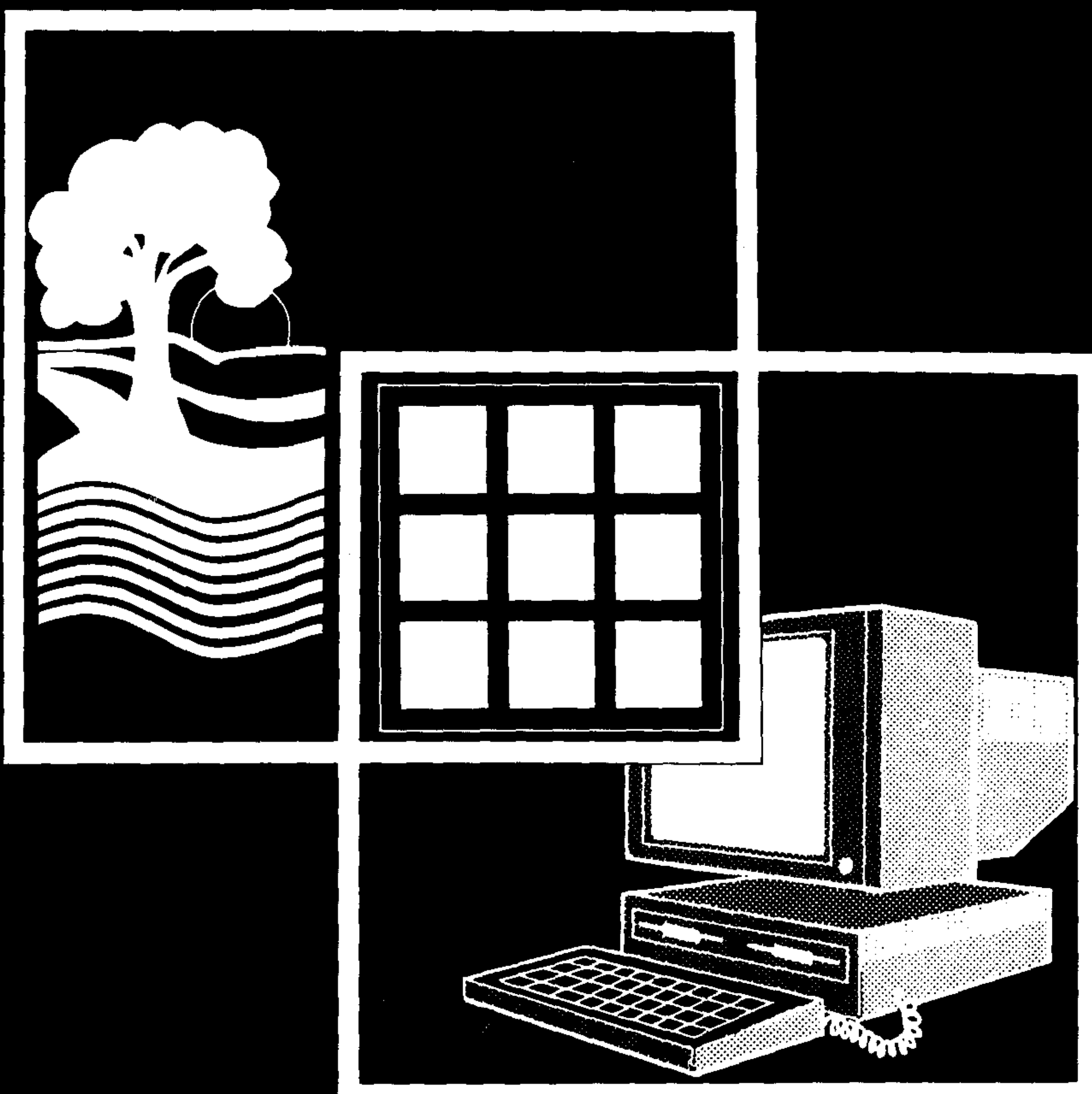
ENVIRONMENTAL SOFTWARE

Volume 10 No. 1 1995 ISSN 0266-9838



ENVIRONMENTAL SOFTWARE

Volume 10 1995

Elsevier Applied Science

ENVIRONMENTAL SOFTWARE

Aims and Scope

The journal publishes research articles, review papers and short communications on recent advances in environmental modelling and software: organization of theories into structure algorithms, mathematical models, model evaluation, software optimization, scope and application of computer programs, etc. Each article should discuss availability and transferability of the presented software. The inclusion of computer listings, when appropriate, is encouraged. Articles on commercially available software will also be published.

