FLOOD HAZARD NEWS

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CONTRACT MAINTENANCE FOR DRAINAGE AND FLOOD CONTROL FACILITIES

by Mark R. Hunter, Chief, Maintenance Program
and L. Scott Tucker, Executive Director

INTRODUCTION

Maintenance of public facilities is a matter of serious concern to all public works officials. Much has been said recently about the deterioration of public works systems; and maintenance of urban major drainageways is no exception. The purpose of this paper is to discuss the approach taken by the Urban Drainage and Flood Control District (UDFCD) in the Denver, Colorado area toward maintenance of urban major drainageways.

BACKGROUND

The Denver area suffered severe flood damages in 1965 on the South Platte River and its tributaries. Following the 1965 flooding, serious attention was devoted to addressing the metropolitan area's flood control needs. These efforts resulted in the Colorado General Assembly creating the UDFCD in 1969 by passage of the Urban Drainage and Flood Control Act. The UDFCD is a multi-jurisdictional governmental entity covering the Denver metro area which consists of the City and County of Denver, parts of the unincorporated areas of five suburban counties, and 29 incorporated municipalities. The population of the UDFCD is about 1.7 million. The area of the UDFCD is about 1,200 square miles and contains approximately 1,100 miles of major drainageways.

The 1969 enabling legislation authorized the UDFCD to levy up to 0.1 mill for operation of the organization. The initial efforts of the UDFCD involved major drainageway planning. Based on this planning, the legislature in 1973 authorized the UDFCD to levy an additional 0.4 mill for construction purposes. The concept of the construction program was that local governments would own *and* maintain the completed facilities. It soon became apparent that local governments were either unable or unwilling to provide the required maintenance on completed facilities. If the UDFCD was to continue to be involved in funding, designing, and construction of major drainageway facilities, a more sure way of providing maintenance would have to be found. This means was provided by the State Legislature when, in 1979, legislation was passed that authorized the UDFCD to levy up to 0.4 mill additional property tax for the maintenance and preservation of floodplains and floodways. Funds from the new levy first became available in 1981. This authorization will expire in 1983 unless extended by the Legislature.

DEVELOPMENT OF THE MAINTENANCE PROGRAM

With the knowledge that a maintenance program would be fully funded in 1981, the UDFCD in 1980 conducted an inventory of maintenance needs on many of the major drainageways within the UDFCD. The inventory provided the basis for establishing maintenance needs and priorities for 1981 and subsequent years.

The 1981 assessed valuation of the UDFCD was $6,768,000,000 and in 1982 the 0.4 mill levy generated $2,671,000 in property tax revenue and $173,600 in specific ownership tax revenue. In 1982 a total of $2,672,600 has been budgeted for maintenance service activities. To insure equitable distribution of the funds the UDFCD's Board adopted the policy that property tax revenues are returned to each of the six counties in the form of maintenance services in an amount equal to the taxes generated within each of the counties.

Staffing the maintenance program has been at the professional/management level. The UDFCD staff emphasis is on program development and management, project identification and development, and project management and control. The maintenance program staff consists of a Program Chief who is a registered professional engineer, three Project Engineers who are either registered or working toward registration, a Manager of the routine portion of the maintenance work and student inspectors.

The UDFCD has identified five categories of maintenance needs which have been prioritized as follows:

- First priority—UDFCD owned facilities
- Second priority—Facilities owned by other local governments but partly financed by UDFCD funds.
- Third priority—Facilities owned by other local governments and constructed by others without UDFCD assistance.
- Fourth priority—Unimproved urban drainageways on public or private right-of-way.
- Fifth priority—Unimproved rural drainageways on public or private rights-of way.

Most public major drainageway facilities are owned by local governments other than the UDFCD. Therefore, the UDFCD is primarily maintaining facilities owned by others. Major drainageway facilities consist mostly of open channels but also included are publicly owned detention facilities.

A unique aspect of the UDFCD's maintenance program is that most design services and all maintenance and construction work are performed by contracting with private consultants and contractors. In working with the private sector, controls have to be developed that are different than if the work were performed by public work forces. The approach is somewhat different for each of the three categories of routine, restoration, and rehabilitative work.

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THE ADAMS COUNTY GREENWAY — IMAGE BUILDER . . . COUNTY CATALYST

by Jim L. Considine, Director
Adams County Community Development Division

Intensive parks, trails, and other recreational development work by the Adams County Commissioners and Staff along the Clear Creek and South Platte River has provided a favorable aspect to the overall community development of Adams County, Colorado. The County, for a period of time, had a less-than-desirable image in the Denver Metropolitan Area; but, during the past four years a concerted effort has been made to improve the County image in the minds of Metropolitan Area residents. One very successful technique has been high-quality planning, design, and implementation of the Adams County Greenway. The Greenway, as proposed, will extend from Denver on the south to the Adams County Regional Park and Fairgrounds and Barr Lake State Park on the north, as well as from Jefferson County on the west to Commerce City on the east.

The cornerstone of the Adams County Greenway development is the "Rendezvous Recreation Area" which focuses on the Confluence of the South Platte River and Clear Creek. Existing development, which in fact meets or exceeds the high quality development in the Denver Metropolitan Area, includes the Vasquez Bridge, Clear Creek Low Water Crossing, Engineer Lake, assorted picnic areas, and the South Platte River Trail. The newly-constructed 350' Corten steel bridge is the longest bike, hike, and horse bridge of its kind in the State of Colorado. It connects the completed parks and trails system with Engineer Lake, which is an existing waterbody that is currently being developed as an Adams County-sponsored Colorado Division of Wildlife Urban Fishery. The existing trail, which extends from the Niver Canal at the South Platte River on the north to the Bridge to the south is 8 feet wide, five inches thick, and made of concrete. A horse path parallels the concrete trail. An additional Clear Creek Trail segment extends west from the Vasquez Bridge to Twin Lakes Park at approximately 70th Avenue and Broadway.

Plans for the Greenway are ambitious. A private gravel firm has agreed to donate to Adams County and develop an 18 acre lake located to the north of Engineer Lake along the South Platte River for use as a park to include camping, horseback riding, and picnicing. From Engineer Lake, which will have fishing areas, a pier, and picnic facilities, the trail as proposed, will connect with Commerce City. The western terminal of the Vasquez Bridge will be connected with the Denver Greenway System by a three mile concrete segment, thereby providing access to Adams County from the south and providing County residents with opportunities to utilize Denver's Greenway. It is anticipated that Twin Lakes Park will connect with the Jefferson County Trails System via the Clear Creek Corridor.

A unique aspect of the Adams County Greenway Development is the level of volunteer participation aiding project implementation. For example, the Cement Masons' Union Joint Apprenticeship Program, which is headquartered in Adams County; and representatives of the Adams County Private Industry Council, have cooperated with Community Development Division Staff to voluntarily construct over one mile of non-funded concrete trails in its system. The volunteer community service project is completed on weekends by apprentices, with materials paid for by the County Commissioners. Lunches are prepared by other volunteers from the Adams County Trails and Open Space Foundation. The entire program is indicative of implementation of the existing County Commissioners' philosophy of public-private joint ventures for community development. Increased volunteer efforts will no doubt continue to benefit residents and visitors alike.

Representatives from numerous groups, governmental entities, and the private sector have already supported the development of the Adams County Greenway. In addition to the individuals from those previously-mentioned organizations, support in one form or another has been received from the Adams County Horsemen's Association and Mountain Bicyclists; the Colorado Department of Highways, Division of Parks, Division of Wildlife, and Mined Land Reclamation Board; Public Service Company of Colorado; North Washington Water and Sanitation District; Albert Frei and Company; Brannan Sand and Gravel Company; Denver Metropolitan Sewage Disposal District; Northwest Water Corporation; Siegrist Construction Company; Western Paving Company; the South Platte River Greenway; and the Urban Drainage and Flood Control District.

Vasquez Bridge

Above and below—Cement masons working on South Platte River Trail.

Proper planning and design, significant volunteer participation, concern and involvement from relevant agencies and the private sector, and commitment by the County Commissioners and Staff is resulting in the image-building development of the Adams County Greenway. A new excitement is spreading to individuals and groups throughout the County. That excitement is a catalyst and focal point for other aspects of residential and social development. The Adams County Greenway, as a positive and visible aspect of community development, is a beneficial foundation for planned growth in the County . . . one that will prove its image is changing for the better.

Tucker-Talk

by L. Scott Tucker

Timely Comment from the District's Executive Director

Westerly Creek and the Federal Water Resources Program

Westerly Creek is a small drainage basin consisting of about 11.5 square miles where Denver, Aurora, and an unincorporated part of Arapahoe County come together. After a considerable planning effort, the Urban Drainage and Flood Control District, Aurora, and Denver have embarked on a cooperative effort to construct channel improvements in the lower part of the basin. In addition to the lower channel improvements, detention facilities are required on Lowry Air Force Base which is located immediately upstream of the channel improvements now under construction.

Because the detention facilities required are located on Lowry Air Force Base, Federal property, the Corps of Engineers was involved early in the planning process. As a part of that process it was decided that there was a federal interest in the improvements and that the Corps of Engineers would construct the detention facilities required on Lowry Air Force Base.

