

STORMWATER QUALITY DATA COLLECTION PROGRAM IN DENVER

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INTRODUCTION

The rainfall-runoff-quality process is a complex one and is not well understood. While Section 208 of P.L. 92-500 mandated that stormwater quality problems be addressed, the legislation did not provide funds for data collection required to understand the problem. Although water quality planning on an areawide basis is laudable and desirable, stormwater quality planning is not practical at this point in time from the standpoint of the state-of-the-art.

In 1975, a Section 208 planning effort was initiated by the Denver Regional Council of Governments (DRCOG) for the Denver area. Denver, being no exception, lacked the data needed to address stormwater quality problems. Although an adequate data base could not be established in time to aid the initial 208 planning for stormwater quality management, a modest three-year stormwater quality/quantity data collection and interpretation effort was initiated in 1975. The program was not expected to provide all the data needed to comprehend urban runoff phenomena and the resulting water quality problems, but it was hoped it would provide some insight about urban runoff quality in the Denver area.

Data collection and interpretation was a joint effort between the U.S. Geological Survey, the Urban Drainage and Flood Control District, the Denver Water Board, and the Denver Regional Council of Governments. The program's cost of \$193,000 was shared by each participant with the USGS providing 50% of the total. Data was collected through June 1977 and, at this time, is being interpreted. A basic data report is being readied by the USGS for release in 1978.

The authors wish to acknowledge the high professional and scientific caliber of the USGS staff associated with this program. The USGS effort was directed by Mr. Sherman Ellis and is being assisted in the data interpretation by Mr. Bill Alley.

DATA COLLECTION PROGRAM

Water quality sampling stations were established in the Denver area by the USGS in the Summer of 1975 at the three locations shown on Figure 1. Each station was equipped with an automatic sampler, flow measuring devices, and rainfall gages connected to a single digital recorder. Rainfall, runoff, and quality data was collected simultaneously whenever a pre-set minimum gage height was exceeded. Data was collected at intervals ranging from 2 to 60 minutes. Up to 24 water quality samples could be taken before replacement of the sampling bottles was needed. This, however, has resulted in data loss whenever two rainfall events occurred within 24 hours or over a weekend. Although precipitation data was not collected during the winter months, runoff data was.

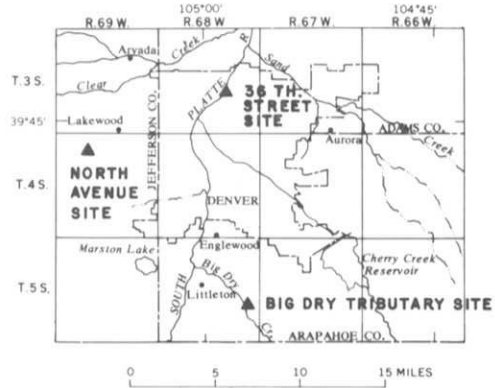


FIGURE 1. LOCATIONS OF URBAN-RUNOFF QUALITY MONITORING SITES

The characteristics of the three catchments are summarized in Table 1. The 36th Street Catchment, Figure 2, is adjacent to the central business district within the City of Denver. It represents some of the more intensely developed portions of the city. The Big Dry Creek Tributary Catchment, Figure 3, is located 10 miles south of the 36th Street station and represents a suburban single-family residential neighborhood. The North Avenue Catchment, Figure 4, is located 10 miles west of downtown Denver and was intended to represent new high density residential and commercial land use.

Table 1
Catchment and Instrument Data

Item	36th St.	Big Dry Creek Trib.	North Ave.
Area Sq. Mi.	3.5	0.95	0.12
% Open/Park	6	25	53
% Commercial	20	—	17
% Medium Density Res.	37	75	—
% High Density Res.	37	—	30
% Impervious	70	30	30
Gutter Miles	113	38	3.7
Sewering	Full	Partial	Partial
No. of Rain Gages	3	3	1

Unfortunately, the early portion of this effort was set up to gather data only. Data evaluation, analysis and interpretation were not performed as the data became available. Had this been done, some of the equipment and procedural problems which were later encountered may have been recognized earlier. Early data interpretation is one of the more important tasks in data collection because it reveals early where data collection is not accomplishing its intended tasks. Computer modeling during data collection could be used as one of the data interpretation techniques by providing valuable feedback to the collection effort. However, use of computer models

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for this purpose could mislead data collection into verifying the assumptions built into the model rather than revealing new information and should be used with caution.

Continuous samples were obtained for approximately 10 events at the 36th Street station and for 8 events each at the Big Dry Creek Tributary and North Avenue stations. Additional quality data was obtained through the use of grab samples. A complete list of the constituents measured is presented in Table 2; however, not all constituents were successfully measured for all of the recorded events.

Table 2
Constituents Measured

Chloride	NO ₂	Temperature
Arsenic	NO ₃	Discharge
Copper	TKN	Specific Conductance
Lead	Dissolved Phosphorus	BOD ₅
Zinc	Ortho Phosphate	pH
Residue - 180° C	DOC	Non-Filterable Residue
Fecal Coliforms	SOC	Total Nitrogen
Streptococci	Sodium	Ammonia

Early in the program, an attempt was made to obtain BOD₅ data. It was discontinued when the presence of lead, copper, and iron in large concentrations was discovered. The presence of these trace metals clouds the meaning of BOD₅ data, and it was not clear how reliably the results could be used in the water quality evaluation.

PRELIMINARY FINDINGS

A limited amount of preliminary interpretation of the data was performed by the authors. At this time, the USGS has completed a more detailed interpretation of the trace metal data. Some of the USGS findings will be

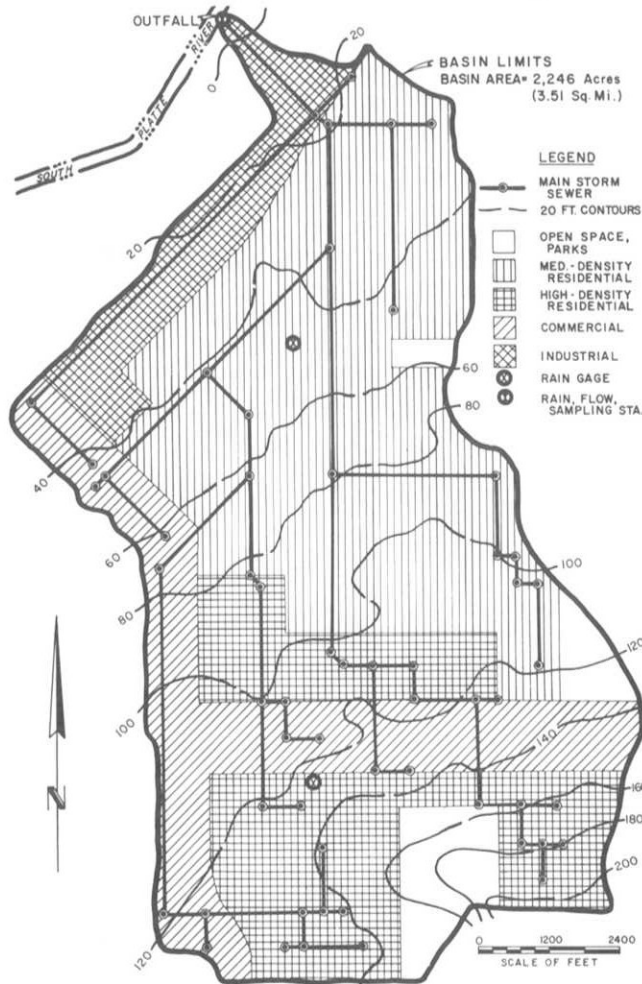


FIG. 2 - 36 TH. STREET DRAINAGE STATION CATCHMENT

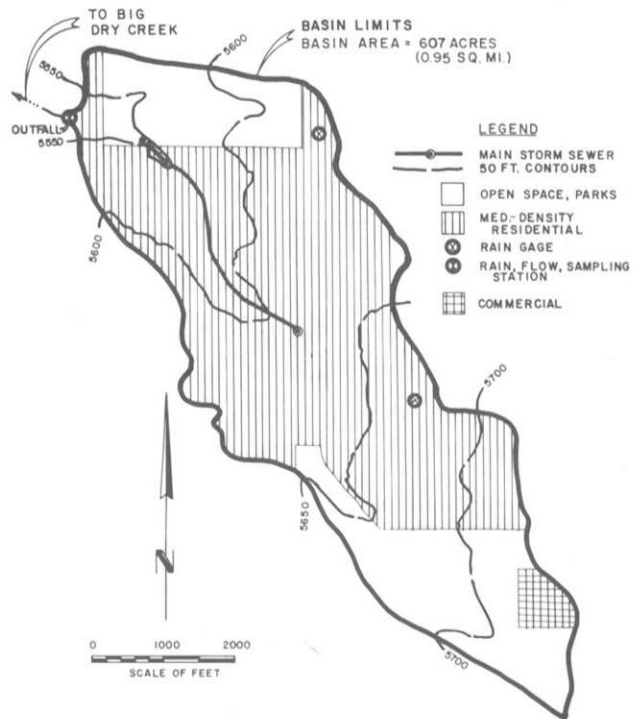


FIG. 3 - BIG DRY CREEK TRIBUTARY STATION CATCHMENT

presented in July at the International Symposium on Urban Stormwater Management (1).

