliminating pumps and leading to more cost-effective approaches. This also makes this UDUS option more favorable in the colder regions where sewers are constructed below the frost line which is deeper.

Induced Overland Flow (IOF): IOF is generally more acceptable when used in combination with relief sewers than UDUS. However, this is not easily established before a detailed survey of the area is completed and ground slopes are identified together with realistic storage location options.

Regional Storage (large) vs. UDUS (small): Economies of scale make construction of regional storage system cheaper if consolidation conduits are not required to convey flows to the storage system. Otherwise, as is often the case, control alternatives using regional storage may be more expensive than the UDUS options. Site specific evaluation must be done.

Public Preferences: Public perception of flooding affects selection of control options. The Evanston residents more troubled with basement backup are reluctant to store water on streets but are willing to accept streets being used for IOF, provided that water is drained from the street within 30 minutes after the end of storm. In Sacramento, however, storage on streets was not considered acceptable to City residents who have few basements and have been frequently inflicted by street flooding. They thus conceive of any water on the streets as problems. These preferences lead to the development of different approaches in each case.

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