This has resulted in the Omaha District of the Corps preparing the necessary plans, forwarding them to the Missouri River Basin, who in turn approved and forwarded them to the Board of Engineers of Rivers and Harbors, who in turn approved and forwarded them to the Chief of Engineers of the Corps, who in turn has approved and forwarded them to the Secretary of the Army. The recommendations are now with the Secretary of the Army and from there they will go to the Office of Management and Budget with the idea being that eventually a project would be recommended by the Executive Branch to Congress for project authorization.

In the process of working with the Corps and the Congressional system I have become aware of the Federal Water Resources program and the politics involved. In fact, the realization is that there is no Federal Water Resources program, as no new water resources project has been authorized by Congress since 1976. The initial problem developed during the Carter administration when a breach developed between Congress and the Executive Branch as to who was making water policy. President Carter tried to change policy essentially without the approval of Congress. Congress balked on the basis that it was their prerogative to make policy and not the Executive Branch's. The Executive Branch simply would not accept any new water project starts and in effect stymied water resource development.

The Reagan administration seems ready to recommend new project starts but they again are developing their own policy, particularly with regard to cost sharing. Again, Congress is in the position of reacting to recommendations made by the Executive Branch. In terms of flood control the President is recommending that non-federal interests pay for at least thirty-five percent (35%) of the total cost of flood control projects. This compares with the previous or existing policy of local governments providing all lands, easements, and rights-of-way. This has typically resulted in local governments paying for about twenty percent (20%) of project costs.

The only real movement I see in Congress is in the House Subcommittee on Water Resources of the Public Works and Transportation Committee. They have held extensive hearings which covered a total of 123 proposed water projects costing well over 7.8 billion dollars. The House Subcommittee will presumably be attempting to put together a water projects authorization bill stemming from the testimony they have received. In light of the Congressional Budget restraints, however, it would seem that any new authorization bill would have rough sledding, especially in the Senate where there has been no move to draft a new authorization bill.

While the game continues in Washington, needs continue to build up and with each passing year more and more projects are added to the list. As more projects are added to the list it will become increasingly difficult to develop the support for just a few water projects that would make sense from a budget standpoint.

It appears to me that unless the House of Representatives and the Senate can get together to develop a federal policy on water resources, little will happen in the way of federal water resource development. A few projects may slip through the system here and there, but without a policy and a sense of direction developed by Congress and the Executive Branch I do not see much happening in the way of federal water resource development.

In the meantime, we keep plugging away, trying to get the Westerly Creek Project authorized. We feel we have a chance because of the large commitment already made by local government; whether or not it can be slipped through the system, however, remains to be seen.

404 Permit Process—An Issue of Local Control Versus Federal Government

On October 18, 1972, Congress enacted the Federal Water Pollution Control Act (FWPCA) Amendments of 1972 with the announced purpose of restoring and maintaining the chemical, physical and biological integrity of the nation's waters. The FWPCA established a number of goals, requirements, prohibitions, and programs to achieve this purpose and addressed the problems of water pollution by using many different approaches.

One part of the FWPCA, Section 404, has a profound effect on urban flood control activities. Section 404 of the FWPCA established a permit program administered by the U.S. Army Corps of Engineers to regulate the discharge into the waters of the United States of dredged material and of those pollutants that comprise fill material.

In 1974, the Department of Army published regulations that limited the Section 404 permit program to waters that are subject to the ebb and flow of the tide and/or waters that are presently used, were used in the past, or are susceptible to use to transport

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interstate or foreign commerce. The National Resources Defense Council (NRDC) and the National Wildlife Federation (NWF) challenged this limitation on the jurisdiction of Section 404 as being inconsistent with the intent of Congress to regulate "all waters of the United States" as expressed in the FWPCA's definition of "navigable waters". As a result of a court challenge by the NRDC and NWF, the District Court for the District of Columbia in 1975 ordered the revocation and rescission of that part of the Department of Army's regulation which limited Section 404 permit jurisdiction to "navigable waters" as the Corps had defined it.

The term "navigable waters" was eventually administratively defined by the Corps of Engineers to include the following: "Coastal waters, wetlands, mud flats, swamps and similar areas; fresh water lakes, rivers, streams that are used, were used in the past, or are susceptible to use to transport interstate commerce, including all tributaries to these waters; interstate waters; certain specified intrastate waters, the pollution of which would affect interstate commerce; and fresh water wetlands, including marshes, shallows, swamps, and similar areas that are contiguous or adjacent to the above described lakes, rivers, and streams, and that are periodically inundated and normally characterized for growth and reproduction". The Corps of Engineers' revised regulations went on to specify that permits would not be required for discharges beyond "headwaters" of a river or stream unless the interest of water quality required assertion of jurisdiction above the headwaters. "Headwaters" was defined as "the point on the stream above which the flow is normally less than 5 cubic feet per second".

We now find ourselves, as a result of the FWPCA, the court challenges by the NRDC and NWF, and the final regulations of the Corps of Engineers, to be in a position where the Federal Government controls, by a permit process, the discharge of any material into any stream in the United States downstream of a point at which the flow is normally less than 5 cubic feet per second. The Corps has modified the definition of headwater based on the median flow rather than the average flow. A median flow of 5 cubic feet per second means that 50% of the time the flow is greater than 5 cubic feet per second and 50% of the time the flow is less than this value. This approach more realistically represents normal base flows of streams with highly irregular flows such as those that occur in the Western portion of the United States. These streams could be dry at the headwater point for most of the year and still average on a yearly basis a flow of 5 cfs or greater because of high volume flash-flood type flows which greatly distort the average.

The result of the 404 Permit process is that it has become an onerous burden on public and private organizations alike. For example, a local government agency that wishes to modify a stream with its own funds because of a locally perceived and defined need must obtain a permit from the Corps of Engineers if it falls within the definition of navigable water. The Corps has attempted to mitigate the inevitable bureaucratic monster created by the permitting requirements by identifying nationwide permits and general permits, but the final result has still placed local governments at the mercy of numerous special interest groups that, through the 404 Permit process, can substantially delay or completely stop efforts by local governments to solve their own problems.

My basic objection to the system as it is now, is one of local control versus federal control. The current law, in effect, removes control from the local level and places it in the hands of the federal government. I submit that when local problems are at stake and are being solved with local monies, then local government should be able to proceed without federal interference. Special interest groups comprised of fairly small numbers of people now exert a tremendous influence over the permit process. The only way of making a basic change is for Congress to amend the definition of the "Nation's waters" to exclude small streams or to exempt local or state governments from the 404 Permit process except when a clear federal interest is involved, such as on truly navigable waters.

Assistant Secretary of the Army, William Gianelli, has been working on modifications to the 404 Permit regulation process which will help reduce some of the red tape. Secretary Gianelli's efforts should be supported, but because of the 1975 District Court decision, I do not believe the modifications will go far enough. Congress must be encouraged to amend Section 404 of the Federal Water Pollution Control Act or local government agencies will be forever saddled with the onerous requirement of getting permission from the Corps of Engineers to make improvements or repairs to streams and channels that fall within their area of responsibility and jurisdiction.

MEET THE NEW BOARD MEMBERS

JOSIE HEATH
Commissioner, Boulder County

Boulder County Commissioner Josie Heath took office on March 15, 1982, filling the position vacated by Maggie Markey.

The former regional director of the federal ACTION agency, Heath has a degree in government from Eastern Oregon College and a master's degree in counseling and guidance from the University of Wisconsin. She worked with ACTION from 1979 to 1981. She directed a six-state region from Denver offices, including the Peace Corps, VISTA, the Retired Senior Volunteer Program, Foster Grandparents and the Senior Companions Program.

Heath was also appointed to the Federal Regional Council which coordinated federal, state and local programs. For two years she served on the U.S. Circuit Court Judicial Nominating Committee and from 1977 to 1979 she chaired the Colorado Commission on Women. Prior to taking the position with ACTION, Heath was an administrator for the Community College of Denver for five years.

Heath and her husband, Rollie, have three children. They have lived in Boulder County for 12 years.

Since taking her place on the Boulder County board, she has reactivated the Boulder County Consortium of Cities Committee which holds monthly meetings to discuss areas of mutual concern to the cities and county. She has also served on the Nuclear War Education Committee and instituted the Drunk Driver Public Service Program to serve her road district and other county agencies.

DESIGN AND CONSTRUCTION NOTES

B.H. Hoffmaster
Chief, Design and Construction Program

The year has brought completion of several projects and initiation of several new ones. In the design phase, projects completed were Upper Sloans Lake from Sloans Lake to 20th Avenue and Ingalls, and a detention facility at 25th Ave. and Vance. A new design study for the reach between will be put out after the first of the year.

Little Dry Creek (Arapahoe Co.) in the City of Englewood was studied for alternatives. The study indicated it was more economical to construct a small detention facility on Englewood High School grounds and a 100-year design channel through the City than to build any more upstream dams. The design is now underway by the City and we will soon be participating in right-of-way acquisition. A model study of the conduit under Cinderella City Shopping Center was initiated by Englewood and is expected to be operational in November, 1982. This culvert has long been a source of disagreement concerning its flow capacity.

Van Bibber Creek Detention Facility has been a thorn in the sides of residents located near the proposed facility. Although the design is now complete the Board directed an alternative study be made following protests by citizens. This study is expected to be released by the end of November.