A summary of the constituent loadings analyzed to date is presented in Tables 3 and 4 for 11 of the measured events. The loadings vary considerably between storms, and no clear trend was found between loadings and the number of days preceding the last storm. Also, no significant first flush effect was observed. However, the effects of street salting in snow removal are clearly indicated by the chloride loadings for the 3/6/76 and 3/29/76 events.

Table 3
Typical Sampled Organic, Nutrient, and Chloride Loadings in Pounds Per Acre Per Inch of Runoff

Event Date	DOC (2)	SOC (3)	TKN(n) (4)	NO ₂ + NO ₃ (n) (5)	cl (6)	Runoff Inches (7)
a) 36th Street						
3/6/76	N/A	N/A	.83	.16	135	.043
3/26/76	4.6	.50	.73	.24	4.2	.009
4/29/76	2.3	.93	.79	.13	1.2	.05
10/6/76	7.6	6.6	.82	.03	2.3	.07
2/14/77	9.4	4.0	1.0	.20	N/A	.011
b) Big Dry Creek Tributary						
3/29/76	2.2	N/A	.29	.07	1.5	.0003
4/13/77	6.6	4.4	.77	.62	2.8	.004
6/11/77	2.4	4.2	.44	.15	.84	.11
c) North Avenue						
3/29/76	2.9	2.2	.73	.07	35	.003
4/12/77	N/A	N/A	.53	.13	N/A	.07
4/19/77	1.9	3.7	.32	.12	2.1	.15

What do the loading rates in Tables 3 and 4 tell about the quality of urban runoff in the Denver area? It is apparent that for some of the constituents, the loading rates vary more between different events at one site than between the three sites. The loading rates appear to have greatest consistency for Total Kjeldhal Nitrogen (TKN) and for most of the heavy metals. We believe this data is not sufficient to draw firm conclusions. However, an "order of magnitude" type of total load estimates should

Table 4
Sampled Trace Metal Loadings In Pounds Per Acre
Per Inch of Runoff (Ref. 1)

Event Date (1)	Arsenic (2)	Copper (3)	Lead (4)	Zinc (5)	Iron (6)
2/14/77	.0029	a) 36th Street .028	.20	.15	1.8
4/18/77	.0012	b) Big Dry Creek Tributary .0045	.061	.033	N/A
6/11/77	.0016	.0097	.11	.050	2.3
4/12/77	.0040	c) North Avenue .013	.096	.098	7.6
4/19/77	.0021	.0080	.063	.056	N/A

provide some insight into the urban runoff quality.

Estimates of the total pollutant loads were made for the three sites for the sampling period between April 1 and October 31, 1976. Table 5 contains not only the estimated total loadings, but also the total pollutant loadings that would originate in a secondary wastewater effluent from each of the three sites. Comparing the urban constituent loads to secondary effluent loads, it becomes apparent that urban runoff produces only a fraction of the total organic and nutrient loads. On the other hand, urban runoff accounts for most of the lead and an equivalent amount of zinc.

Rainfall data was collected through the use of multiple gages at two of the catchments. As a result, another area of complexity was confirmed. Large variations in rainfall were measured between the three gages at the 36th Street and Big Dry Tributary catchments, indicating that rainstorms in the Denver area are very localized. It now is evident that metro areawide modelling of urban runoff will require the use of multiple rain gage data and/or thorough understanding of spatial rainfall distribution. The problem may be too complex for pure deterministic modelling and may require a stochastic approach.

Table 5
Preliminary Comparison of Loadings
Coming From Runoff and Secondary Effluent
Between April 1 and October 31, 1977*

Constituent	36th St.	Big Dry Cr. Trib.	North Ave.
DOC + SOC	60,000 lbs. 300,000 lbs.	6,000 lbs. 24,000 lbs.	1,000 lbs. 3,000 lbs.
TKN (N)	5,300 lbs. 180,000 lbs.	310 lbs. 15,000 lbs.	100 lbs. 1,900 lbs.
NO ₂ + NO ₃ (N)	1,000 lbs. 2,600 lbs.	180 lbs. 210 lbs.	20 lbs. 27 lbs.
Lead	1,300 lbs.*** 180 lbs.	44 lbs.** 14 lbs.	15 lbs. 2 lbs.
Zinc	1,000 lbs. 1,400 lbs.	23 lbs.** 98 lbs.	15 lbs. 12 lbs.
Precipitation	8.6 inches	5.2 inches	10.0 inches
Runoff (Est.)	3.0 inches	1.0 inches	2.5 inches

* Upper number is the load in runoff and lower number is the load in secondary effluent from same area based on 60 gallons/capita/day flow rate.

** From reference (1).

*** Based on one snowmelt event.

OBSERVATIONS AND CONCLUSIONS

The most important observation and conclusion resulting from the stormwater quality collection effort in the Denver area is the need for a local data base to define urban stormwater quality. One cannot rely on computer models calibrated using stormwater quality data from Tulsa and Chicago as input. In fact, the validity of the state-of-the-art computer models is being questioned by investigators of urban stormwater pollution. Statistical

analysis by Bradford (2), of urban runoff quality data collected throughout the United States reveals:

- Methods for predicting pollution from urban streets are deficient.
- Significant patterns in the relationship between land use and pollutants could not be shown.
- Attempts to develop pollutant load equations through multiple regression have been reasonably successful only using data from a single local area, such as Tulsa.
- Climate is thought to be a primary variable.

The Denver area data collected and analyzed to date confirm Bradford's conclusions and point out that data collected in other regions of the country is not transferable directly to Denver.

Barkdoll, et. al., (3) demonstrated a direct link in the Knoxville, Tennessee area of pollutant buildup to dustfall, thereby explaining why climate and site specificity may be the primary variables in the non-point source pollution process. They also demonstrate that not all pollutants are washed only off paved surfaces as is assumed by most computer models.

Most commonly used computer models rely on linear buildup rates and an exponential pollutant runoff function from paved surfaces. Very little knowledge exists on how to predict pollutant buildup rates, thereby requiring input of locally collected data before any modelling process can begin having a degree of credibility. Barkdoll, et. al., also question the validity of the presently available water quality models and state, "Any study dealing with urban stormwater quality must proceed under the constraints of site and pollutant specificity."

Research efforts by Bradford and by Barkdoll, et. al., back up the primary conclusion reached on the basis of the data collected in Denver. It would be too simplistic to assume that the loading rates measured during the limited effort in Denver provide sufficient information to plan urban stormwater pollutant control for the Denver area. At the same time, it would be even more ill-advised to plan for urban stormwater quality control based solely

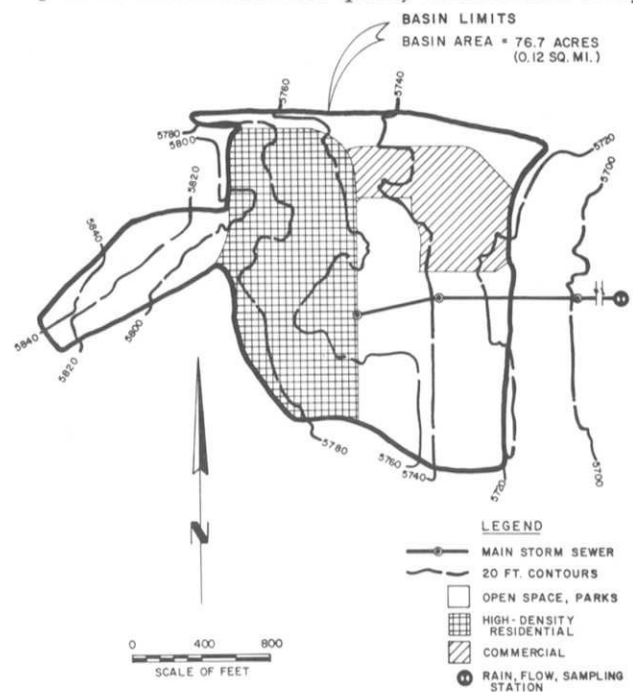


FIG. 4 - NORTH AVENUE DRAINAGE STATION CATCHMENT

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Tucker-Talk

by L. SCOTT TUCKER

Timely Comment from the District's Executive Director



Maintenance

Those of us in the business of drainage and flood control know what a complex and perplexing problem area it is. We are, on the one hand, trying to convince people who own or may own property in the flood plains of the wisdom of flood plain regulation. On the other hand, we are building flood control improvements for the benefit of those that work or reside in flood plains and floodways. Flooding problems are in large part caused by unwise location in the flood plain, but, in most situations, the problems are aggravated by increased runoff due to upstream development. We are also trying to find ways and means of financing and incorporating multi-uses in drainage and flood control projects. Non-structural solutions to flood control problems are adding another important dimension to flood control and drainage planning. In other words, it isn't easy.

From amongst all these problems, maintenance is emerging as a critical concern. At least this is the case in the Denver area. In general, when the Urban Drainage and Flood Control District is financially involved in a flood control project, the participating local governments must agree to own and maintain the completed facilities. We are finding, however, that maintenance is not consistently performed, and in many cases, no maintenance is



Vandalism of gabion structures continues to be a serious maintenance problem.

performed at all. The recourse is for the District to "require" local government to perform the necessary maintenance. This poses two difficulties. The first is the inability to accurately define what we mean by "required maintenance." The second is that many local governments just simply do not have the available funds and you cannot squeeze blood out of a turnip.