While the emphasis of the journal is on new developments and techniques, applications and case studies will also be published when deemed to improve readers' understanding and knowledge in important areas. Authors are encouraged to prepare review papers through a preliminary contact with the Editors.

Relevant aspects of the following are included:

- Environmental physics, chemistry and biology
- Environmental dynamics: meteorology, hydrology, geophysics
- Pollution: air, water, soil, noise, radiation, multi-media
- Environmental accidents, prevention and emergency response
- Global pollution and global changes
- Environmental engineering and technology
- Remote sensing, satellite data and image processing
- Geographic information systems

- Mathematical, numerical and statistical modelling
- Model performance evaluation
- Data assimilation and filtering

- Software performance optimization
- Vectorization and parallelization of computer codes
- Multi-grid techniques
- Data visualization and animation, multi-media presentations

ELSEVIER

Environmental Software, Vol. 10, No. 1, pp. 1–9, 1995

0266-9838/95 $9.50+0.00

0266-9838(95)00001-1

Using a cost-to-benefit index (CBI) to set priorities for a city master plan drainage system

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(Received 15 February 1994; accepted 16 January 1995)

ABSTRACT

A computer program is developed that aids in prioritizing the importance of future flood control projects within a city master plan of drainage. The Cost-to-Benefit Index (CBI) method described is a graphical means to communicate important information regarding master planning prioritization of flood control system elements targeted for improvement. Using the CBI approach, decisions can be made regarding which system elements may be ranked as having the highest priority in construction scheduling. Additionally, CBI maps aid in communicating to the public the relative importance of any particular element with respect to the overall master plan.

Key Words: Cost-to-Benefit Index, Master Plan of Drainage, Prioritization

Software Availability

Name of Software:

CBI (Cost to Benefit Index Method)

Developer and Contact Address:

Ted Hromadka and
Chung-Cheng Yen

Boyle Engineering Corporation
1501 Quail Street
Newport Beach, CA 92658

Year First Available: 1994

Hardware Required: IBM or Compatible personal computer

Software Required: MS DOS, DBASE Application of Boyle Facility Management System, and Rational Method Computer System (RATCAD) by Advanced Engineering Software

Program Language: FORTRAN 77

Program Size: 140 KB for executible

Availability and Cost:

Distributed by Advanced Engineering Software (AES), Riverside, California, USA. Price $495.00 (US).

INTRODUCTION

In urbanized areas, where development is essentially uniform with respect to drainage to streets, the flood damage potential may be related to the flood depth in the adjacent street section. For a particular street geometric cross-section, a given flood depth may be correlated to different levels of flood damage potential depending upon the development of contiguous land areas. Additionally, the greater the flood depth in the street section, the higher the flood damage potential to the adjacent property. The flood damage potential can be estimated if relationships between the street section flood depth and the various associated land use designations exist. By a Master Plan of Drainage study of the flood control system, the cost of reducing the potential flood damage (according to local agency standards) can be estimated. Details regarding development of such Master Plans of Drainage, linkage to geographic information systems, and other methods for prioritization of flood control system elements can be found in Hromadka et al, (1993).