A new design start is getting underway with the signing of agreements with Westminster for design for facilities on Little Dry Creek (ADCO) in Westminster. This project is estimated to have a construction cost of nearly $3 million. It is expected that Adams County will join the study in the near future.

Construction was initiated on the second and third schedules of Little's Creek in Littleton where Northern Contracting Company was awarded a $1.8 million contract in May. Over 300 caissons have been drilled to date for this project from which the walls of the channel will hang.

Also during the year, a $1 million contract was awarded to Schmidt-Tiago Construction Company for the construction of the Upper Sloans Lake project which was an open channel from Sloans Lake to 20th and Ingalls, a distance of 3950 feet. The contractor took about half the time allocated for completion of the work. The work already has proved of benefit during intense storms this past summer, although the storm caused considerable problems to the contractor.

Following completion of Schedule II, Schedule III of Westerly Creek Project was awarded to Binder Construction Company for $1.2 million by the District and Denver. This project is from approximately Colfax and Yosemite to approximately 12th Avenue. The project consists of 1119 feet of double box culvert and 450 feet of open channel. Schedule IV will be awarded about January, 1983.

The District and Wheat Ridge awarded a construction contract to Siegrist Construction Company for $1.2 million for Lena Gulch Schedule II. The project includes 242 feet of double 10 ft. x 10 ft. box culvert and 1374 feet of channel and appurtenant street crossing. This project is planned for completion in November, 1982. Schedules III and IV will be awarded about January, 1983.

The District, Denver and Adams County awarded W. 52nd Avenue Storm Drain project to Binder Construction Company. This project was completed during the year for $464,700.

STATUS OF DISTRICT DESIGN PROJECTS

Project	Participating Jurisdictions	Status
Little Dry Creek (ARAPCO)	Englewood, Greenwood Village	Feasibility of Alternatives-Complete
Upper Sloans Lake		
Schedule I, II, IV	Lakewood, Edgewater, Denver	95% Completed
Schedule III	Lakewood, Edgewater	Begin Spring 83
Lena Gulch	Wheat Ridge	100% Completed
Hidden Lake	Adams County	Design Complete
Van Bibber Creek Detention Reservoir	Arvada, Jefferson County	Complete
South Jefferson County Drainage Flow Separation	Arapahoe County, Nevada Ditch Company, Last Chance Ditch Company	90% Completed
Little Dry Creek (ADCO)	Westminster	Start Nov. 82
Boulder Creek Slough	Boulder	Start Nov. 82

STATUS OF DISTRICT CONSTRUCTION PROJECTS

Project	Participating Jurisdictions	Cost	Status
Westerly Creek			
Schedule II	Aurora	$2,444,300	Complete
Schedule III	Denver	1,859,600	95% Complete
Schedule IV	Denver	1,185,600	Advertise Nov. 1982
Weir Gulch			
Schedule V	Denver	753,000	Complete
Upper Sloans Lake			
Schedule I	Denver, Edgewater, Lakewood	1,400,200	Complete
Lena Gulch			
Schedule I	Wheat Ridge	1,141,300	Complete
Schedule II	Wheat Ridge	1,590,600	Complete
Schedule III	Wheat Ridge	1,240,100	Advertise Nov. 1982
Little's Creek			
Schedule I	Littleton	363,800	Complete
Schedules II & III	Littleton	1,621,000	32% Complete
Little Dry Creek			
Schedule I	Englewood	691,500	Complete
Harlan Street Storm Drain	Wheat Ridge	1,644,900	Complete
Cherry Creek			
Wazee to Champa	Denver	403,800	Complete
Wonderland Creek @ 26th Ave.	Boulder	109,900	Complete
W. 52nd Ave.	Denver	440,400	Complete

RECENT ACTIVITIES IN THE PLANNING PROGRAM

by Ben Urbonas
Chief, Master Planning Program

A radar precipitation mapping study was conducted under contract to the District by GRD Weather Center, Inc. It was a cooperative effort between the Urban Drainage and Flood Control District and the Denver Regional Council of Governments which was funded by U.S. Environmental Protection Agency. The study evaluated the feasibility of using the National Weather Service radar located in Limon, Colorado for measuring rainfall amounts reaching the ground. Although much was learned about rainfall distribution, it was determined the radar equipment and its location severely limited the accuracy of predicted rainfall amounts reaching the ground.

Another task of the study was to determine if there are preferred thunderstorm corridors in the Denver region. On the basis of two years of information, definite preferred thunderstorm corridors were identified. However, before this finding can be transformed into working design information for the engineer or planner, long term rainfall data at a large number of locations throughout the Denver Region will have to be collected and analyzed. Such data will require an expensive commitment for a 10 to 20 year period.

Finally, a revised riprap section of the *Urban Storm Drainage Criteria Manual* is going to print and will be mailed out to Manual owners shortly. This section of the criteria is a state-of-the-art document which presents some technically difficult material in an easily understood format. Its preparation took nearly two years, and involved not only the District staff but also consulting services of Dr. William Hughes of the University of Colorado at Denver and Dr. Michael A. Stevens formerly from Colorado State University and now working as a free lance consultant.

We are also completing a major revision in the section of the *Criteria Manual* dealing with urban hydrology and rainfall for the Denver region. These revisions will be first released in draft form for engineers to use on a trial basis. We hope to learn from this what may need to be re-evaluated, revised or clarified.

Eight major drainageway planning studies were underway and three were completed in 1982. We expect to be starting up two or three more studies in 1983. One of the projects is expected to be the master plan for the South Platte River. Much already has been done on the South Platte River and we will attempt to consolidate, into a single document, what has been implemented and what is planned by the District and local governments for this major waterway in our region. The accompanying table summarizes the current planning activities of the District.

STATUS OF PLANNING PROJECTS

PROJECT	COMPLETED IN 81-82	UNDERWAY	PLANNED FOR 1983
Brantner Gulch		*	
Boulder Comprehensive Plan			*
City of Louisville Outfall System and Criteria		*	
Clear Creek-Youngfield thru Golden	*		
Greenwood Village Drainage Criteria	*		
Hayes Lake Outfall in Arvada		*	
Lafayette Criteria Update			*
Henry's Lake		*	
Sand Creek		*	
South Platte River			*
South Boulder/Boulder Cr. Confluence		*	
Tucker Gulch and Kenney Run		*	
Upper Slaughterhouse Gulch		*	
Upper Westerly Creek Tributary	*		

MEET THE NEW BOARD MEMBERS

MARJORIE E. "BUNNY" CLEMENT

Commissioner, Jefferson County

Marjorie E. "Bunny" Clement was appointed in December, 1981, to fill the unexpired term of her late husband on the Jefferson County Board of Commissioners. Bunny is the first Republican woman to serve on the Jeffco Board. Mrs. Clement worked closely with her husband in his capacity as County Commissioner for nine years, so she thoroughly understands the workings of government.

Commissioner Clement is active in many clubs and organizations, including the Jefferson County Republican Party; the Jefferson County Historical Commission and Society; Horsemen Associations; and, the Festival of the West. She has managed Lawrence and Clement properties, which includes apartments, commercial and residential, since 1974.

Bunny is a third generation native of the Denver area and attended the University of Colorado. She currently resides in Lakewood at the same address she has had for the past 26 years. She has two grown children and five grandchildren.

FLOODPLAIN MANAGEMENT PROGRAM

by Bill DeGroot
Chief, Floodplain Management

A significant portion of the Floodplain Management Program effort of the District is spent on the review of proposed developments in or near 100-year floodplains. One issue which comes up time and time again in our review comments is the effect of on-site detention on peak flows on major drainageways.

The issue is the discharge to be used on major drainageways when local governments in the upstream drainage basin require on-site detention to maintain developed 100-year discharges from the sites at historic rates. The District has a policy of utilizing 100-year discharges in major drainageways which are based on a fully urbanized basin. We do not recognize local, on-site detention. We only recognize regional, publicly owned detention. Developers, on the other hand, want to use discharges based on historic or present basin development, on the basis that on-site detention required by local governments will limit flows in the major drainageways to what would occur prior to development.

We have several reasons for following our present policy:

1. Although we know that on-site detention, when properly designed and constructed, can limit 100-year flood peaks from newly urbanized areas to pre-urbanized levels, the increased volumes which also occur still remain. The result is to have the historic peak discharge from an on-site detention facility occurring for a longer duration. The net effect on the peak discharge of the major drainageway from a random distribution of these on-site detention facilities is unknown.

2. In the past there has been no consistency in the design of on-site detention facilities between different local governments located within the same drainage basin, and, for that matter, in many cases there has been no consistency of design within a single jurisdiction. Again, this inconsistency results in an unknown effect on the discharge in the major drainageway.

3. Most local governments do little or nothing in the way of inspection of the construction of on-site detention facilities, and even fewer do follow-up inspections to insure that the facilities are kept in working condition over the years. Most on-site detention facilities remain in private ownership, and the adequacy of maintenance of these facilities is questionable or unknown. In fact, we know of no local government which has a readily available inventory of on-site detention facilities so that routine inspections could be made, even if funds were available to inspect the facilities.

4. Finally, we hear the stories about the detention facilities that were designed but never constructed, or were constructed but later removed.

Based on the above factors, plus our mission to reduce or prevent flood damage, we feel the prudent course is to not recognize on-site detention facilities when determining 100-year discharges on major drainageways.