Flood control facilities, including open channels, dams, conduits, and open flood plains all require maintenance to keep them functional. Trash and debris must be continuously cleaned out of the channels; erosion damage must be repaired; gabion baskets must be replaced; sediment must be cleaned from conduits, etc. If drainageways and other drainage facilities are properly maintained they

will function as intended and will be assets to the community. If they are not maintained, they may not function and can actually be the source of problems. In other words, maintenance is critical if drainage facilities are to have a continued useful life.

Funding is the basic problem. Also, time exacerbates the problem because as more and more facilities are completed, maintenance requirements increase in proportion. The need for maintenance goes on year after year, and its cost increases with inflation. In other words, the problem is going to get worse before it gets better.

One approach the Urban Drainage and Flood Control District is considering is to assess a mill levy over the entire metro area for maintenance purposes. The District would then contract with local governmental entities to provide the required maintenance. The maintenance would be performed on the basis of established criteria and the local governments would be reimbursed by the District based on the maintenance performed.

The provision of a mill levy for maintenance can be accomplished by amending the District's legislation or by holding a general election in the Denver metropolitan area. If the Board of Directors of the District decides on a mill levy approach, they will most likely seek an amendment to the legislation during the 1979 legislative session. While difficult, it is much easier to deal with 100 legislators than 1,300,000 citizens. It is also much less costly, as a special election in the Urban Drainage and Flood Control District would cost an estimated \$160,000.

It is not a pleasant or easy task to increase property taxes for any purpose. This approach, however, appears to be the best option available at this time to finance necessary maintenance.

New Organization Formed to Address Urban Drainage and Flooding Problems

A new organization was formed late in 1977 to work for the reduction and elimination of urban flooding and improved water conservation. The new organization is called the National Association of Urban Flood Management Agencies (NAUFMA).

The motivating factor behind establishing the organization is the lack at the Federal level of any focus on urban drainage and flood control problems. The typical problem faced in the Denver area is flood management along urban drainageways which drain from five to twenty-five square miles: In some flood plains, severe encroachment has considerably reduced the ability of the drainageway to handle flood waters. In other locations, there are still open flood plains remaining which provide an opportunity to incorporate other approaches in the flood plain management process.

We find, however, that the only Federal programs available other than block grants or revenue sharing are through the Soil Conservation Service and the U.S. Army Corps of Engineers. The Soil Conservation Service programs must have a rural orientation. For any Corps of Engineers project, except those authorized under Section

205, the Congress must first authorize the project and then appropriate the necessary funds. While there is some opportunity to involve the Corps of Engineers in urban flood control projects, it is a difficult procedure, to say the least, to convince the Congress of the special needs of a particular area.

There is a need to have a Federal focus and Federal support of urban flood plain management in a broader spectrum than is now the case. Corps of Engineers participation in an urban flood control project is limited in its extent because of complex regulations. For example, the best alternative for solving an urban flooding problem may be acquisition of flood plain properties and relocation of flood plain occupants. In accordance with Corps regulations, however, right-of-way costs are a local responsibility. This places a great incentive on the decision making process to opt for a structurally oriented project vis-a-vis an alternative that would emphasize property acquisition. In other words, local cost is minimized by minimizing property acquisition. Also corps support can be applied only to the flood control aspects of the project. This situation usually does not support a multi-use approach of flood control projects.

The present thinking of NAUFMA is that new legislation is needed that addresses urban flood plain management problems in a broader context than is now possible. Legislation is being drafted in a preliminary form that will address these concerns.

The NAUFMA is essentially an association of operating agencies involved with planning and implementation related to urban flood plain management problems. Anyone interested in additional information should contact Mr. Ron M. Linton, Executive Director, National Association of Urban Flood Management Agencies, 1015 - 18th Street, NW, Suite 200, Washington, D.C. 20036.

Stormwater Quality

Included in this issue of *Flood Hazard News* is an article on the "Stormwater Quality Data Collection Program in Denver." This article summarizes some of the efforts in the Denver region regarding the quality of urban stormwater runoff. These efforts are admittedly very limited as quality data was collected for only one year on three urban catchments. The data has, however, provided us some important insights as to what we may be facing regarding the urban stormwater runoff pollution problem.

A most important conclusion we have reached is how little is really known about urban stormwater runoff quality. Many of us in the field of urban water resources have been struggling with urban hydrology for many years. In spite of our efforts, urban hydrology is still as much an art as it is a science. When quality considerations are imposed on hydrology considerations, the complexity of the problem is magnified considerably. To assume that the profession knows the answers with regard to the significance of stormwater quality and how to deal with it is unrealistic.

The Environmental Protection Agency (EPA), at the national level, has recognized the situation and is attempting to develop a program to identify the problem and potential solutions from a sound data base. Also, the Congress has very graphically highlighted this dilemma by not including any monies in the 1977 Amendments to the Clean Water Act for implementation of urban non-point source pollution controls. Congress has in effect said that there is not adequate evidence to justify Federal expenditures to clean urban storm runoff.

However, Region VIII of the EPA, which includes the

Denver area, has not gotten the message. This regional office of EPA has indicated they will require that local governments show progress towards implementing the non-point source controls recommended by the Denver area 208 plan. These controls include increased street sweeping activities, more frequent catchbasin cleaning, adoption of anti-litter ordinances, adoption of anti-dog dropping and cat dropping ordinances, adoption of environmental controls, reduction of street sanding, cleaning of leaves from street gutters, etc.

This all sounds good except for the fact that EPA does *not* know how often local governments now sweep streets, let alone how much local governments should increase their street sweeping activities and what the effect of increased street sweeping programs might be. The EPA does *not* know how many catchbasins there are in the Denver region, how often they are now being cleaned, how often they should be cleaned, or what the effects of additional cleaning might be. The EPA does *not* know the effects of the build-up of leaves in curbs and gutters on the quality of receiving waters. In short, the Region VIII office of EPA does *not* know what the problem is, but they are telling local general purpose governments how they shall proceed with solving that unknown problem.

It was interesting to observe in President Carter's address to the Illinois State Legislature in May his concern with the inadequacy and the unresponsiveness of the Federal Bureaucracy, while at the same time, we are being pummeled with requirements from high government officials that are based on little or no fact. A credibility gap is developing.

COMPENSATION FOR FLOOD DAMAGE

The Secretary of Housing and Urban Development, Patricia Roberts Harris, has clarified the National Flood Insurance Program's regulations concerning restoration of a structure. According to New Jersey law, structures damaged more than 50% of value, when located in a regulatory floodway selected and adopted as such by the local government, may not be destroyed. Residents were concerned that in the event of a disaster, they might not be compensated by insurance for the full loss of a home where rebuilding was precluded.

In a letter to the Senator from New Jersey, Clifford Case (Feb. 16, 1978), Secretary Harris states a policy that where repair of a structure damaged by an insured peril is prohibited by statute or regulation, the loss becomes a constructive total loss, and the owner's flood insurance claims will be appropriately adjusted. "It is to the taxpayer's and the program's benefit that existing, heavily subsidized risks be eliminated," she states. "At the same time, the citizens required, in effect, to purchase insurance cannot justly be called upon to bear the chief economic burden because of inadequate insurance coverage, narrowly construed. So while we sincerely applaud states and local communities for their various flood plain management regulations, we are not going to walk away from insureds who face tremendous economic loss because of insufficient recoveries under their policies as compared to their actual losses where a reasonable construction of the federal policy permits the interpretation that such losses are covered under the policy."

This article first appeared in "Natural Hazards Observer", Volume II, Number 4, June, 1978.

GROWING WITH THE PLATTE RIVER GREENWAY

by Mary Blish
Civil Engineer

Wright-McLaughlin Engineers

Beginning in 1974, the Platte River Development Committee, headed by Joe Shoemaker, has pushed for the transformation of the once derelict Platte into what is now the region's most dynamic recreational area.

A major, if not the foremost, element of the ten-mile redevelopment concept is flood control and protection. While this concept generally goes unnoticed by most who see only the creation of a new park, it is the most basic and determining factor in the design and performance of the pathway systems, pedestrian bridges, channel improvements, and river-front structures.

The need for the upgrading of the Platte Valley had been set almost as soon as Green Russell slopped up the river banks over a hundred years ago. Disrespecting the repeated warnings not only from the wise Indian neighbors, but also from high water itself on both Cherry Creek and the Platte, our forebears set the roots of Denver in *both* flood plains. Denverites have been and will always be touched in one way or another by these beginnings. The history of flooding and the study of how to tame and revitalize these waterways had persisted for many years. Then, in 1974, after numerous false starts; time, budget, and concept came together and were focused on the "Platte River Greenway;" and the momentum to revamp the Platte Valley step-by-step finally began.

The Greenway is by no means restricted to the South Platte. The project includes improvements along Cherry Creek, Lakewood, Weir, Sanderson and West Harvard Gulches. It will tie into existing and planned recreational facilities at both the Cherry Creek Dam and Chatfield State Recreational Areas (also flood control projects), and proposed trail improvements along Clear, Sand, and Bear Creeks.