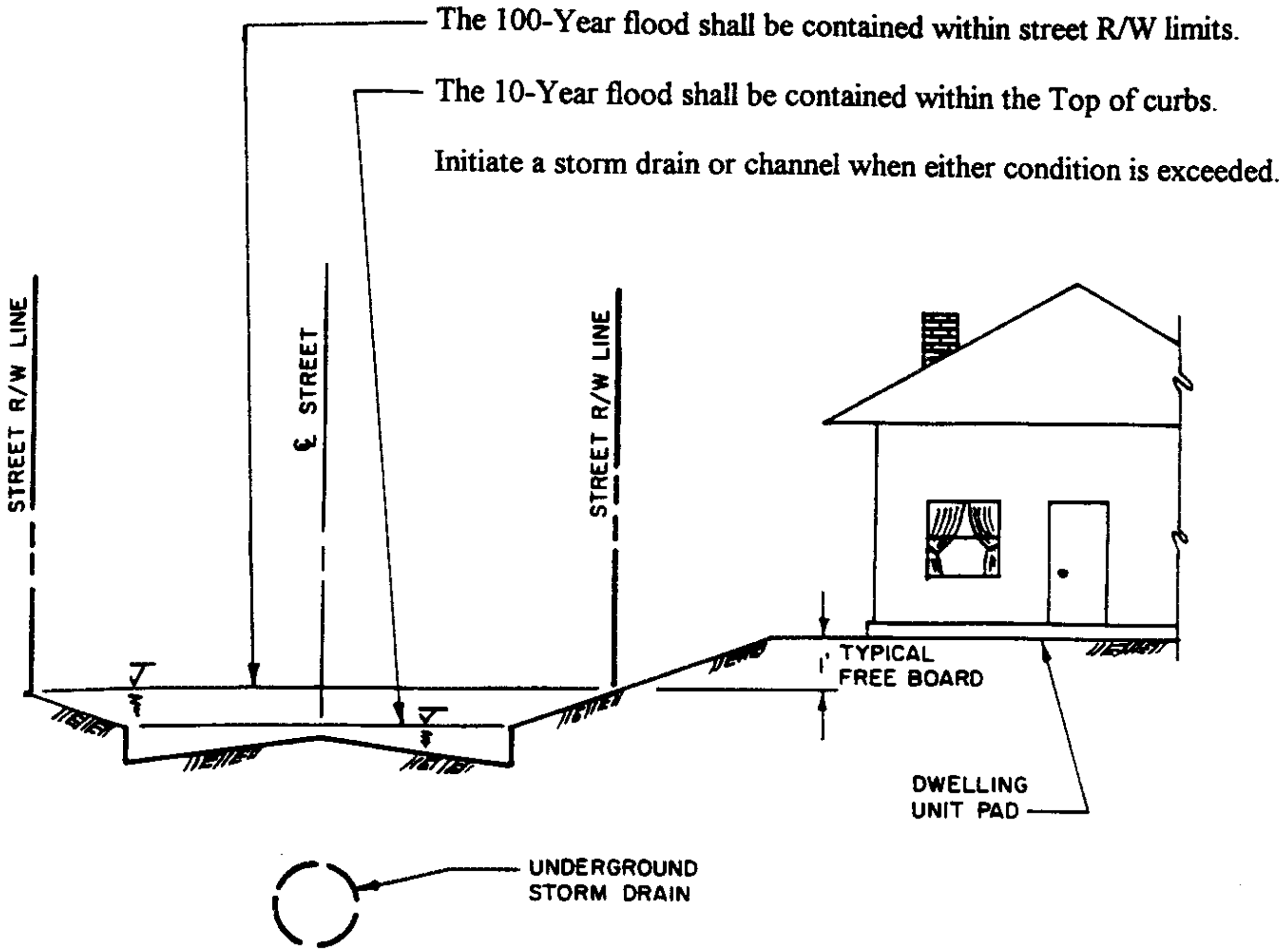
Dividing the flood damage potential by the cost of upgrading the appropriate flood control system determines a cost-to-benefit index. A higher cost-to-benefit index value indicates that more benefits can be achieved with the associated investment to upgrade the local flood control system. A prioritization of the master plan of drainage system elements can then be developed based upon a ranking of each master plan system element's cost-to-benefit index. A computer model, called "CBI", was prepared to perform the above described tasks. The CBI approach enables a prioritization of master plan system improvements in order to increase utilization of agency funds to remove system deficiencies. By graphically displaying CBI values, prioritization becomes more visually apparent in that systems demonstrating a more efficient use of agency funds (in removing deficiencies) are graphically identified. The CBI mapping approach draws upon well-known experience in plotting other phenomenon, such as earthquakes, as geometric symbols (such as hexagons) whose diameters reflect, for example, the magnitude of the earthquake and the symbol's centroid is located at the earthquake's epicenter. In the CBI graphical display, the geometric symbol's diameter reflects the CBI magnitude and the symbol's centroid is located at the mid-point of a drainage element at which the CBI value applies.

COUPLED STREET AND STORM DRAIN SYSTEM DEFICIENCY CATEGORIES

A typical drainage system elemen from master plan of drainage consists o the combined capacity of a particular stree section, with an underlying pipe or bo flood control system. For evaluatio purposes, three deficiency classifications o coupled street and storm drain models ar used in the CBI analysis; these categorie reflect the varying storm-flow carryin capacity of each street section used in th study. The categories are:

<u>Deficiency Category I (Roadwa Sumps):</u> For street grades equal t zero, deficiencies typically correlate t the volume of runoff ponded at th particular vicinity, for the selecte design storm event.