Although the above discussion appears to be very negative toward on-site detention, it is not meant to imply that on-site detention has no value. Rather, it is meant to point out real problems which must be dealt with before on-site detention can truly be considered a viable, long-term solution to urban runoff problems.

There are ways to address these problems. For example, my personal feeling is that drainage and flood control facilities, including on-site detention, are public utilities, and they should be publicly owned and maintained, just as water supply and sanitary sewer systems are publicly owned and maintained. Obviously this approach would require additional public funds which are difficult to come by these days. Nevertheless, it is an idea which must be seriously considered if on-site detention is to ever reach its potential.

On-site detention is now mandated by many local governments as *the* solution, thereby taking other possible solutions, such as enlarged conveyance facilities or regional detention, out of the hands of the design engineer. Yet the mandated solution has uncertain effects, as noted earlier. Other adjustments must be allowed to be considered in order for the best, most cost-efficient drainage solution to be implemented.

An example of using other solutions is the Temple Pond project, a cooperative effort between the District, Denver and the Denver Technological Center (DTC). In this case the DTC is participating financially in the construction of a regional detention and public park facility in lieu of providing on-site detention on its development site.

Another approach which can increase the effectiveness of on-site detention and address some of the problems noted earlier is to master plan an entire drainage basin, to include on-site detention. The District has done this on one basin, in cooperation with Lafayette and Boulder County. This master plan mandates on-site detention, with specific criteria, and sizes the downstream conveyance facilities accordingly. We expect this master plan to be successful because the on-site detention and the downstream facilities have been planned together.

In summary, the District does not recognize the effect of random on-site detention on peak flows in major drainageways for the reasons cited above. However, on-site detention is a feasible solution to some problems. The obvious conclusion is that additional thought is required to develop more workable ways to utilize on-site detention.

Conference on Stormwater Detention

An Engineering Foundation Conference on Planning, Design, Operation and Maintenance of Stormwater Detention Facilities was held last August in Henniker, New Hampshire. The conference attracted 75 participants representing consulting engineers, universities, and local, state and federal governments. Over 20 percent of the participants were from outside of the United States, representing Australia, Canada, England, Nigeria, Sweden and South Africa. The conference was co-chaired by Scott Tucker, Ben Urbonas and Bill DeGroot, who took the lead to organize it. Scott and Ben also presented papers at the conference. The proceedings, edited by Bill DeGroot, are being printed at this time by the American Society of Civil Engineers.

The conference was judged by all those present to be an outstanding success. Its proceedings will provide the practitioner, the academician and the administrator with a thorough discussion on a wide variety of topics that are current in the planning, design, operation and maintenance of stormwater detention facilities. The proceedings will be available through ASCE and everyone is urged to buy, borrow or otherwise obtain a copy.

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An annual maintenance program is developed for each county based on the allocation of funds for that county. The UDFCD uses the maintenance inventory and priority of maintenance categories along with discussions with all local governments to develop the annual program. The work is divided into three types of activities consisting of routine work, restoration work, and rehabilitative work. Each of these categories is discussed in greater detail with particular attention given to the topics of definition, justification, the "contract," work criteria, and costs.

ROUTINE MAINTENANCE WORK

Definition—Routine maintenance work on improved urban drainageways consists of vegetation mowing, trash and debris cleanup, weed control, and revegetation efforts. These are work items that, on any given grass-lined drainageway, warrant a consistent level of effort year after year. It is the kind of work that can be easily anticipated, quantified and budgeted for every year.

Justification—Although routine maintenance can be easily projected, quantified, and the cost estimated, it often bogs down in the budgetary process when it has to compete for hard to acquire tax money with other public works activities of higher visibility, higher use, and more esthetic value. The direct benefit to the tax paying public is difficult to define. Unfortunately, its value becomes most visible during and immediately after a storm tests the drainageways. Even then, if the routine maintenance efforts have been successful, their merit lies in the damages they helped to prevent, a very difficult commodity to quantify. The UDFCD believes the improved urban drainageways in the Denver metropolitan area should be maintained on a routine basis for the following reasons:

a. Vegetation Mowing—Scheduled cuttings of the vegetation will stimulate continued growth and vigor of the lower parts of the plants, including the roots, which form the vital erosion resisting sod. Mowing the weeds before they go to seed will reduce their potential of taking control of the vegetative cover. Weeds aren't as good as perennial grasses in providing an erosion resistant ground cover because most weeds are annuals and therefore each year's growth, including the roots, dies after the growing season. An improved urban drainageway is a major investment of tax money. It should be kept functioning at its design level as long as possible. It is also an investment that local officials and neighborhoods can be proud of and it should be maintained in a functional manner.

b. Trash and Debris Cleanups—Often the bulk of damage occurring in a metropolitan area during flooding is caused by debris blocking culverts, channels, and bridges and effectively raising the water surface above the already flood-swollen stage. It is not uncommon for streets to be overtopped and subsequently damaged by storm waters as a result of a blocked pipe, or for culverts and bridges to be "washed out" as a result of debris accumulations on the upstream side of the structure exerting additional lateral stress on the foundation. A significant portion of the routine maintenance activities involves removing from the drainageway, on a regular schedule, any material that could contribute to debris blockage of culverts or bridges. It is far better to remove as much possible of this type of trash and debris from the drainageway before it is carried downstream by high water to contribute to flood damage.

Besides reducing the potential for flood damage, trash and debris cleanups result in a more aesthetically pleasing drainageway. The maintenance program efforts have revealed that once a drainageway is under contract for regular cleanups, the neighborhoods and the field crews of the local government will take notice and will voluntarily assist in monitoring the drainageway for any accumulations of debris. When the local creek is perceived as a clean, functional amenity to the neighborhood rather than a debris choked eyesore, all involved parties will benefit.

c. Weed Control—The type of climate Denver enjoys is also enjoyed by a wide variety of weeds. Sporadic rains and frequent sunshine in the proper proportion can bring energetic growth to the weeds. This type of weed growth is detrimental to the more desirable perennial grasses because the weeds will take a large share of the moisture, soil nutrients, and sunshine as they briefly flourish during this type of weather pattern. Weeds and grasses are in constant competition for the same commodities. If weeds are allowed to capture a large share of the available moisture, nutrients and sunshine it means there is that much less for the grasses to use. The longer it takes for the grasses to establish control of the vegetative cover, the longer the channel slopes are vulnerable to easy erosion.

The maintenance program pursues weed control by using two different approaches. The preferable method is by properly timed mowings of the vegetation. These mowings should be scheduled such that the weeds do not have an opportunity to go to seed and do not get so tall as to starve the shorter grasses of sunlight. This method is more environmentally pleasing to many; but it is slower because it does not eliminate the competition for moisture, nutrients and sunlight but only reduces it.

The second method of weed control is direct chemical application. This is a fast acting procedure and is particularly useful when the weeds have firm control of the vegetative cover.

d. Revegetation—When what was supposed to be a grass-lined channel has become a dirt-lined or weed-lined channel, specific action is justified. The Denver climate is such that a durable erosion resistant vegetative cover does not readily establish itself. The maintenance program strives to establish a strong ground cover as quick as possible in order to reduce the erosion potential from storm flows in the channel and from local flows entering the channel. If an existing grass-lined channel shows signs of disease or weed encroachment, the needy areas will be lightly scarified, the soil fertilized, reseeded, and mulched. A well established grass-lined channel is resistant to damage from most flood flows and is an aesthetically pleasing neighborhood drainageway improvement.

The Contract—During preparation of the maintenance work program for 1982, more than 25 miles of urban drainageways were included in the routine maintenance category. Over the previous several years, the UDFCD had learned enough about routine work that it became possible to prepare contract documents and solicit bids for the 1982 work. The 25 miles of work were divided into six bid packages of varying size and complexity. Bids were requested from those contractors that had previously done satisfactory routine work. In the past, contracts had been awarded by negotiating unit prices with a fairly small group of contractors. By bidding the work for 1982 the maintenance program realized far more competitive unit prices than previously experienced. The costs are below what had been anticipated, and there has not been an unusual amount of contractual problems. The UDFCD feels the contractor is making a fair profit and is able to produce the desired quality of work.

For 1983 the bids will probably be

packaged a little differently in order to balance the amount of work across the bid packages. The number of bid packages may be reduced in order to increase the amount of work to be performed in each package so that a successful bidder will receive enough work so he can organize his manpower and equipment more efficiently. The maintenance program might also try to size the packages so that a successful bidder will receive a meaningful amount of work if he succeeds in winning only one bid. Two of the packages in 1982 were won with bids in the $8,000 to $10,000 range. That's a small contract for many contractors to take very seriously.

Besides the bid form, the contract documents contain an abbreviated set of general conditions, instructions to bidders, notice of award, a contract, notice to proceed, specifications, aerial photos, and a change order form. The general conditions are reduced in scope to include only those paragraphs and clauses that address this type of work. The aerial photos are well worth their cost because of the detail they provide in defining the work limits for each work item. Performance and payment bonds are not required. The UDFCD felt there would be sufficient control through a ten percent retainage clause and the fact that payment would be made for only those reaches of the work that are complete and accepted.