All of the improvements along the Greenway were designed to withstand major damage from high water and debris buildup during flooding, as well as to improve the flood risk to adjacent areas where possible. General design guidelines which were incorporated in the layout of the improvements include:

- The path location and other improvements were set with respect to the 100-year water surface elevation. Many times it was necessary to lower the desired elevation to clear bridge low chords and to avoid obstacles. Design discharge rates for the South Platte River were provided by the Army Corps of Engineers. The Corps' HEC-2 computer methodology was used to arrive at the 100-year water surface profiles from which vertical path alignment could be determined.
- Filling of the waterway was avoided. Excavation of the banks and channel was encouraged to increase flood-carrying capacities.
- A non-structural approach was pursued throughout design. Structures such as gabions, transition walls, and pedestrian bridges were used only when soft alternatives were exhausted.
- Bank and channel debris and rubble were carefully noted for removal and reuse. Concrete rubble from the flood damaged 15th Street bridge and from the numerous concrete truck dumpings which lined the river banks were reused to provide path subgrade

and bank stability in areas subjected to significant flooding.

- Banks were graded at a minimum 3:1 slope. Flatter slopes were preferred where possible. In some instances where channel right-of-way, available bank area and obstacles presented constraints and steeper slopes were required, a maximum slope of 2:1 was used. This type of bank was heavily rip-rapped with natural rock, hydromulched, and seeded.

There are many engineering highlights along the Greenway Project. Centennial Bridge at Confluence Park (Figure 1) spans more than 90 feet across Cherry Creek. The bridge abutments rest on concrete retaining walls which were built in the early 1900's. If the water surface during the 100-year flood rises above the bridge deck, the abutment connections are designed to shear, thus freeing the bridge. Cables which are attached to the north bridge abutment hold the bridge against the down stream bank until flooding subsides. This prevents the bridge from



Figure 1.—Centennial Bridge. The left abutment connections will shear under pressure from high water or debris and the bridge will swing to the right bank.

acting as a debris collector during high flows and decreases the backwater effects and flooding capability upstream. The other "breakaway" pedestrian bridges have been installed across the South Platte.

The Plaza at Confluence Park (Figure 2) which seems to float, was actually cast directly on river bed fill. The structural design of the Plaza incorporates over 60 steel H-piles driven at least eight feet into the shale bedrock underlying the entire structure. This results in a complete structural system capable of resisting the river's hydrostatic, hydrodynamic, uplift and drag forces. Other architectural features, such as lighting, handrails, and seating are furnished with special consideration to high water and debris collection.

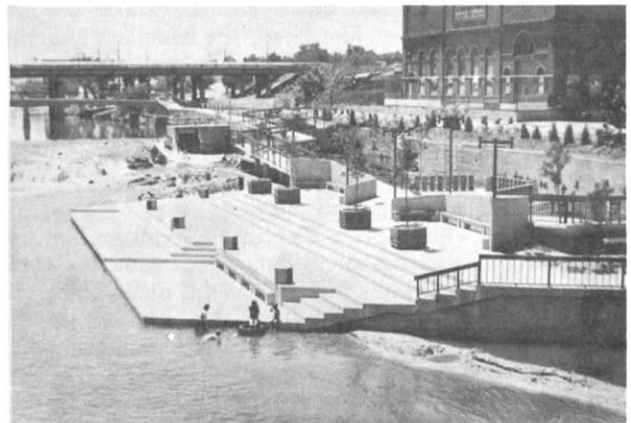


Figure 2—The Plaza at Confluence Park.



Figure 3—Rafting through the Zuni White-Water By-Pass.

Two boat chutes have been constructed thus far to allow boaters and tubers to get around obstacles in the river. Navigating the Platte is now considered a fun, and sometimes even thrilling weekend whitewater experience. Perhaps the most exciting boating area is the recently dedicated Zuni White-Water By-Pass (Figure 3) at the Public Service Company's (PSCo) power plat at 13th Avenue.

The Zuni chute was constructed to allow boaters to pass over the permanent PSCo fabri-dam which is itself a flood control device. The chute is a heavy gauge, corrugated structural steel plate which acts as a slide. The upstream portion of the slide rests on top of the fabri-dam, and the downstream end is supported by an extension of the existing concrete base. The weight of the slide presses the upstream portion of the slide into the fabri-dam, which allows the water to enter the chute. The slide is

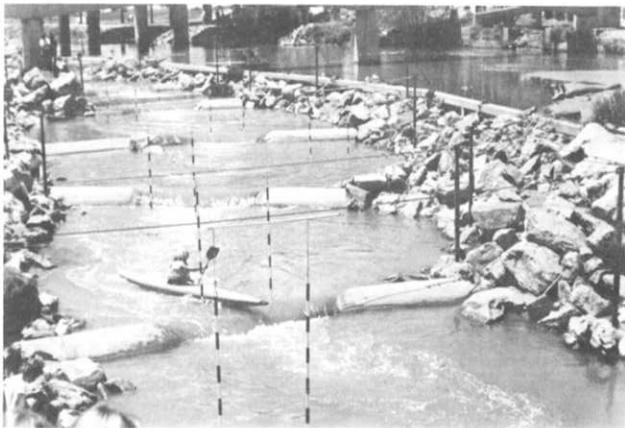


Figure 4—Kayak racing at the Confluence Park boat chute.

attached to an upstream anchor system with a heavy rubber sheet. This allows movement at the upstream end of the slide in the vertical direction, but restrains horizontal downstream movement. The slide slopes from the upstream water surface to the lower control pool at grades between 25 and 33 percent.

Another thriller is the boat chute at Confluence Park (Figure 4) which was installed around the Farmers and Gardeners diversion structure. White water enthusiasts return again and again to run the Confluence Park slalom. The boat chute is a series of 12 notched concrete weirs arranged in a continuous hydraulic sequence. Large rock placed in conjunction with the weirs creates pools and eddies which delight kayakers and tubers alike. The normal water surface drops about nine feet in the 350-foot long chute. A distensible dam at the entrance gate

of the chute automatically maintains the upstream water surface for diversions to the Farmers and Gardeners Ditch. During high flow or flooding conditions, the chute will act as a side channel spillway.

Since the average flow in the river is small in comparison to the size of the channel, special efforts were necessary to make the river navigable. These efforts included concentrating the low flows with the careful placement of gabion structures and large imported rock; and, in some locations, excavation of low flow channels.

The full effect of the Platte's transformation is only beginning to reach the people of the Denver region. Many years in the future, citizens of the Denver area will be remarking on the foresight and planning that has taken place, just as the people of Denver do now of present and treasured area landmarks.

Wright-McLaughlin Engineers is one of four primary design consultants on the Platte River Greenway. Other firms include Gingerly Associates Inc.; McCall, Ellingson and Morrill, Inc.; and Oblinger-Smith Corporation.

TIMELY AND AVAILABLE

Some Current Publications

Feasibility Evaluation, Methodology For Evaluation of Feasibility: Multi-Jurisdictional Urban Drainage and Flood Control Projects

This document has been developed to provide engineers working for the Urban Drainage and Flood Control District with a methodology to systematically prepare and display the information needed to select among alternative drainage and flood control projects. It grew out of a research project involving District officials, Colorado State University, Leonard Rice Consulting Water Engineers and W. J. Shoemaker, attorney. The work was financed by the U.S. Office of Water Research and Technology and the District, and was coordinated through the CSU Environmental Resources Center.

The cost is \$5.00 plus \$0.50 for postage and handling. *Flash Flood Warning Recommendations For Front Range Communities*

This publication was prepared to assist local governments in the formulation and implementation of flash flood warning plans. Although the emphasis of the report is on flood hazards in, and at the mouths of canyons, much of the information in the report is applicable to communities in other areas. The report was authored by Thomas E. Downing from the Institute of Behavioral Science, University of Colorado, as a part of a larger research effort funded by the District.

There is no charge for the publication. Please enclose \$0.50 for postage and handling. Limit one.

What People Did During The Big Thompson Flood

This report makes comparisons between the actions of the survivors and non-survivors and the warned and non-warned populations in the canyon at the time of the flood. The author is Eve Grunfest from the Institute of Behavioral Science, University of Colorado. The research was funded by the District.

The cost is \$3.00 plus \$0.50 for postage and handling.

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District Adopts Flood Disaster Plan

by

BILL DeGROOT

Chief, Flood Plain Management Program

Following the disastrous Big Thompson flood of July 31, 1976, it occurred to the District's staff that we were unsure of what the District's role might be in the event of a similar disaster within the boundaries of the District. With this thought as the catalyst, we began the process of developing a Flood Disaster Plan which would identify those roles which the District could and would fulfill as well as those roles which the District could not undertake. It was felt that adoption of a plan by the District would also inform local governments and other disaster response agencies of the District's expected role.

The proposed Flood Disaster Plan was developed over a period of several months. Wright-McLaughlin Engineers (consultant to Governor Lamm on the Big Thompson recovery effort), was retained to develop background information concerning the roles of local government and all other disaster response agencies, and to assist the District staff in developing alternative roles for discussion at a workshop.

The workshop was attended by approximately 40 local government officials and 10 representatives of state and federal disaster response agencies. The morning was spent discussing a hypothetical flood within the District and the problems that would result, possible alternatives for District involvement, and assets and limitations which would affect the District's response capabilities. During the afternoon, the participants were broken into five smaller groups. These groups discussed assigned portions of the alternatives and reported their recommendations concerning the alternatives to the full group.

Following the workshop, District staff assembled a draft plan, circulated the plan for comment, and presented the plan to the District's Board of Directors. Comments concerning the plan which were received from the Board and the other reviewers were incorporated into the plan. The final Flood Disaster Plan, which follows, was adopted by the Board of Directors on March 16, 1978.