<u>Deficiency Category II (Arteri Streets):</u> For any street with maximum allowable design flo depth less than or equal to the stre top-of-curb. A typical case is when is required to maintain one or mo



Notes:

Protection criteria shown are District typical minimum requirements. Special conditions, or other authorities may require stricter controls; i.e.; for reasons of traffic or pedestrian safety, maintenance problems behind curbs, etc., lower maximum depths of flow in streets may be required.

(Reference: Riverside County Flood Control And Water Conservation District, Hydrology Manual, 1978.)

FIGURE 1. TYPICAL DEFICIENCY CATEGORY III

lanes of traffic flood-free during a design storm event. Generally, such a criterion applies to major or arterial streets.

Deficiency Category III (Residential Streets): For any street with a maximum allowable design flow depth greater than or equal to top-of-curb, for the selected design storm event. Generally, residential streets fit into this category (see Figure 1).

DEFINITION OF FLOOD DAMAGE POTENTIAL

A set of flood damage potential curves (see Figure 2) are needed for each deficiency category. The flood damage potential curves define a street flow depth versus flood damage potential relationship, for various land use designations. Generally, flood damage of habitable structures can be estimated to occur at a specific depth of flow above

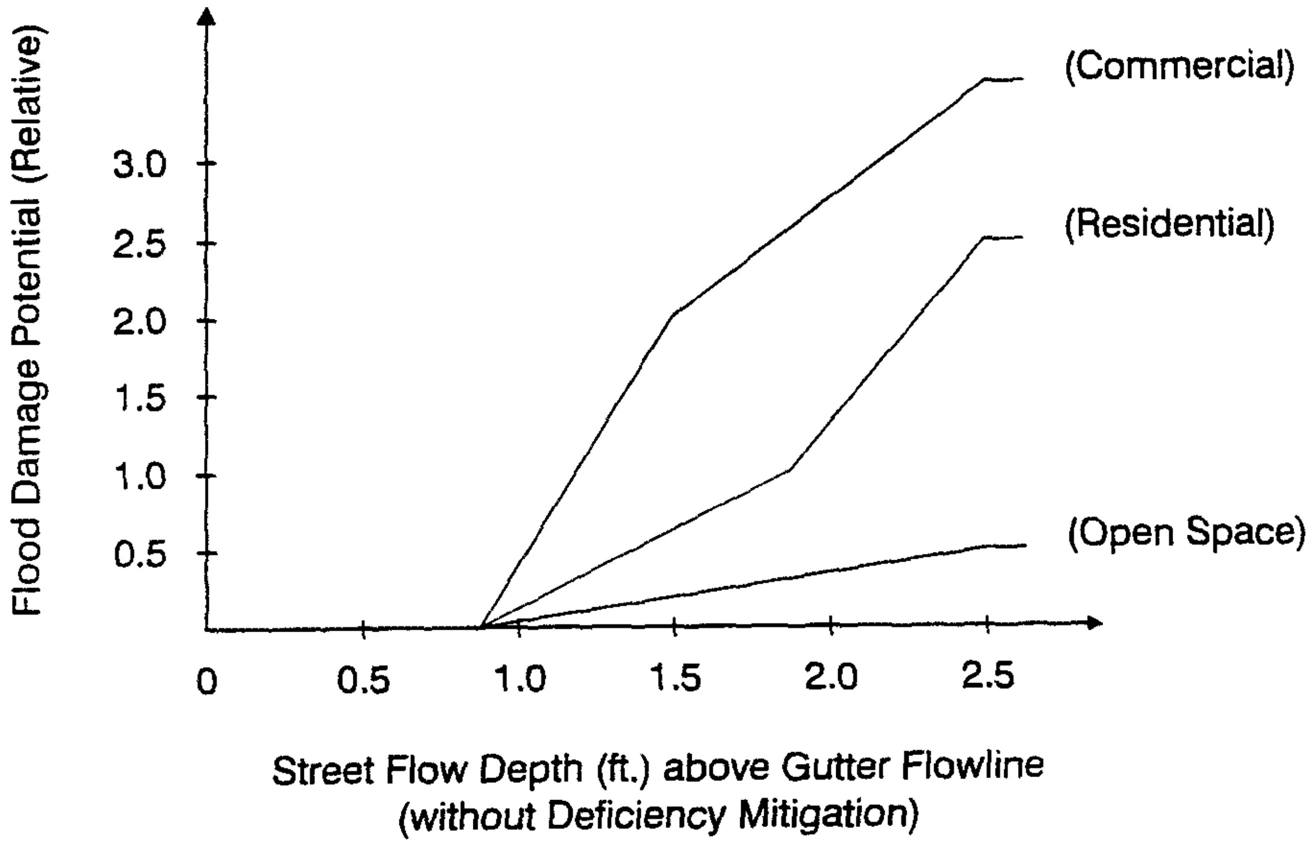


FIGURE 2. FLOOD DAMAGE VS. STREET FLOW DEPTH

street top-of-curb (such as a one-foot depth above top-of-curb). At this depth, it is assumed that flood flows are damaging property, and potential damage costs can be computed. For greater depths, higher potential damage values may be assigned. For lesser flow depths, where property damage might not occur, a "penalty" may be assigned that generalizes "damage" due to traffic obstruction, risks to emergency services, among other factors. For example, assuming a ten-percent damage potential, for flow depths 0.5 foot above top-of-curb, may be appropriate. As shown in Figure 2, a continuous damage potential versus flood depth relationship is defined. Although potential damage costs may be computed, they are not necessary in the CBI approach as a subsequent normalization of CBI values is used for prioritization purposes. Consequently, the key to the CBI analysis is a relative flood damage potential definition, with respect to both flood depth in the street and land use designation. The ranking of maste plan system elements with respect to CB values is analogous to the mor standardized cost-to-benefit ratio approac such as is used by the U.S. Army Corps c Engineers (Sheaffer et al., 1982).