Work Criteria—Based on several years experience in routine drainageway maintenance the UDFCD established the level of maintenance service desired on each drainageway.

a. Vegetation Mowing—Three mowings per year are scheduled on the drainageways that are to be maintained. The mowings are concentrated around the spring and summer growing season. The contractor is to cut the vegetation to a 4 to 6 inch height. The work limits include cutting of vegetation down to the water's edge.

b. Trash and Debris Cleanups—Three to five clean operations, concentrated around the rainy spring and summer months are sufficient to keep the channels clear of all serious accumulations of trash and debris. If, in the determination of the UDFCD, a runoff event having a return period of 5 years or greater occurs the contractor is relieved of the contract requirements. If a cleanup after such a storm is justified the cost of the operation will be negotiated with the contractor. The UDFCD set up this procedure because the debris accumulations after a major storm are so unpredictable. In general, the contractor is to clean up anything that could contribute to the blockage of a culvert or bridge. This includes tires, shopping carts, tree limbs and concentrations of domestic trash. It does not include litter pickup. If the contractor encounters debris that cannot be removed by a 3-ton winch, the contract allows that the price for that specific operation be negotiated. Car bodies and fallen trees are examples.

c. Weed Control and Revegetation—These operations are scheduled as required based on visual inspection of the drainageways. A weed control operation is accepted if after two weeks a satisfactory kill has been achieved.

Revegetation operations vary from channel to channel. The seed mix, fertilizer, mulch, watering, and particularly the time of year of the operation are controlled to the extent possible to insure that the work is successful. The preferred seeding timetable is Febru1 to May 15 and September 1 to November 15, with April being prime time. Since it's so difficult to quantify the acceptability of a vegetation operation the maintenance program

(continued on page 10)

TABLE 1—ROUTINE MAINTENANCE COST SUMMARY (1982)

DRAINAGEWAY	WORK DESCRIPTION	UNIT	QUANTITY	FREQUENCY	UNIT COST	TOTAL COST
South Platte	Mowing	Acres	27	3	$ 349.00	$ 28,269.00
	Cleaning	L.F.	52,800	3	0.154	24,393.60
Cherry Creek	Mowing	Acres	22	6	358.00	47,256.00
	Cleaning	L.F.	17,500	46	0.018	14,490.00
Lakewood Gulch	Mowing	Acres	1.5	3	365.00	1,642.50
	Cleaning	L.F.	1,650	3	0.11	544.50
Weir Gulch	Mowing	Acres	14.3	3	296.00	12,698.40
	Cleaning	L.F.	5,720	5	0.077	2,202.20
Sanderson Gulch	Mowing	Acres	23	3	296.00	20,424.00
	Cleaning	L.F.	16,770	5	0.077	6,456.45
West Harvard	Mowing	Acres	3	3	296.00	2,664.00
	Cleaning	L.F.	2,700	5	0.077	1,039.55
Main Harvard	Mowing	Acres	5.3	3	314.00	4,992.60
	Cleaning	L.F.	4,284	5	0.07	1,499.40
Goldsmith Gulch	Mowing	Acres	24	3	74.60	5,371.20
	Cleaning	L.F.	10,105	5	0.065	3,284.12
Westerly Creek IV	Mowing	Acres	2.5	3	144.00	1,080.00
	Cleaning	L.F.	525	5	0.25	656.25
Lena Gulch	Mowing	Acres	6.5	3	225.00	4,387.50
	Cleaning	L.F.	2,290	5	0.03	343.50
SJCD South, North	Mowing	Acres	5.1	3	225.00	3,442.50
Tributary	Cleaning	L.F.	4,253	5	0.03	637.95
Pleasant View	Mowing	Acres	1.5	3	225.00	1,012.50
	Cleaning	L.F.	1,432	3	0.03	128.88
Niver Creek	Mowing	Acres	10	1	100.00	1,000.00
	Cleaning	L.F.	5,700	3	0.07	1,197.00
Niver Detention	Mowing	Acres	—	—	—	—
	Cleaning	Acres	9.5	2	Lump Sum	600.00
Tributary L	Mowing	Acres	3.5	1	100.00	350.00
	Cleaning	L.F.	1,400	2	0.07	196.00
Westerly Ck. I & II	Mowing	Acres	12.3	3	100.00	3,690.00
	Cleaning	L.F.	4,625	5	0.08	1,850.00
Little Dry Creek	Mowing	Acres	3.5	1	190.00	665.00
	Cleaning	L.F.	5,800	4	0.20	4,640.00
Little's Creek	Mowing	Acres	3.9	1	185.00	721.50
	Cleaning	L.F.	1,032	2	0.07	144.48
Englewood Dam	Mowing	Acres	22	1	190.00	4,180.00
	Cleaning	Acres	—	2	Lump Sum	200.00
	Weed Control	Acres	8.3	1	66.50	551.95
Holly Dam	Mowing	Acres	5.5	1	195.00	1,072.50
	Cleaning	Acres	—	2	Lump Sum	200.00
	Weed Control	Acres	2.3	1	86.00	197.80

(continued from page 9)
staff stays closely involved during the process to be sure the contractor is satisfactorily performing his duties. Once staff is satisfied with the contractor's work the rest is left to nature.

Inspection and approval of the routine maintenance work is done by several engineering students who work part time for UDFCD. They are responsible for monitoring the contractor's progress and for preparing the monthly payment requests.

Costs—As mentioned earlier, 1982's bid process yielded lower unit prices than had been seen in previous years. This was due to direct competition and the fact that the contractors were better able to visualize economies of scale and plan their work program for the year. A breakdown of the successful bids for 1982 are shown in Table 1.

Mowing of some of the channels involves up to 90% weed eater work and is on fairly difficult terrain. The unit prices reflect the difficulty of the work as well as that particular contractor's desire to get the job.

RESTORATION WORK

Definition—Maintenance work on drainageways is not always easy to quantify into a unit of work that can be competitively bid. Other projects are so small that it's not justified to go through a full bid procedure. Examples of such restoration work in the Denver metropolitan area are: detention pond mucking, trash rack cleaning, rebuilding steep rundowns, tree thinning and clearing operations, extending trickle channels, repairing local erosion problems, and doing local channel grading and shaping.

Justification—The types of work described above are valuable to the well-being of the drainageway. Unfortunately, they are the type of work that ends up low on the priority list of the local government's work programs due to pressing public improvement needs, competition for tax money and other more politically visible projects.

Restoration work often eliminates the need for more costly rehabilitative work at a later date. Perhaps, it is drainageway maintenance work in its truest sense. If "an ounce of prevention is worth a pound of cure" is true, restoration work is indispensible in preserving and protecting valuable drainageway capital improvements. Admittedly, restoration work is not done according to sophisticated, technical construction documents prepared by an engineering firm; but at the same time, it is not work that will go away by merely looking the other way. Drainageway problems have a knack for getting worse before they get better. The UDFCD approach is to respond to a problem while it is still small rather than wait until major repairs are needed.

The UDFCD is able to get a lot of mileage from the maintenance program money. In a year's time, 15 to 20 restoration projects can be done within the UDFCD boundaries. Those projects range in size from $1000 to $50,000. This means the UDFCD is able to solve drainageway maintenance problems within many of the local jurisdictions each year.

The Contract—By its nature, restoration work is difficult to package into a competitively bid project. Out of necessity, the majority of the work is awarded through solicited proposals or direct negotiations. When proposals are solicited, staff members will routinely walk the job site with at least three potential contractors before they submit their proposals to be sure they understand the work required. Some projects are of such a nature that the work is performed on a time and materials basis. The major considerations in awarding a restoration project are; the contractor's approach to and understanding of the particular job, equipment rates, wage rates, unit prices (whenever possible), and contractor's qualifications.

The typical restoration work contract contains an abbreviated set of general conditions, a contract, appropriate detail and technical specifications, and the contractor's proposal. Detailed plans and highly technical specifications are seldom a part of restoration work.

Work Criteria—No two restoration projects are alike so it would be inappropriate to discuss the specifications for all the work items. Staff typically uses specifications that are common to the local engineering and construction community. Those work items that are paid for based on time and materials are closely monitored by staff to insure that the specifications are being met through efficient and productive use of manpower and equipment.

Costs—The type of work classified as restoration does not lend itself to being competitively bid. However, when proposals are solicited or a contract is directly negotiated, staff does compare unit prices, equipment rates, manpower rates and the contractor's qualifications and understanding of the work. This procedure allows the UDFCD to be quite selective as the staff considers the contractor's experience and knowledge of the project. The UDFCD is able to move fairly fast in awarding a contract and getting construction underway. Once work has begun, costs are monitored by co-signing the contractor's weekly time sheets which reflect his manpower and equipment hours and the cost of materials used. Staff stays in close communication with restoration contractors and regularly discusses construction strategies, work schedules, inspection needs, and work specifications. Frequent progress discussions with the contractors allow the staff to monitor the accumulated costs of the projects and compare them to the estimated project costs which are the "not to exceed" values of the contracts.

In the last 18 months the experience with contractors doing restoration work has been excellent. Their integrity and highly professional approach to the work has resulted in quality projects at reasonable costs.