SECTION 1.0 PURPOSES. This Flood Disaster Plan has been established with the following purposes intended:

- 1.1 To designate tasks to be accomplished by the District before, during, and after a flood disaster within the boundaries of the District. This plan in no way imposes a responsibility on local agencies.
- 1.2 To inform local governments and federal, state, and private disaster agencies of the assistance available from the District in the event of a flood disaster.
- 1.3 To establish tasks and procedures to be accomplished by the District to mitigate flood damage and loss of life.
- 1.4 To establish tasks and procedures to be accomplished by the District to assist local governments and disaster agencies during a flood and during a post-flood recovery period.
- 1.5 To establish tasks and procedures to enable the District to learn more about the effects of flooding and the value of mitigative efforts in effect at the time of a flood.

SECTION 2.0 PRE-FLOOD DISASTER TASKS. In order to reduce the effects of floods within the District prior to their occurrence, the District will begin or continue the following tasks in accordance with annual work programs and budgetary constraints:

- 2.1 Develop flood control master plans for multi-juris-

dictional drainageways in cooperation with the appropriate local governments.

- 2.2 Implement all or portions of the master plans described in Section 2.1 in cooperation with local governments. Allocation of District funds shall be in accordance with District policy as outlined in Resolution No. 11, Series of 1973, as amended by Resolution No. 49, Series of 1977.
- 2.3 Annually notify occupants of flood hazard areas in accordance with Resolution No. 37, Series of 1976.
- 2.4 Delineate flood hazard areas and provide the delineations to local governments for their use in managing the flood hazard areas.
- 2.5 Assist local governments with their flood plain management efforts. Monitor the effectiveness of local flood plain management efforts in accordance with Resolution No. 20, Series of 1977. Enforce the District's Flood Plain Regulation (Resolution No. 11, Series of 1970, as amended by Resolution No. No. 26, Series of 1974) within the boundaries of those local governments not adequately regulating their defined flood plains in accordance with applicable state, federal, or District criteria. Board action is required prior to enforcement of the District's regulation.
- 2.6 Support the National Flood Insurance Program and encourage occupants of flood hazard areas to purchase flood insurance.
- 2.7 Cooperate with local governments and other appropriate agencies in the planning and installation of flood detection systems and the formulation of flood warning and flood disaster plans.
- 2.8 Annually, before the flood season, encourage local governments to inspect their existing flood detection systems and practice their existing warning plans. Provide District staff assistance on request of local government. This task applies to those detection systems and warning plans funded with District monies, or which the District helped prepare.
- 2.9 Develop and keep current, a checklist of what actions other agencies will take in the event of a flood disaster.
- 2.10 Coordinate flood damage documentation responsibilities with the Colorado Water Conservation Board, U.S. Geological Survey, Corps of Engineers, National Weather Service, Division of Disaster Emergency Services, and others. Reaffirm District responsibilities annually.
- 2.11 Develop a minimum emergency roadway network plan. This plan will be used in future master planning and implementation projects (Sections 2.1 and 2.2) to determine the design frequency required at key drainageway crossings to insure movement of emergency vehicles during flood events.
- 2.12 Other tasks which become apparent and are approved by the Board of Directors at some future date.

SECTION 3.0 WARNING PHASE TASKS. Staff and equipment limitations restrict the ability of District staff to assist local governments during the warning phase of a potential flood disaster. To the extent possible under the given circumstances, the District will undertake the following tasks:

- 3.1 Those documentation tasks coordinated with other agencies under Section 2.10 of this Flood Disaster Plan.
- 3.2 Other assistance requested by affected local governments.

SECTION 4.0 *EMERGENCY RESPONSE PHASE TASKS*. Staff and equipment limitations will also restrict the ability of District staff to assist local governments during the emergency response phase. To the extent possible under the given circumstances, the District will undertake the following tasks:

- 4.1 Inspect and photograph affected District funded flood control facilities for operational effectiveness during the flood event.
- 4.2 Those documentation tasks coordinated with other agencies under Section 2.10 of this Flood Disaster Plan.
- 4.3 Provide other assistance at the request of affected local governments.

SECTION 5.0 *RECOVERY PHASE TASKS*. During the recovery phase, the District will undertake the following tasks:

- 5.1 Those documentation tasks coordinated with other agencies under Section 2.10 of this Flood Disaster Plan.
- 5.2 Inspect affected District funded flood control facilities for effectiveness and damage incurred. Determine if damage was normal or unusual and unexpected. Determine why unexpected damage occurred and make appropriate adjustments to design and construction procedures.
- 5.3 Evaluate the effectiveness the District's annual notification effort (Section 2.3) may have had in reducing the flood damage and loss of life.
- 5.4 Evaluate effectiveness of affected District funded flood detection systems and flood warning plans in reducing damage and loss of life. Determine what changes or improvements should be made.
- 5.5 Compare actual flood discharges, depths and outlines with affected District flood hazard area delineations. Determine how well the actual and predicted flood plains compare and the reasons for any substantial differences.
- 5.6 Evaluate the emergency roadway network plan (Section 2.11) for its effectiveness and its applicability to the recovery planning effort.
- 5.7 Assist local governments in their recovery planning efforts by:
 - (1) Offering to evaluate existing master plans for their applicability to the recovery planning effort.
 - (2) Offering to manage the development of a recovery plan for the affected drainage-way(s). Funding arrangements for this task will be subject to approval of the Board of Directors.
 - (3) Providing, to the extent possible under the given circumstances, technical assistance to local governments on request.
- 5.8 Insure that past flood plain development mistakes are not repeated during the recovery phase by:
 - (1) Monitoring the effectiveness of flood plain management efforts of affected local governments. If the Executive Director determines that local governments are not regulating the flood plain in accordance with applicable state, federal, or District criteria, he shall bring this fact to the attention of the Board of Directors, who shall consider enforcement of the District's flood plain regulation in those areas.
 - (2) Requiring Board of Directors' approval of all flood control facilities to be built on

multi-jurisdictional drainageways in the disaster area.

- 5.9 Consider allocation of District capital improvement funds for recovery plan implementation upon request of local governments. Such consideration will take place at a regular or special session of the Board of Directors.
- 5.10 Other assistance requested by affected local governments and approved by the Board of Directors.

SECTION 6 ADMINISTRATION

- 6.1 The Executive Director shall administer the provisions of this Flood Disaster Plan.
- 6.2 The Executive Director shall establish a Standard Operating Procedure (SOP) to ensure the prompt implementation of this Flood Disaster Plan.
- 6.3 The Executive Director shall review this Flood Disaster Plan and the Standard Operating Procedure prior to each flood season. Any required changes shall be brought before the Board of Directors for their consideration.
- 6.4 Prior to implementation of Section 5, *Recovery Phase Tasks*, the Executive Director shall, after consultation with affected local governments and the Chairman, or in his absence, the Chairman Pro Tem of the Board, determine that a flood disaster exists.

Several features of the plan are worthy of further discussion. First of all, the plan outlines activities for District action before, during, and after a flood event. It does not, in any way, usurp power from any other unit of government which might be involved in some capacity in a flood disaster. What it does is define areas in which the District can become involved if it is deemed to be beneficial to do so.

Originally, the draft plan considered only the warning, emergency response, and recovery phases of a flood disaster. The pre-flood tasks were added to the plan to present a complete picture of District activities and action before, during, and after a flood event. Most of the pre-flood tasks have been on-going for some period of time.

Another important point is that in the resolution adopting the Flood Disaster Plan, the Board of Directors also authorized the Executive Director to expend up to \$10,000 without further Board action in the event of a flood disaster, in order to implement those portions of the plan which require quick action. This authorization will allow the District's staff to move quickly at a time when speed of implementation will be extremely important.

Adoption of the Flood Disaster Plan is only the first step. During the ensuing months, the staff will be developing a Standard Operating Procedure so that by the flood season of 1979, the District will be in a position to act rapidly and efficiently in response to any serious flooding within its boundaries.



The District is trying a concrete drop structure to try to get away from the vandalism problems with gabion structures. The rip-rap will be buried and seeded, thus leaving only the concrete wall in sight.

Some Findings in the Rainfall-Runoff Data Collected in the Denver Area

by
BEN URBONAS
 Chief, Master Planning Program

The Urban Drainage and Flood Control District, in 1969, contracted with the U. S. Geological Survey (USGS) to collect simultaneous rainfall and runoff data in the Denver metropolitan area. In 1976, the District and the USGS began to evaluate the data collection program and to utilize the data gathered to improve the hydrologic techniques employed by the District. Some of the initial findings can be reported at this time. The reader is cautioned not to formulate any firm conclusions. Initial findings from one data collection site cannot possibly be representative of the Denver area and are presented only to stimulate discussion and thinking about the hydrologic tools the engineering profession employs on a daily basis.

As a part of the data gathering efforts, the USGS acquired complete rainfall data from the National Weather Service for a 73-year period (1898-1971) at the Denver raingage. This rainfall data is being used for three purposes by the District. The first is to analyze the rainfall depth duration charts contained in the District's *Urban Storm Drainage Criteria Manual* (USDCM) and in the *Precipitation-Frequency Atlas of the Western United States, Volume III-Colorado* by NOAA (subsequently referred to as NOAA charts). The second is to analyze the effects on runoff calculations when using the so-called "design storms." The USDCM contains a procedure for reducing rainfall-depth duration charts to design storms. The rainfall data is being used to determine the validity of the assumption that, let's say, a 10-year design storm will generate a 10-year flood when used in combination with a calibrated runoff model. Thirdly, the 73 years of rainfall data is being used to analyze the entire Colorado Urban Hydrograph Procedure (CUHP) and to improve the accuracy of the CUHP.