CBI MODEL INTERFACE WITH OTHE COMPUTER PROGRAMS

The CBI model (see Figure 3) wa written to interface with the Advance Engineering Software (AES) RATCAD/G hydrology model (Hromadka, 1987a, Hromadka et al, 1987) and the Boy Facility Management System (BFMS) da base application (Boyle, 1994). Tl RATCAD program provides the peak flo rates for each coupled street/storm dra element (i.e., link) within the catchme master plan. The BFMS utilizes t RATCAD peak flow rates to identify t deficient reaches within the enti drainage system and provi

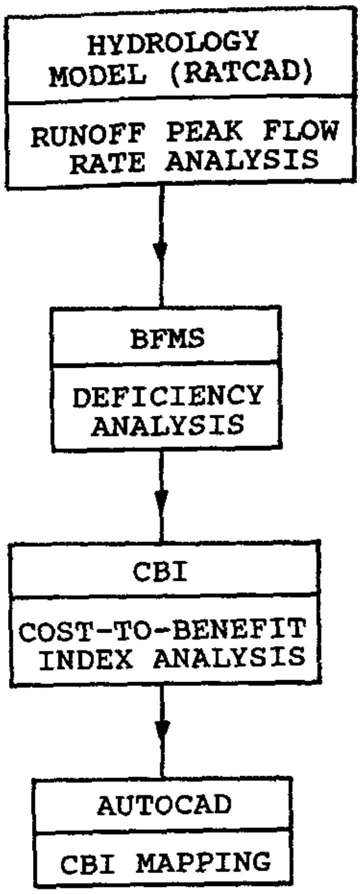


FIGURE 3. CBI MODEL INTERFACES WITH OTHER PROGRAMS

improvement options based upon the Agency's standards (for example see the County of Los Angeles Hydrology Manual, 1992). Next, a data base file is created by the BFMS for use with the CBI analysis. After determining the cost-to-benefit index for each element in the entire master plan of drainage, a graphics data base file is created for use in preparing CBI mapping.

COST-TO-BENEFIT INDEX (CBI) PROCEDURE

A flow chart of the cost-to-benefit index (CBI) analysis procedure is depicted in Figure 4. Descriptions of the specific procedures shown in Figure 4 are given below.

<u>Determine Element Deficiency Category</u>

The element deficiency category under study can be determined by using the master plan system element's street cross-section information (contained in the data base) and the element's deficiency category definitions as described previously.

<u>Determine Existing Condition Street Flow Depth</u>

Manning's equation for normal depth flow is used to determine the existing condition (i.e., no new drainage improvements) street flow depth, for each system element, by using the peak flow rate, existing storm drain capacity, and street cross-section information. The street flow homographs from the Los Angeles County Flood Control District Design Manual (Hydraulic) can be used to estimate the normal street flow depth. This flow depth corresponds to the condition where storm drain improvements have not yet been made to remove deficiencies, for the selected design storm event.