REHABILITATIVE WORK

Definition—Sometimes drainageway improvements are neglected or overlooked for so long that by the time they finally do receive the maintenance attention they warrant some serious problems have developed. If these problems are complicated and/or technical in nature, the maintenance program will call on engineering consultants to assist in designing a solution. The intent of the rehabilitative work is to reclaim and rejuvenate existing installations whenever possible. Rehabilitative projects are of such a scale that they can be quantified into units of work that can be competitively bid. It is the type of work that will benefit from the investigation and detailed design provided by a consultant. Examples of rehabilitative work are: rebuilding or replacing drop structures, installing trickle channels, reshaping channels, installing riprap to correct or prevent erosion, establishing maintenance access into drainageways, and providing protection for existing box culverts, retaining walls or road crossings.

Justification—Capital improvements on major drainageways are costly investments. The original justification for them was the reduction in loss of life and property along the drainageway. If such improvements have been neglected for some time, they may have lost some of their design capacity or stability. Once again, competition for tax dollars within the local governments may restrict them from attending to the maintenance needs of all drainageways. The UDFCD rehabilitative projects are intended to return previously improved drainageways to their original design conveyence and stability. The maintenance program staff wants the neighborhood and the local government to be able to look at a rehabilitated drainageway and once again feel confident of its investment.

The Contracts—Because the UDFCD does not have a design staff of its own, all rehabilitative engineering must be done by outside consultants. Similarly, the construction is performed by private contractors. These two types of contracts are briefly discussed below.

a. Engineering Contract—For this category of maintenance work the consultant is selected through the request for proposal—interview process. The contract between the UDFCD and the consultant contains the type of provisions and scope of services found in most engineering contracts.

b. Construction Contract—Upon completion of the plans, detailed specifications, and bid package, the project is publicly advertised. Bids are publicly opened and read. If all is in order, the low bidder is awarded the contract. The construction contract documents contain the same type of conditions, provisions, forms and specifications found in other construction contracts in the Denver region.

Work Criteria—The UDFCD has established criteria and design standards for riprap, drop structures, and sloping rock drop structures. The UDFCD has also developed an *Urban Storm Drainage Criteria Manual* which provides an in-depth discussion of hydrology, hydraulics, design standards for local storm drainage improvements, and drainageway planning. The UDFCD requires that the consultant use UDFCD design criteria whenever it's applicable. The consultants often use the Colorado Department of Highways standard specifications, or they may use their own construction specifications for the contract documents provided they are familiar to the local construction community.

Costs—All rehabilitative work is competitively bid on a unit price basis. An inspector is on the job site approximately 75% of the time. It is his or her responsibility to monitor the contractor's progress and prepare the monthly progress payments.

Representative unit prices we have received on some common work items bid over the last half of 1981 and the first half of 1982 are shown in Table 2.

TABLE 2—REHABILITATIVE MAINTENANCE COST SUMMARY (7/81-6/82)

DRAINAGEWAY	WORK DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL COST
	Riprap				
Lakewood Gulch	12″	Ton	400	$ 16.70	$ 6,680.00
Lakewood Gulch	24″	Ton	920	19.95	18,354.00
Little Dry Cr. (Arapco)	12″	Ton	2000	20.00	40,000.00
Goldsmith Gulch	9″	Ton	134	23.20	3,108.80
Goldsmith Gulch	18″	Ton	1066	23.80	25,370.80
Sanderson Gulch	9″	Ton	1450	18.00	26,100.00
	Bed Course Material for Riprap				
Cherry Creek		Ton	270	14.00	3,780.00
Lakewood Gulch		Ton	760	15.90	12,084.00
Little Dry Cr. (Arapco)		c.y.	542	12.00	6,504.00
Goldsmith Gulch		Ton	270	13.92	3,758.40
McIntyre Gulch		c.y.	610	19.00	11,590.00
	Filter Fabric				
Goldsmith Gulch		s.y.	1140	2.00	2,280.00
Grange Hall		s.y.	5030	2.20	11,066.00
	Grout for Riprap				
Lakewood Gulch		c.y.	13	90.00	1,170.00
Little Dry Cr. (Arapco)		c.y.	24	105.00	2,520.00
Bear Canyon		c.y.	99	100.00	9,900.00
Sanderson Gulch		c.y.	40	105.00	4,200.00
	Gabions (w/rock)				
Lakewood Gulch		c.y.	96	85.00	8,160.00
Sanderson Gulch		c.y.	33	115.00	3,795.00
	Concrete				
Cherry Creek	6½″ thick	s.y.	1865	22.50	41,962.50
Little Dry Cr. (Arapco)	w/o steel	c.y.	188	190.00	35,720.00
McIntyre Gulch	w/o steel	c.y.	112	240.00	26,880.00
McIntyre Gulch	w/o steel	c.y.	30	300.00	9,000.00
	Topsoil				
Little Dry Cr.-Capital		c.y.	2400	5.00	12,000.00
Sanderson Gulch		c.y.	2000	3.75	7,500.00
	Common Excavation				
Lakewood Gulch		c.y.	2440	5.50	13,420.00
Little Dry Cr. (Arapco)		c.y.	6000	3.75	22,500.00
Goldsmith Gulch		c.y.	2000	2.76	5,520.00
McIntyre Gulch		c.y.	3500	4.30	15,050.00
Sanderson Gulch		c.y.	2400	5.80	13,920.00
	Common Fill				
Lakewood Gulch		c.y.	590	3.30	1,947.00
Little Dry Cr. (Arapco)		c.y.	1851	2.35	4,349.85
Goldsmith Gulch		c.y.	1400	2.76	3,864.00
McIntyre Gulch		c.y.	1200	7.25	8,700.00
Sanderson Gulch		c.y.	1800	4.40	7,920.00

CONCLUSIONS

The UDFCD maintenance program is only two years old; but in that time, the department has addressed many drainageway maintenance problems. Through the routine, restoration and rehabilitative work categories detailed above the UDFCD will continue to provide maintenance assistance to the local governments within its boundaries. Combined with the UDFCD master planning program, floodplain management program, and capital improvement program, the maintenance program completes the circle of providing good major drainageway management. It is only fitting that maintenance be a part of the overall program. The UDFCD is proud of the many improvements that have been completed on local drainageways. A good maintenance program will allow them to maintain that pride.

Editor's Note: This paper was presented at the APWA International Congress and Equipment Show, Sept. 15, 1982, Houston, Texas.

DESIGN NOTES

Supplement to Flood Hazard News (December, 1982)

Some Notes on Riprap for Flood Control and Drainage Structures

by Michael A. Stevens, Ph.D.

INTRODUCTION

Each year the Urban Drainage and Flood Control District oversees the design and construction of numerous drains, culverts and drop structures. Rock riprap is the most common material used to prevent erosion in or downstream from these structures. Some pertinent questions concerning the use of rock riprap are:

What causes the riprap to fail?

Should the riprap be uniform (all one size) or graded (assorted sizes)?

How is the size determined at the quarry or at the structure?

Do closely packed rocks make better riprap protection than loose rocks?

These questions and others are addressed and some of the writer's experiences are presented.

HOW RIPRAP FAILS

The purpose of rock riprap is to prevent the velocity of the water from eroding the bank and bed materials of the structure in which it is flowing. Failure occurs when the riprap fails to accomplish this purpose.

The riprap fails in one of two ways. First, the hydrodynamic forces of the flowing water on the particles of riprap move the riprap uncovering the underlying material. Secondly, the underlying material is removed or leached out through the voids in the riprap.

Movement of Riprap: Consider a particle of rock at rest on the surface of a riprap blanket. As shown in Figure 1, the particle is submerged in quiescent water. The pressure acting on this rock reduces its weight, the pressure being larger on the bottom of the rock than on top. Weighing less in water than in air, the rock rests its weight on its neighbors. There is no net force in the sideways directions.

In Figure 2, there is flow over the particle creating a change in the pressure distribution, mainly on the top portion of the particle. Experiments by Urbonas [7] indicate the following. On the top at the upstream side where the flow impinges, the pressure is greater than hydrostatic. On the top at the downstream side, the flow separates from the particles causing the pressure to be less than hydrostatic and sometimes less than atmospheric. On the bottom half, the pressure remains essentially hydrostatic.

The change in pressure caused by flow over the particle of riprap causes a net force trying to lift the particle out into the flow where it will be washed downstream. As shown in Figure 3, the upward component of this force is termed the lift force; the downstream component is called the drag force.

As long as the force and moment caused by the weight of the particle is greater than the force and moment caused by the hydrostatic pressure, the particle will remain at rest.

The hydrodynamic pressure forces increase as the square of the velocity. As the velocity increases, the particle becomes less stable. At the threshold velocity, the moment caused by the hydrodynamic force just balances the moment caused by the weight of the particle. Any further increase in velocity will cause the particle to roll out and move downstream.

It follows then that the two main factors determining the stability of the particle are the velocity of the flow and the weight of the particle. The design problem is to predict the velocity of the water and then select a riprap with enough weight to resist the hydrodynamic forces.

Criteria for the design of riprap come from two sources; field experience and model studies. The inquiring reader is referred to the wealth of literature on this subject. An excellent place to start is with Izbash and Khaldre's book on the hydraulics of river channel closure [3] and the California Highway's practice on bank and shore protection [2].

Leaching: It was shown by Posey [5] in experiments conducted in the Iowa State University's Hydraulics Laboratory that it is flow through the voids in the riprap in the downstream direction which causes the erosion of the underlying material. He covered a thick layer of white sand with the thinest layer of red sand of the same size and with particles of potassium permanganate. Through the side of his flume he could observe the streams of potassium permanganate and any movement of the sand.