Rainfall Chart Analysis

A statistical analysis of the 30-minute rainfall depths recorded at the Denver gage was performed and the results are shown on Figure 1. The analysis was performed using partial duration series, namely, using the 73 largest 30-minute recorded depths regardless of the number of occurrences during any one year. The partial duration series will yield the true probability of occurrence of a stated rainfall depth during any year even though a single wet year may have a series of large events. The 30-minute depths obtained using the rainfall charts found in the USDCM and the NOAA charts are also shown on Figure 1. The USDCM agrees very well with the rainfall data for up to 10-year return periods. NOAA charts best fit the data at 50- and 100-year return periods.

Also plotted on Figure 1 are the 7-day antecedent precipitation data. Antecedent data were plotted to correspond to the plotting positions of the associated rainstorm on Figure 1. The 7-day antecedent precipitation is random in its occurrence and no trend is observable. Consequently, it is not possible to conclude from Figure 1 what effect antecedent precipitation has on stormwater runoff statistical distribution. The analysis of rainfall data indicates a need for a refinement in both the USDCM charts and in the NOAA charts and/or in the procedures used to reduce the published charts to a 30-minute depth.

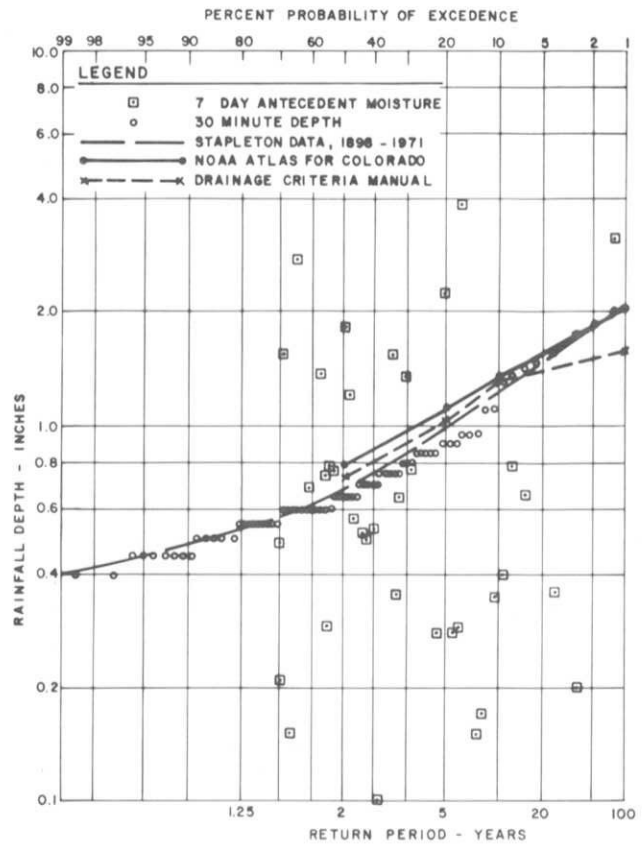


FIGURE 1. PROBABILITY DISTRIBUTION OF 30 MINUTE RAINFALL DEPTH AT STAPLETON AIRPORT

Calibrating Runoff Models

After evaluating several runoff computer models, it was decided to use a linear model having a unit hydrograph calibrated for the study catchment. Infiltration was modeled using Horton's exponential decay function; namely,

$$f = f_0 + (f_i - f_0)e^{-\alpha t}$$

where, f = infiltration rate (in/hr)

f_i = initial infiltration rate (in/hr)

f_0 = final infiltration rate (in/hr)

α = decay coefficient (1/sec)

t = time (sec.)

The unit hydrograph model was chosen for its simplicity and low cost of synthesizing runoff for a large number of storm events. A catchment located in the Montbello area of Denver had usable data for eleven rainfall-runoff events and was used to calibrate a unit hydrograph and the rainfall abstractions for this catchment.

The U.S. Army Corps of Engineers HEC-1 computer program was used to reduce the rainfall-runoff data to unit hydrographs. The eleven resultant unit hydrographs were then composited into a single representative unit hydrograph for the catchment. Next, the recorded rainfall data were used with the composited unit hydrograph to calculate runoff. Calculated runoff volumes and peaks were then compared against the measured hydrographs and rainfall abstractions were adjusted until a reasonable fit of the measured runoff data was obtained.

Because of rainfall-runoff data measurement accuracy and because the point rainfall measurement cannot de-

scribe the spacial distribution of rainfall over the entire catchment, it is not possible to reconstitute perfectly all observed hydrographs. Thus, the calibrating process attempted to minimize the average variance. Although, at the end, the calculated peak for one event was 29 percent higher than measured and another was 33 percent lower than measured, the average variance between calculated and measured peaks was approximately one percent. The variance between calculated and recorded peaks did not show a trend with the storm intensity and appears to be random. The rainfall data for this catchment exhibited a wide range of intensities with one of the events recording 1.74 inches of rainfall in 30 minutes (see Figure 1 for probability). Thus, the calibrating process was not limited to a small range of events and is expected to have resulted in a rainfall to runoff transfer function representative for a wide range of storms.

The test catchment is composed mostly of a single-family residential neighborhood with a small portion of the basin having an apartment building complex. The soils are not typical to the Denver area and are very sandy. High rates of infiltration were measured in similar soils on nearby Stapleton International Airport. The observed and calibrated characteristics of this catchment are summarized in Table 1.

TABLE 1—BASIN CHARACTERISTICS

Area	-	.29 Sq. Mi. (observed)
Drainageway Slope	-	.006 ft/ft (observed)
Imperviousness	-	40 percent (observed)
Initial Infiltration	-	5 inches/hour (calibrated)
Final Infiltration	-	1.1 inches/hour (calibrated)
Infiltration Decay	-	.0007/second (calibrated)
Drainage System	-	Very efficient. Sewers and concrete lined channels. (Observation)

Design Storm Analysis

Using the calibrated infiltration rates and the calibrated unit hydrograph, runoff was simulated for the 73 largest rainstorms recorded at the Denver raingage after accounting for the effects on rainfall abstractions by the antecedent precipitation preceding each storm. The resultant peak flows were then statistically analyzed using the Log Pearson Type III computer program developed by the U.S. Water Resources Council. Runoff simulated using actual rainstorm data was compared against the simulated runoff obtained using the "design storms" developed from the USDCM and the NOAA Atlas rainfall charts. The results summarized in Table 2 indicate how the "design storm" technique produces results that can vary significantly from the probability distribution of runoff simulated using actual rainstorm data.

**TABLE 2
Calculated Peak Flows in Cubic Feet Per Second
Using Calibrated Unit Hydrograph and Rainfall Abstractions**

Return Period Years	73 Recorded Storms	USDCM "Storms"	NOAA Atlas "Storm"
2	97	116	116
10	190	231	272
100	400	343	484

For this basin, the USDCM and the NOAA design storms overestimate the runoff for the 2- through 10-year return periods. The USDCM design storm results in a 14% underestimate of the 100-year peak flow and the NOAA design storm overestimates the 100-year peak by 21%.

Analysis of the CUHP

In order to judge how well the existing CUHP method would predict the runoff peaks from the Montbello test catchment, a comparison was made between the synthesized runoff using:

- a) The CUHP with design storms
- b) Synthesized runoff using the calibrated unit hydrograph with recorded rainfall data.

The USDCM recommends the infiltration rates be field measured before use; however, if field data is not available, the following infiltration rates are suggested:

1. For 2- to 5-year storms: 1 in/hr for first ½ hour
½ in/hr after first ½ hr.
2. For 10-year and larger storms: ½ in/hr from beginning of storm.

Runoff peaks were synthesized using both the calibrated infiltration rates and the rates recommended above in conjunction with the USDCM and NOAA "design storms."

The results are summarized in Table 3 and are compared against the statistical distribution of peaks synthesized using the calibrated unit hydrograph and actual rainstorm data.

**TABLE 3
Comparison of CUHP Peak Flows
Against Calibrated Condition Flows
In Cubic Feet Per Second**

Return Period Years	Calibrated Flows From 73 Storms	CUHP		
		USDCM Infiltration USDCM Storms	NOAA Storms	Calibrated Infiltration USDCM Storms
2	97	110	123	103
10	190	337	346	204
100	400	448	608	303

The comparison in Table 3 shows how important the use of appropriate infiltration rates can be regardless of the type of storm used. Although in this case, the USDCM storm with calibrated infiltration and the CUHP resulted in an approximate 30% underestimate of the 100-year peak, the same procedure resulted in the best results for 2- to 10-year events. Use of the USDCM infiltration rates, namely, not going to the trouble or expense of obtaining field measured infiltration rates overestimated the peak flows for all return periods with the greatest error occurring at the 10-year return period. If 5- or 10-year drainage structures were to be provided, the cost of obtaining field measured infiltration rates could have been paid for many times over by the savings in constructed facilities.