<u>Determine Flood Damage Potential</u>

After determining the existing condition street flow depth, the flood damage potential is determined from the flood damage potential curves, based upon the proper street deficiency category and the adjacent land use. If the system element under study contains mixed land uses, the flood damage potential for each land use is calculated, and an area-averaged value is used to represent a composite flood damage potential, for the selected design storm event.

<u>Determine Improvement Costs to Remove Deficiencies</u>

Improvement costs, for each deficient street/storm drain reach, is provided by the master plan of drainage results. These costs reflect the cost to remove deficiencies, consistent with agency standards, for the selected design storm event.

<u>Calculate the Cost-to-Benefit Index (CBI) Value</u>

The cost-to-benefit index is calculated

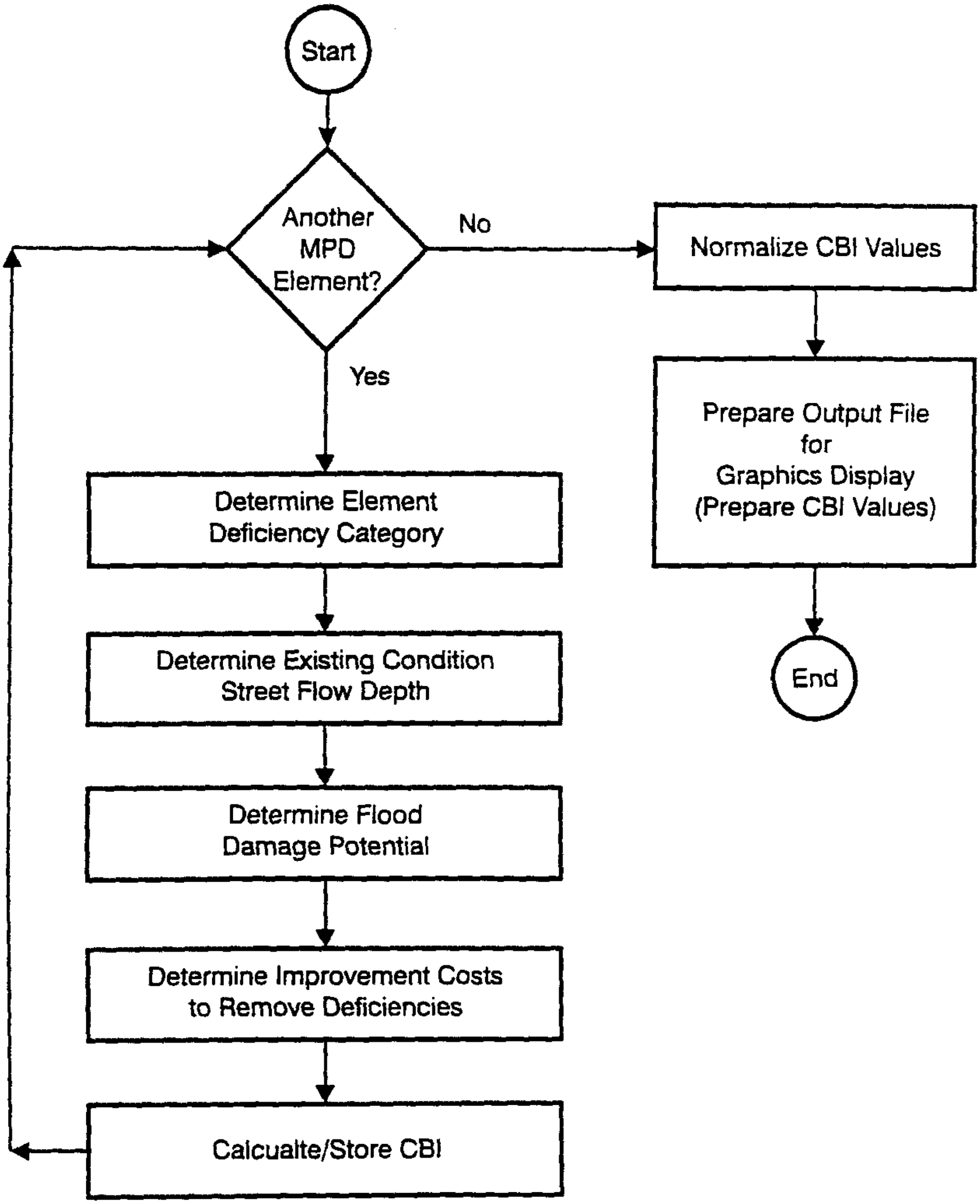


FIGURE 4. FLOW CHART OF CBI ANALYSIS PROCEDURE

as follows:

CBI (cost-to-benefit index)

= (Flood Damage Potential)/ (Improvement Costs) (1)

Store CBI Values

The CBI value computed by Equation (1) for each street/storm drain reach is then stored in the computer data base with respect to its deficiency category.