At low flows, there was no movement of the sand and the streams of dye in the riprap were roughly parallel to the bed, indicating flow through the riprap is driven by pressure differences originating from the main flow. As the

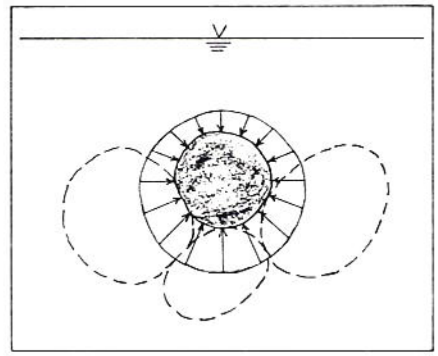

FIGURE 1
Pressure on the surface of a particle of riprap in quiescent water. The pressure is hydrostatically distributed being larger on the bottom than on the top; thus making the rock weigh less in water than in air. The rock rests lightly on its neighbors.

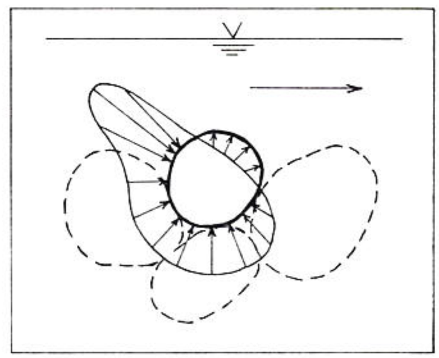

FIGURE 2
With flow over the rock, the pressure distribution changes, mainly on the top portion of the particles. On the upstream side the pressure is high where the flow impinges and can be very low where the flow separates from the particle at the top and downstream side. The pressure on the bottom remains essentially hydrostatic.

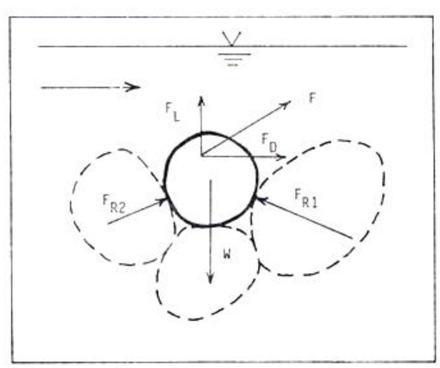

FIGURE 3
The hydrodynamic pressures caused by flow over the riprap result in a force F tending to rotate the particle from its rest position out into the flow. The upward component of this force F_L is known as the lift force; the down stream component F_D is called the drag force. Until the velocity becomes large, the weight of the particle holds it in place against its neighbors; the reaction forces of the neighbors being F_{R1} and F_{R2}.

discharge was increased, the intensity of the seepage through the rocks increased until ". . . finally violent bursts began to move the red sand at several points" [5, p. 533]. The pressure gradient in the riprap is caused by different hydrodynamic pressures on the surface rocks.

From this test, it can be deduced that the seepage velocity through the riprap increases as the flow velocity above the riprap increases. The seepage velocity is greater when there are more large voids in the riprap. It is not the number of voids but the size of the voids which is the critical factor.

WHAT MAKES THE BEST RIPRAP?

The best riprap is a mixture of rock particles which do not move at the design velocity of the flow and, when placed in minimum amounts, prevents leaching of the underlying material.

Movement: Suppose we need a certain median rock size to prevent movement of riprap at the design discharge. Should all the particles be this same size or should the riprap be well graded? Laboratory tests by Anderson et al. [1] provide the answer to this question. They selected three gradations of riprap, each having the same median size of 0.875 inches. The gradations are shown in Figure 4. A well-graded riprap has a large gradation coefficient, o, which is defined as:

$$\sigma = 1/2\left[\frac{d_{84}}{d_{50}} + \frac{d_{50}}{d_{16}}\right]$$

Here, d_{84}, d_{50} and d_{16} are the particle sizes for which 84, 50, and 16 percent of the riprap, by weight, is finer. Really σ is a measure of the slope of the gradation curve. When all rocks are the same size, $\sigma = 1.0$.

The three types of riprap were tested under the same flow conditions, and the amount and sizes of riprap removed by the flow were measured. The amount of riprap removed was least for the uniform riprap and most for the well-graded riprap. With the uniform and slightly graded riprap, the larger sizes moved first, these being isolated on the surface. With the well-graded riprap, the fine and intermediate sizes moved first; there were no large isolated particles exposed.

The ideal riprap has a gradation coefficient such that all sizes of the material which first move are the same as those in the blanket. That gradation coefficient is approximately 2.0. When the gradation coefficient is smaller, the large particles move first leaving the remaining riprap smaller than desired. When the gradation coefficient is larger, the fine and intermediate sizes

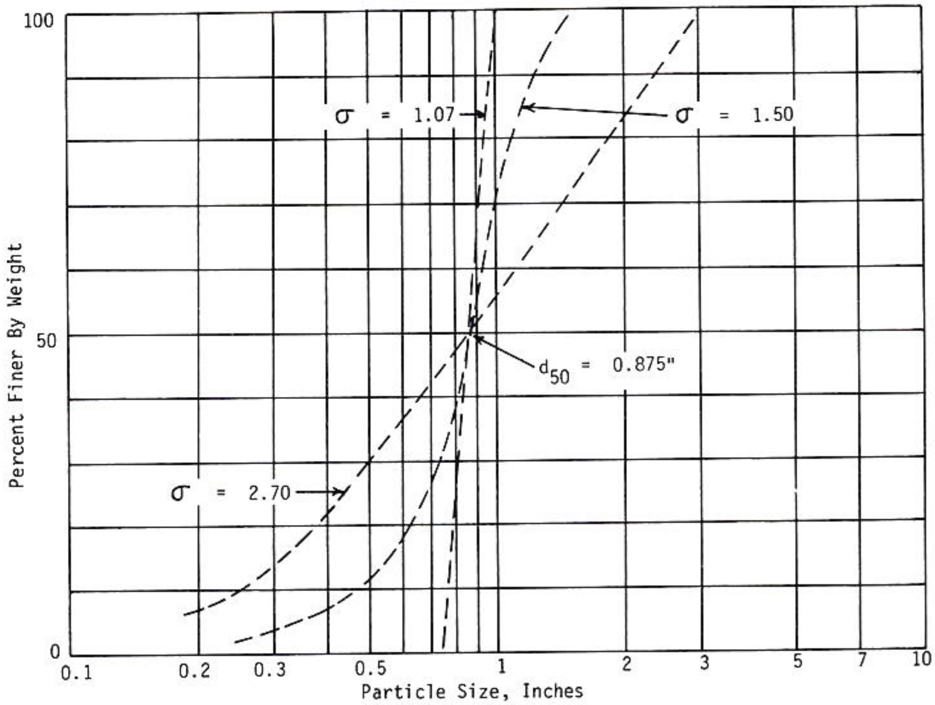

FIGURE 4
In their laboratory experiments, Anderson et al. used 3 gradations of riprap each with a median size of 0.875 inches. The well-graded riprap ($\sigma = 2.70$) has particles as large as 3 inches, whereas for the uniform material ($\sigma = 1.07$), the largest particles are only 1 inch in diameter.

move first, making the remaining riprap larger. However, why pay for material which is going to be washed away without any benefit?

Posey's [5] examinations were less comprehensive. He graded his riprap according to the Terzaghi-Vicksburg specifications for gradations of filters [8] and expected that the current would remove the finer particles from the mix first. Such was not the case. Posey used as the protective blanket for the underlying loess (d50 = 0.022 millimeters) a layer of well-graded sand with approximately 15 percent fine gravel. He did not report the gradation coefficient but it was probably in the order of 3.0.

Although the studies of Anderson et al. and Posey do not provide a definitive value for the gradation producing the best protection against movement, the studies indicate that a "best" value exists. That is, σ should be approximately 2.0.

Leaching: Suppose a median rock size to prevent movement has been selected. How does one go about protecting the underlying erodible material from leaching?

One way is to provide a very thick layer of riprap thus isolating the pressure gradients in the flow at the surface of the riprap from the erodible material by distance. Posey [5] tried this with uniform riprap and found that it is uneconomical. A great increase in the thickness of the riprap layer is required for only a slight increase in the allowable (non-leaching) velocity. Posey was better able to protect the loess using a 2-inch thick layer of Terzaghi-Vicksburg mix than by employing 8 inches of uniform material having a d_{50} equal to 0.75 inches, the same size as the d_{100} in the Terzaghi-Vicksburg mix.

The results of Anderson et al. [1] were similar. It required a thickness $t = 3d_{50} = 2.63$ inches to prevent leaching through their uniform riprap ($\sigma = 1.07$) with $d_{50} = 0.875$ inches. For $\sigma = 1.50$, they needed a thickness $t = 2d_{50}$ to prevent leaching.

Anderson et al. continued their experiments by placing different fine gravel ripraps and filters over different sand bases. The outcomes were that the effects of the protective layer depend strongly on the number of layers of riprap and not very strongly on the size of the base. A layer of protection or filter was defined as one median diameter thick. One layer of 16-mm riprap on top of one layer of 4-mm filter provided better protection against leaching than 2 layers of 16-mm riprap. The riprap and filter required only 6.66 pounds of material per square foot whereas 2 layers of riprap required 10.73 pounds per square foot. Consequently, using thin layers of riprap and filter provided better protection with less material.