The use of NOAA storms with the CUHP results in large overestimates of the peak flows for this catchment. The "design storm" rainfall distribution is suspected as being responsible for the large disparities in the synthesized peak flows. The rainfall distribution algorithm in the USDCM requires the placement of the largest intensity rainfall increments after the first half-hour of the storm. This algorithm is the same for all frequencies of design storms. However, a review of the Denver raingage records reveals that for the bulk of the storms in the Denver area the greatest intensities occur during the first half hour of the storm. This was observed to be particularly true of the more frequent events, namely, 2- to 10-year storms.

By shifting the large intensities back in time, the calculated peak flows are increased since the retention losses no longer reduce the excess precipitation and the infiltration rates are considerably smaller than earlier in the storm. Thus, the distribution of rainfall in the "design storms" will require further investigation and adjustment as part of the ongoing rainfall-runoff effort.

Conclusion

Similar analysis as described above will be conducted on approximately 15 other catchments for which rainfall-runoff data is available. The foregoing is presented to illustrate the approach being taken and how the calculated results can vary with the use of different assumptions. It is expected the end result will be a refined Colorado Urban Hydrograph Procedure which will be backed by an extensive data base and analysis.

It is hoped this has brought forth some of the complexity behind the hydrologic tools employed by engineers

(Continued on Page Fourteen)

FLOOD PLAIN MANAGEMENT

by
BILL DeGROOT

Chief, Flood Plain Management Program

WESTERLY CREEK FLOOD WARNING PLAN IN EFFECT

In 1974, the Urban Drainage and Flood Control District, Denver, Aurora, Lowry Air Force Base, and the Corps of Engineers began a master planning study of Westerly Creek. The consulting engineering firm of Camp, Dresser & McKee, Inc. was retained to do the study. During the study, a severe hazard was identified with respect to Kelly Road Dam which is located on Lowry Air Force Base immediately upstream from a Denver residential area. The consultant determined that a 40-year flood could overtop and breach the earthen embankment. Further study by the National Weather Service's Tulsa River Forecast Center indicated a possible discharge from a dam break of 26,000 cfs, and from 150 to 400 deaths.

While planning and implementation of solutions to the dam break hazard and the other problems in the Westerly Creek Basin has continued, a Westerly Creek flood warning plan has been formulated and placed into effect to provide advanced warning should a serious situation develop. The Urban Drainage and Flood Control District was the lead agency in the preparation of the plan, but its completion and implementation would not have been possible without the efforts of Denver, Aurora, Lowry Air Force Base, and the National Weather Service. A description of the plan and an example of its operation follows.

The Westerly Creek basin lies in Aurora, Denver, and Lowry Air Force Base, and the creek flows through all three jurisdictions (Figure 1). The most hazardous portion of the flood plain is located in Denver and Aurora

downstream from Kelly Road Detention Dam. A second major detention facility in the basin is Pond A-B which is located in Aurora upstream from Lowry. The capacity of Pond A-B, in terms of flood frequency, is greater than Kelly Road Dam although it will be spilling during the 100-year flood event.

The Highline Canal effectively isolates the upper basin from the lower basin for frequent runoff events. For larger events, the canal is susceptible to breaching or overtopping at almost any point in the basin. While it is possible for the canal to carry upper basin runoff out of the basin under certain conditions, it is equally possible that runoff from basins to the west can be carried into the Westerly Creek basin and spilled. In the lower basin, local drainage problems exist which will present problems to those responsible for warning, and the flood plain occupants as they try to evacuate.

The detection and evaluation of the hazard portion of the plan is designed to be put into operation in a short period of time and is relatively inexpensive. It is a people-oriented system. The weaknesses in the system are that several people have to perform in the proper manner for it to work, and it requires several communication links, with the loss of any of them hampering the effectiveness of the system.

The elements of the detection and evaluation system are:

1. The National Weather Service (NWS) office at Stapleton Airport and their Limon Radar.
2. Rainfall observers located in the drainage basin. Observer locations have been established at Lowry Civil Engineer Service Desk and at two Aurora Fire Stations. A rainfall station also exists at the NWS office which is located within the basin.
3. Staff gages to measure the depth of water and rate of rise in Pond A-B and Kelly Pond.
4. A central location to receive data, evaluate the threat, and report the condition of the flood hazard. The Lowry Command Post fulfills this role.
5. Rule curves for Kelly Pond and Pond A-B to be used by Lowry Command Post to evaluate the threat, and by Denver and Aurora to determine when to disseminate warnings. These rule curves have been developed by the District to cover variations which might result in the need to evacuate.
6. One designated location each in Denver (Denver Fire Alarm) and Aurora (Aurora Fire Dispatcher) which is operational 24-hours a day. These locations are responsible for insuring that the appropriate decision makers have the facts and can activate the warning dissemination system should the decision be made to do so.
7. Communications arrangements. Primary communication is by telephone. Denver and Aurora are working on a plan to establish radio communications. Help is also provided by a CB club and Ham operators.

As a part of their normal operations, the NWS will be alert for conditions conducive to extreme weather events. When conditions are such that heavy rainfall is possible, the NWS will issue an "internal alert" (not for public dissemination) to Lowry, Denver, and Aurora. Lowry and Aurora will alert their rainfall observers. Aurora, Denver, and Lowry review their warning and evacuation plans. It is realized that NWS quite often will not be able to detect weather conditions early enough to provide the "internal alert."



FIGURE 1. WESTERLY CREEK BASIN

The NWS continues to monitor weather conditions and, if warranted, will issue a "flash flood watch," which means it is possible that rains will cause flash flooding in a specified area (usually the specified area will be larger than the Westerly Creek basin). The "watch" goes to Lowry, Denver, and Aurora; and the media for broadcast. Aurora sends a radio equipped vehicle to Pond A-B to monitor the water level. Lowry sends a radio equipped vehicle to Kelly Road Dam to monitor the water level there. Aurora and Denver evacuation teams are placed on stand-by.

The NWS monitors the situation with their Limon Radar and confirms rainfall amounts and intensities with rainfall observers, who have an SOP on when to report to the NWS. The observer at Pond A-B reports water depths to Aurora Fire Dispatcher for relay to Lowry and Denver. The observer at Kelly Dam also reports depths to Lowry.

From this point on, the NWS may issue a "warning" or Denver and Aurora may decide to evacuate based on information provided by Lowry. When conditions warrant, NWS issues a "flash flood warning" to Aurora, Denver, and Lowry and to the media for broadcast. A warning means that flash flooding is occurring or is imminent in the specified area (usually larger than the Westerly Creek basin), and Denver and Aurora should consider issuing exacuation orders. Radio equipped cars from Denver and/or Aurora can be dispatched to Kelly Pond to observe conditions. Lowry would continue to monitor the depth of water in Kelly Pond and Pond A-B and inform Aurora and Denver of significant changes.

It is possible that the conditions on a rule curve with regard to Kelly Road Detention Dam will be exceeded prior to issuance of a warning by the NWS. If this happens, Lowry will contact Aurora, Denver, and the NWS, and advise them of the situation. Denver and/or Aurora make a decision on evacuation. Whichever city makes the decision to evacuate notifies the other and the media.

Another area of concern is the intersection of Havana and Alameda. When the Pond A-B rule curve limit is exceeded the intersection of Havana and Alameda will be closed. The closing is the responsibility of Aurora and Denver.

Once the decision to warn and/or evacuate has been made, it is necessary to quickly and efficiently disseminate the warning to the flood plain occupants. Dissemination should be made by as many different means as possible, but care should be taken to insure that warnings from different sources are similar in content. For Westerly Creek, warnings will be issued by the broadcast media and by loud speaker equipped vehicles. Confirmation of the initial warnings is desirable whenever possible. People tend to seek confirmation before reacting to a warning.

A map of areas to be warned and/or evacuated, including entity responsibility and priorities for notification has been developed and distributed to the agencies responsible for the warning. Sample messages keyed to different portions of the rule curves have been developed and distributed to the warning agencies and the broadcast media. The messages are written in fill-in-the-blank format, so they can be finalized and sent out quickly.

If the desired response to a warning is not obtained, the whole warning system will have failed. Cultivation of the desired response must begin in advance of any flood threat by heightening the public awareness of the flood hazard.

The District annually mails a brochure to all occupants of the Westerly Creek flood hazard area. The brochure contains a map of the flood hazard area and information

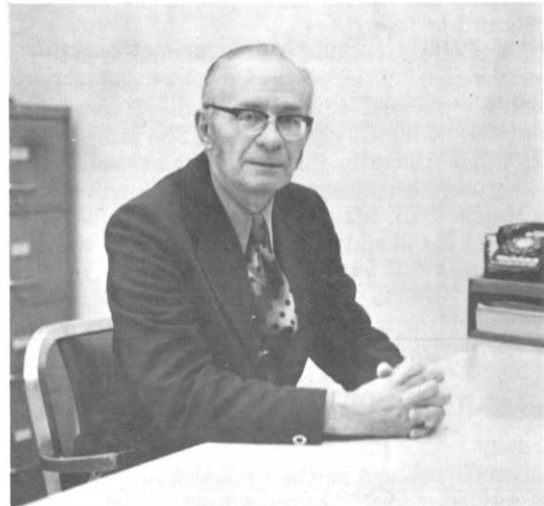
on steps to take prior to flooding (plan avacuation routes, buy flood insurance, etc.) and in the event of a flood warning. Media coverage of the hazard is also sought.