Normalize CBI Values

After completion of the CBI analysis for the entire master plan of drainage, statistical calculations of mean value and standard deviation, for each of the three different deficiency categories, are prepared. By dividing the entire CBI range of values by the maximum CBI value (based upon the deficiency category), normalized CBI values are computed with a range of zero to one. These normalized values are written to another data file for subsequent graphics display purposes. Note that a CBI value of zero corresponds to a zero deficiency pursuant to Agency standards and the selected designed storm event. A CBI value of 1. corresponds to the maximum value of the CBI per Equation (1).

CBI GRAPHICS DISPLAY

A graphical representation of the CBI values can then be prepared by plotting graphics symbols onto the storm drain system maps. The composite CBI map will have three different symbols to represent each deficiency category:

Deficiency Category I: triangle (sumps)

Deficiency Category II: hexagon (local streets)

Deficiency Category III: circle (arterial streets)

The standard unit plot (e.g., see map legend) for each symbol represents the mean CBI value, for each respective deficiency category. From the map, the larger the symbol, the greater the CBI value, proportional to the symbol diameter. In other words, the larger the symbol, the higher the ranking of the prioritization within the associated deficiency class.

APPLICATION

The City of Santa Ana encompasses approximately 29 square miles and is located in Orange County, California. The CBI analysis was applied to the City's latest master plan of drainage system to provide prioritization for the recommended improvements. A graphical map that displays the CBI analysis results has been compiled. Figure 5 depicts the legend used to represent different deficiency categories. The diameter of each symbol represents the mean CBI value for each deficiency category. In this application, the mean CBI values are 0.22, 0.29, and 0.26 for Deficiency Category I (Roadway Sumps), Deficiency Category II (Arterial Streets), and Deficiency Category III (Residential Streets), respectively.

Part of the City's CBI graphical display is shown in Figures 5. Systems A, B and C, which are also depicted on Figure 5, illustrate a portion of all the City's CBI graphical display for each deficiency category. These systems are examples of how CBI symbols are used to prioritize clusters of deficiencies. Prioritization for the City's MPD system is then determined by ranking the clusters from largest to smallest for each deficiency category. Prioritization for the City of Santa Ana master plan of drainage system (Boyle Engineering Corporation, 1994) can be determined by ranking from the largest to the smallest cluster size of symbols for each deficiency category.

The City identified the need to establish a prioritized list of the top 50 projects for implementation. Based upon the Cost-Benefit Index values and engineering evaluation procedure (described below), the top 50 projects were identified.

A descending data base sort of the CBI values for all deficient links within the system was prepared. Based upon this listing, the top 50 projects were conceptualized by identifying sites with the highest CBI value, along with all deficient downstream reaches (regardless of index value) which would necessarily require relief/upgrade before the localized improvement would be effective.