The conclusions are that leaching through riprap decreases with increasing thickness and gradation coefficient σ and filters are more efficient in preventing leaching than many layers of riprap.

Packing: Compacting the riprap so that particles in the riprap form a tight matrix is effective in preventing both movement and leaching. The interstices are made smaller and the surface of the riprap is smoother so hydrodynamic forces are smaller.

In his laboratory experiments, Olivier [4] found packing increased the allowable discharge appreciably. Other factors being equal,

$$q \simeq (1-n)^{5/3}$$

in which q = allowable discharge per unit width of structure, n = porosity of the riprap. Packing decreases the porosity possibly by as much as 30 percent.

Packing can be accomplished by hand placing fine and intermediate sized rocks in voids or by compacting the riprap with machinery. Crawler tractor tracks do a very good job of compacting and leaving the surface smooth but break a few larger rocks.

The Compromise: The choice of gradation coefficient of approximately 2.0 and a riprap thickness of 1.75 to 2.00 times d_{50} appears to be the best compromise. For this riprap, the interstices should be relatively small and poorly connected, preventing leaching; there should be few large isolated and exposed rocks which can be easily moved; and the fine and intermediate materials should move very little at the design discharge. If the riprap is large, filters designed using the Terzaghi-Vicksburg specifications should be used.

The number of layers of filter is another compromise. Multiple layers of progressively smaller filter material is the most efficient use of material. Less pounds of gravel and sand are used per square foot of area. However, it may be less expensive to provide only one filter in a thicker layer. The choice depends on how much material is being placed. More control can be justified when large volumes of materials are being placed. Thin layers must be carefully placed, whereas thick layers can be spread around without the benefit of survey stakes marking the surface of the layer.

INSPECTION

At the Quarry: The inspector should be at the quarry when the contractor begins to process the riprap for the job. Normally, rock particles are picked up with a front-end loader at the blasted face of the quarry and dumped on a grizzly. The grizzly is a sieve made of steel rails placed parallel to each other a fixed distance apart. Rocks smaller than the grizzly spacing fall through onto a conveyor belt which lifts them up to a screen where the fines are shaken out and wasted. Rocks larger than the grizzly spacing roll down the rails into a pile which is saved for other jobs.

The inspector can check to make sure the grizzly openings are no bigger than the maximum size called for in the specifications. He should determine immediately the size and gradation of the material being produced. If the material is too small, the screens can be changed to eliminate more fine particles from the riprap. To upgrade the median diameter of the riprap 2 inches may require the elimination of as much as 30 percent of the material passing the grizzly.

At the quarry, my technique is to ask the loader operator to pick up a bucketfull of riprap which he thinks is representative of the stock pile and place this sample aside. I use a steel meter stick to measure the intermediate diameter of all the rocks in the sample larger than 3 inches. If the rocks smaller than 3 inches are a significant portion of the sample, they are sieved and weighed.

The weight of any particle is

$$W = C\gamma_S \pi k^3/6$$

in which γ_s = density of the solids in the rock, k = intermediate diameter, C = a coefficient.

Table 1
Determination of the Median
Intermediate Axis Size

Size Class k, mm	Number of Stones, n	nk³ mm³	Sum of nk³ mm³	Percent Finer
40	2	128,000	128,000	0.0
50	5	625,000	753,000	0.1
60	7	1,512,000	2,265,000	0.2
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
190	6	41,154,000	443,523,000	48.6
200	3	24,000,000	467,523,000	512.2
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
320	1	32,768,000	815,334,000	89.3
460	1	97,336,000	912,670,000	100.0

In the Denver area, the specific gravity of rock has been determined for all the principle quarries. The range in values is from 2.55 to 2.86. When the particles are spheres, C = 1.0. Cubes have C = 6/π. For one quarry in the Denver area the smaller fractured sizes have a C value of 1.55. Often specifications call for rock of a certain equivalent spherical diameter, d_S which is given by the expression

$$d_S/k = C^{0.33}$$

One needs to determine the value of C for his quarry by measuring the intermediate axes and weighing many stones.

For example, a stone having a specific weight γ = 2.55 grams per cubic centimeter, an intermediate axis K = 6.5 centimeters and weighing 613 grams has a coefficient

$$C = 613/(2.55\,\pi\, 6.5^3/6) = 1.68$$

Its spherical diameter is

$$d_S = 6.5 \times 1.68^{0.33} = 7.7 \text{ centimeters}$$

A representative sample containing all sizes of particles should be selected to determine C. Values of C should be correlated with their intermediate axis dimension to determine if C changes with size. The number of rocks in the sample should be large enough so that the mean and standard deviation of C values is stable. If C does not vary with size, 200 rocks would be a suitalbe sample. When C varies with size, 200 rocks should be chosen for each size class - large, intermediate and small.

For riprap with an intermediate diameter of 6 to 8 inches and a gradation coefficient of approximately 2.0, a person can measure and record the intermediate diameter of 250 to 300 rocks per hour. With two people, one measuring and the other recording, the rate more than triples. A sample of 400 to 1000 rocks is usually adequate. An example of determining the size distribution of a riprap is given in Table 1.

The filter material can be batched from stockpiles of uniform gravel and sand or screened from pit-run gravel. Samples of filter material from pit-run are analyzed in the laboratory for size and gradation. If there is a substantial amount of sand and finer materials in the filter, then the moisture content should be determined immediately prior to transport to the site, so that only the solids are paid for—not the water.

At Construction Site: At the site, the filter material is placed first. If the contract calls for, say, 6 inches of sandy gravel filter, it is convenient to convert this to the number of pounds per square foot. If, for example, the porosity is on the order of 0.3, then 58 pounds of filter is required for each square foot of surface area. This is equivalent to 0.26 tons per square yard.

Using weight instead of volume, one can haul in the correct weight of filter or riprap for his structure. When spread diligently the structure is finished. Structures requiring 24 inches of riprap need approximately one ton of material per square yard.

When the material arriving at the site seems small, I identify a sample of about 200 to 400 rocks and measure them. A shortcut is to divide the sample into two piles, one containing all the large rocks. The number of rocks in each pile is counted. Then a search is made in the large pile to find the rock for which 12 percent (by number) of the rocks are larger. This single rock is close in size to the median or d_{50} size.

When the riprap is hauled in two sizes, the large rocks should be spotted in the structure first, in the most critical positions. For example, at culvert outlets, erosion first occurs on the centerline of the barrel immediately downstream from the outlet. It is prudent to place a few more large rocks in this area and a few less high on the side slopes where the velocity is low.

On riprap paved chutes, it is the crest and the portion of the chute immediately downstream which usually erodes first. Lift and drag forces here can be large because of the seepage through the riprap at the crest. Often large rocks move at the crest even when the flow is less than the design flow. Smith and Murray [6] suggest that a concrete wall or sheet pile wall be used to form the crest. In their model, the riprap failed first at the downstream end of the chute but the failure was not catastrophic. Riprap from upstream rolled down to fill the void created at the failure point. Thus, the failure point appeared to migrate upstream to the crest where it can be arrested by the wall and an extra riprap supply immediately downstream from the wall.

A riprapped chute designed in such a manner will survive a peak discharge 30 percent higher than the design flood. The damage can be repaired easily by placing some more riprap downstream of the wall.

CONCLUSION

In closing, riprap functions better in structures where the flow is controlled. That is, where the design discharge is not exceeded such as is the case in irrigation canals. Where there is no control of the peak discharge, the design flow will be exceeded. The concern is then how much damage will occur. We would like to design riprapped structures which can in some manner survive floods larger than design without expending extra amounts of money. That is the challenge. The newest design procedures call for an assessment of the costs and damages to structures for all floods. The design having the "least economic cost" (capital cost plus annual maintenance) is sought.

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Riprap used to construct a spillway for a small detention pond.

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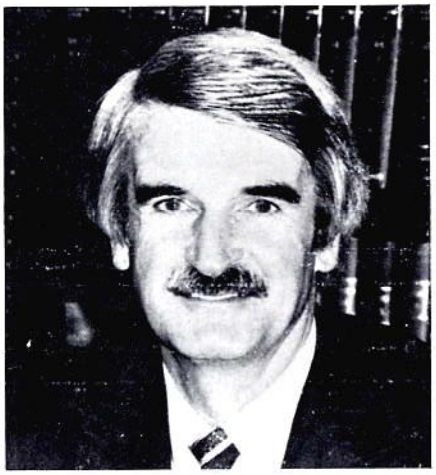

FRED ALLEN
Mayor, City of Westminster

Fred Allen has been on the Westminster City Council since 1973. He was elected Mayor in 1981.

Mayor Allen is an independent real estate appraiser. He was previously Staff Vice President for the Savings and Loan League of Colorado. He has a Bachelor of Arts Degree from the University of Colorado.

Mayor Allen was Westminster's representative to DRCOG (1976-77), a member of the Colorado Municipal League Executive Board (1975) and a member of the Adams County Mental Health Center (1975-81). He is a member of the U.S. League of Savings Associations, associate member of the Society of Real Estate Appraisers and Vice Chairman of the Adams County Housing Authority.

Mr. Allen has seven children. His wife Susanne is Deputy Treasurer for Adams County.

FLOOD HAZARD NEWS
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