The warning plan was placed into effect this Spring. On May 4, a full-scale practice exercise was conducted. During the exercise, Lowry, Denver, and Aurora activated their operations centers and information was fed to them by the National Weather Service and observers at Kelly Road Dam and Pond A-B. A few bugs in the system were identified and have since been ironed out.

On May 17, the warning plan was activated for a real situation. The National Weather Service first issued an internal alert, and then a flash flood watch. Rainfall reports were received by the NWS from the rainfall observers and Lowry dispatched an observer to Kelly Road Dam. Fortunately, for our area, the storm moved to the north where it caused substantial flooding in Wyoming. The pond depth at Kelly Road Dam reached a depth of six feet (spillway crest is at twenty-one feet). Although, fortunately, there was no problem, the threat did exist for a period of time, and the response to the threat was done in accordance with the plan.

Efforts are now underway to automate a portion of the plan by providing an automatic stage gage at Kelly Road Dam, which would be connected by radio to receivers in the Denver, Aurora, and Lowry operations centers. This would allow for more rapid dissemination of information with fewer chances of error. It is hoped to have this system in operation by the next flood season.

MEET THE NEW BOARD MEMBERS



KENNETH M. GORRELL
Mayor, City of Arvada

Mayor Gorrell, a Colorado native, was born in Denver. He is presently Supervisor, Engineering Services for Public Service Company and a registered professional engineer in Colorado. He was first elected to the Arvada City Council in 1963 and has served continuously on the Council since that time. He was elected Mayor by the Council in 1977.

Mayor Gorrell has been a member of the Arvada Planning Commission, President of the Jeffco Governments' Association, District 1 Secreary of the Colorado Municipal League, and Arvada's representative to the Denver Regional Council of Governments. He also served as President of the Arvada Home Rule Charter Convention.

Mr. Gorrell is presently chairman of the Arvada Housing Authority and Vice President of the Jeffco Governments' Association.

MEET THE NEW BOARD MEMBERS



RUTH A. CORRELL
Mayor, City of Boulder

Mayor Ruth Correll came to Boulder in 1961 and has been actively involved in community affairs ever since. She is the mother of three grown children and her husband, Malcolm, is Professor of Physics at the University of Colorado. She has taught English in the Boulder Public Schools and in Japan.

Mayor Correll was one of the original founders of Attention Homes, has served as President of the League of Women Voters, and Chairman of the Human Relations Commission of the City of Boulder. She was a member of the Housing Authority for several years, and has served on numerous other community-related committees.

In March 1973, Mayor Correll was appointed to fill a vacancy on the Boulder City Council, then won election that year to a full four-year term. She was re-elected in November 1977 to a second four year term and was appointed Mayor by her fellow Councilmembers on January 2, 1978.

Rainfall-Runoff (Continued from Page Eleven)

on a daily basis. Regardless of the method used to estimate runoff, any one of the variables such as infiltration rates, surface storage, design storms, etc. can affect the results significantly. The foregoing underscores the need for obtaining reliable site specific information. Without it, the results can be only as reliable as the assumptions made.

Acknowledgements

To develop the information leading up to this article required an enormous effort on the part of the USGS staff and the District's student assistant/intern. The USGS provided the basic data and worked jointly with the District's personnel to quantify the study catchment parameters. Their cooperation in the rainfall-runoff data collection program has been great and commendable. Steve Hogoboom, the District's student assistant/intern has put forth a tremendous effort in processing and analyzing the data. Steve's dedication and unyielding perseverance is very much appreciated. The cooperation of the Denver Wastewater Management Division staff, particularly Nick Skifalides, in providing drainage basin maps and information has been helpful and is acknowledged.

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PLANNING NOTES

by
BEN URBONAS
Chief, Master Planning Program

During the past twelve months, the District's efforts to analyze the rainfall/runoff data collected by the USGS have been accelerated. Steve Hogoboom, our part-time student assistant/intern has been hard at work defining and redefining test basin parameters and reducing volumes of data to understandable information. Some of the preliminary findings to date are reported in this publication. ("Some Findings in the Rainfall-Runoff Data in Denver"). As a result of the data interpretation effort, more confidence has been gained in the validity of the District's hydrologic tools. Although there is room for refinement, it appears now the Colorado Urban Hydrograph Procedure gives reasonable answers.

Another joint venture with the USGS, namely urban runoff quality data collection, has resulted in a paper that was presented by Scott Tucker and myself last October at the ASCE National Convention. It was rewritten and condensed, and appears as the lead article in this issue of *Flood Hazard News*. The USGS is continuing a detailed analysis and expects to release the basic data report and the interpretive report later this year. In the meantime, we solicit your comments, ideas, suggestions, etc., on this subject.

A number of master plans and flood hazard delineation studies were underway during the last twelve months. Table I contains a summary of the status of the various studies completed, underway, and planned.

Table I
Status of Recent Major Drainageway
Planning Projects

Project	Completed Phase A	Completed Phase B	Recently Started	Planned for '78-'79
Boulder Creek Phase B			•	
Clear Creek				•
Coal Creek				•
Direct Flow - 4309				•
Direct Flow - 0067				•
Direct Flow - 3207			•	
Dry Gulch	•			
Dutch Coon and Lilley	•			
Lee and Little Creek	•			
Little Dry Creek (Adco)	•			
Lakewood Gulch			•	
Marston Lake			•	
Massey Draw and S.J.C.D. (south)	•			
McIntyre Gulch	•	•		
Ralston and Leyden Creeks		•		
Sloans Lake		•		
South Lakewood Gulch	•			
Weir Gulch Tributaries	•			

Eight master plans are scheduled for completion during 1978 with the rest scheduled for completion during 1979. Needless to say, this many planning projects required a considerable effort on the part of the consulting engineering firms in Denver. I would like to commend all of the firms involved for their high quality of professional work.

The development of a computer program to perform the calculation of the Colorado Urban Hydrograph Procedure (CUHP) was completed early in 1978. This program has sufficient flexibility to permit the user to reshape the unit hydrograph as needed whenever the standard CUHP shape is not indicated. All local governments and consulting firms in the Denver area are being offered this program. The District has arranged with Boeing Computer Service to store the CUHP program under the District's account and to permit other account numbers to access it.

Anyone wishing to use the CUHP program is asked to contribute a minor subscription charge to defray the cost of program storage and upkeep. Nine consulting engineering firms have subscribed to this service to date. The Boeing Computer Service has also agreed to store in their library files a Flood Flow Frequency Analysis program we obtained from the Hydrologic Engineering Center, making it available to anyone wishing to use it.

Access to additional District programs will be granted in the near future to all CUHP program subscribers. These programs include the above mentioned Flood Flow Frequency Analysis program and a U.S. Army Corps of Engineers modified version of the SWMM model. The Corps has modified the runoff block of SWMM to permit the use of overflow sections whenever the pipe or gutter capacity is exceeded, and have added an option that allows the use of a modified Puls reservoir routing through any desired gutter segment. Additional computer programs will be added in the future as they are developed or acquired by the District. If you are interested in joining the list of CUPH subscribers, contact me for further information.

Stormwater Quality (Continued from Page Three)

on computer models and on data collected in Tulsa and Chicago. However, that is precisely what is being done in a number of 208 planning efforts throughout the country, including Denver.

Not only is Denver water quality data not adequate, but in general, the understanding of the entire urban stormwater pollution process is still in the dark ages. Although considerable progress has been made in the last few years, there remains a lack of understanding of the sources of most of the water quality constituents, how they are introduced into stormwater, how they are affected during transport from the source to the receiving waters, and what their effects are on the receiving water's environment. Also lacking is data on the effectiveness of many of the non-structural stormwater pollution abatement techniques such as street sweeping, leaf collection, animal control, storm sewer flushing, catchbasin cleaning, etc.

For the above stated reasons, we believe that *effective* stormwater quality control on a metropolitan area basis is not yet practical. It should not be dropped and forgotten, however. The data collected so far indicates this subject needs to be addressed in greater detail and a large stormwater quality data base will be needed to define the problems, or lack of them, in each urban area. Demonstration projects that would quantify the effectiveness of various control measures are also needed. Without the knowledge gained through such efforts, any nonpoint source pollution control planning will be of little value.

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MEET THE NEW BOARD MEMBERS

TONY E. RICHTER
Mayor, City of Thornton

Mr. Richter is a native of Colorado and a Thornton resident of 23 years. He was a member of the Planning and Zoning Commission and the Industrial Commission in the early days of Thornton's incorporation. He was first elected to the City Council in 1963 but gave up his seat in 1965 when he moved to another ward. He was elected to City Council again in 1967 and re-elected in 1971. He was elected Mayor in 1975.

Mr. Richter has been active in church and union activities. He is a member of the Adams County Housing Authority Board, and Thornton's Police and Fire Pension Boards. He is also a member of the Mental Health Association and President of Water for Colorado.

Mr. Richter is married and has six children and four grandchildren.



SALLY H. PARSONS
Mayor, City of Littleton

Sally Parsons is a twenty-year resident of Littleton. She has been a member of the City Council since 1973, and was elected Mayor in 1977. She is also chairman of the Police Pension Board, a member of the Firemen's Pension Board, and a member of the Board of Directors of the Chamber of Commerce.

Mayor Parsons has also been active with the Colorado Municipal League, League of Women Voters, United Way, PTA, Republican Party, and First Presbyterian Church. She is married and has two sons.

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