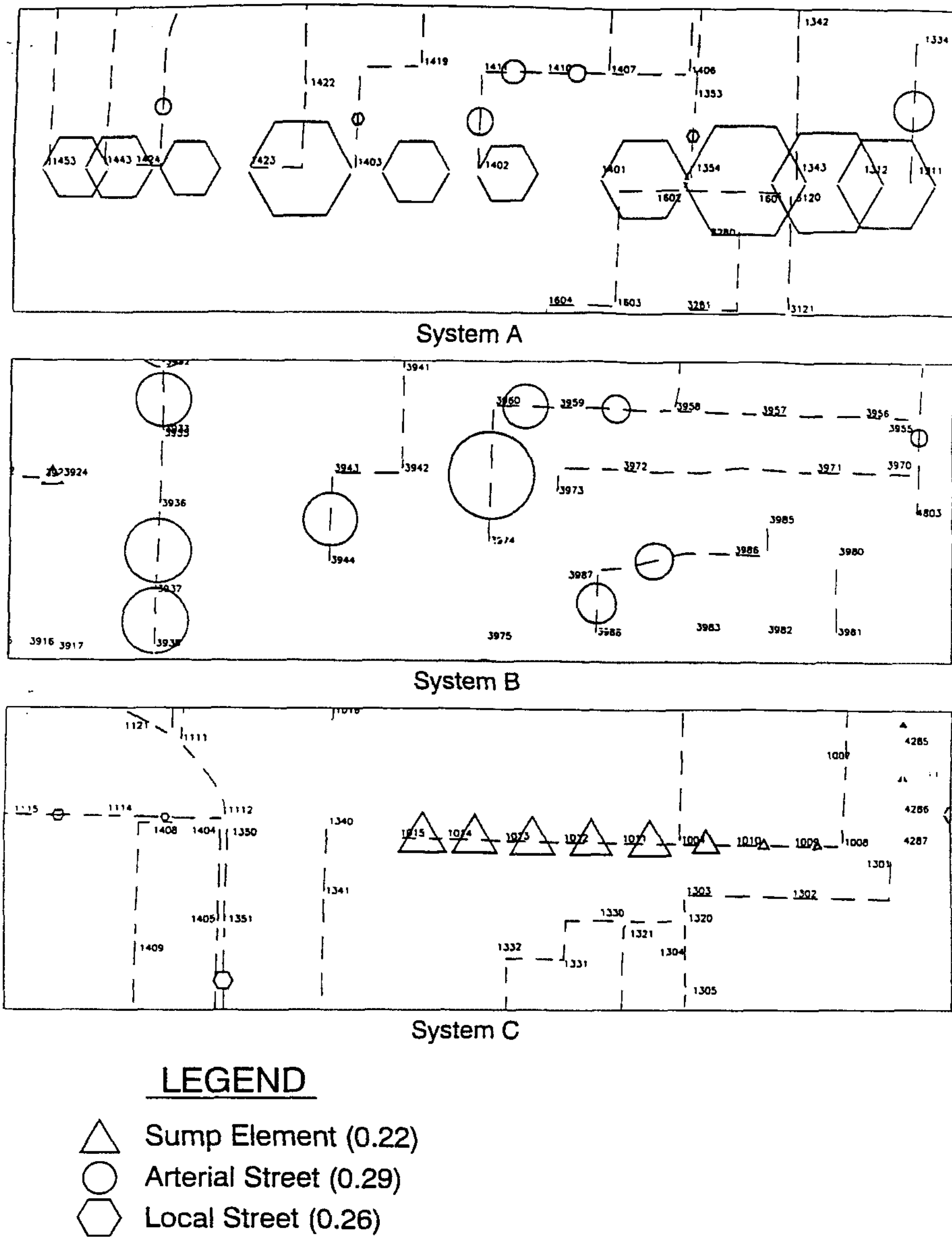


FIGURE 5. CBI INDEX, LEGEND AND GRAPHICAL DISPLAY

Immediately contiguous upstream deficient reaches were also evaluated for relative CBI values as well as logical extensions within same streets (to minimize future multiple neighborhood construction impacts) and were often included in the conceptualized projects. The data base was continually and systematically updated to identify links to be improved until 50 separate projects were developed.

CONCLUSIONS

The Cost-to-Benefit Index (CBI) method is a graphical means to communicate important information regarding master planning prioritization of flood control system elements targeted for improvement. Using the CBI approach, decisions can be made regarding which system reach or system elements may be ranked as having the highest priority in scheduling construction. Additionally, a CBI map aids in communicating to the public the relative importance of any particular element with respect to the overall master plan.

REFERENCES

1. Sheaffer, J.R., Wright, K.R., Taggart, W.C., and Wright, R.M., Urban Storm Drainage Management, Dekker, 1982.
2. Hromadka II, T.V., A Computerized Master Plan of Drainage I: Development, Microsoftware for Engineers, Vol. 3, No. 1, pg. 22-27, 1987.
3. Hromadka II, T.V., A Computerized Master Plan of Drainage II: Software System, Microsoftware for Engineers, Vol. 3, No. 1, pg. 28-43, 1987.
4. Hromadka II, T.V., McCuen, R.H., and Yen, C.C., Computational Hydrology in Flood Control Design and Planning, Lighthouse Publications, 1987.
5. Boyle Engineering Corporation, City of Santa Ana Master Plan of Drainage Final Report, 1994.
6. Riverside County Flood Control and Water Conservation District, Hydrology Manual, 1978.
7. Hydrology Manual, County of Los Angeles, California, 1992 Update.
8. Design Manual, County of Los Angeles Flood Control District, California, 1988.
9. Hromadka II, T.V., McCuen, R.H., DeVries, J.J., and Durbin, T.J., Computer Methods in Environmental and Water Resrouces Engineering, Lighthouse Publications, 503 pgs, 1993.