DELL URICH GOLF COURSE
RANDOLPH SOUTH DETENTION BASIN

TUCSON, ARIZONA

1997 OUTSTANDING CIVIL ENGINEERING ACHIEVEMENT AWARD SUBMITTAL

DECEMBER 17, 1996

Official Entry Form
1997 OUTSTANDING CIVIL ENGINEERING ACHIEVEMENT
Award Program

General Information

Please supply all information requested below, and complete the 150-word project description on the back of this form.

Entries must meet OCEA eligibility requirements and be nominated by an ASCE District Director. Entries also should follow entry format and preparation guidelines stated in the OCEA Entry Kit.

Eight copies of each entry must be submitted. Entries will not be returned, and become the property of ASCE.

Entries Due: January 6, 1997

Send to: Natalie Soulier
Senior Coordinator, Public Relations
American Society of Civil Engineers
1015 15th Street, NW, Suite 600
Washington, DC 20005
202/789-2200

Project Information

Dell Urich Golf Course/Randolph
Project Name (exactly as it should appear on plaque)
South Detention Basin

Tucson, Arizona
Project Location (City, State)

April, 1996
Completion Date

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Office Use Only:
- ☐ Entry Received, Date: ______
- ☐ Nomination Letter Received, Date: ______
- ☐ Receipt Letter Mailed, Date: ______
- ☐ Status Letter Mailed, Date: ______

Entry Number

Project Description

Please use the space below to describe your project in no more than 150 words. The description should highlight how the project meets the OCEA judging criteria: contribution to the well-being of people and communities; resourcefulness in planning and solving design challenges; pioneering in use of materials and methods; innovations in construction; impact on physical environment; and beneficial and adverse effects, including aesthetic value.

Consider this example for the 1996 OCEA winner:

The Ted Williams Tunnel: Boston's Central Artery/Tunnel Project -- the largest, most complex highway project ever undertaken in an American city -- passed its first major milestone when a new tunnel under Boston Harbor opened to commercial traffic on schedule and within budget on December 15.

The 1.6-mile, $1.3-billion tunnel to Logan Airport, includes a .75-mile underwater section with 12 binocular, 325-foot steel tubes in a trench dredged on the harbor floor and connected to land-based cut-and-cover tunnels. Taking four years to construct, the project also includes the largest circular cofferdam and the deepest immersed tube land tunnel interface in North America.

The tunnel reduces congestion and pollution from stalled traffic, and helps advance the construction of an 8- to 10-lane underground expressway to replace the seriously overcrowded elevated highway (I-93), built in the 1950s, that splits downtown Boston. The new Central Artery is being built directly beneath the old 6-lane road, which will be demolished when the underground highway is finished.

The Randolph South Detention Basin/Del Urich Golf Course is a remodeled 18-hole PGA-level municipal golf course that serves as a detention basin to provide 100-year flood protection to residential areas along the Arroyo Chico, an intermittent stream in central Tucson. The existing 100-year peak discharge of 3100 cfs is reduced to an outflow of 240 cfs. The outflow matches the capacity of the arroyo, which runs through a heavily-vegetated desert riparian corridor within an historic residential neighborhood. The total storage volume of almost 500 acre feet is contained within six interconnected sub-basins that were configured to fit within the fairways and "out-of-play" areas between elevated tees and greens on the reconstructed course. The multi-disciplinary team for the $12.5 million project included engineers, landscape architects and a golf course designer. The design and construction phases of this multipurpose project took two years and were carried out as a cooperative effort between the County, City and Federal governments.

Dell Urich Golf Course/Randolph South Detention Basin
OCEA Project Summary

The watershed of the Arroyo Chico, which covers the central part of the city of Tucson Arizona, is fully urbanized and experiences severe and frequent flood damages. Urban encroachment into floodplain has occurred over the years, severely limiting the opportunities and the rights-of-way needed for implementation of traditional flood control measures like channel improvement, bank protection/levee, structure relocation, etc. Another important constraint is imposed by the desire of the residents and public representatives for preserving the riparian values of the existing watercourses, and the historic character residential neighborhoods withing the watershed. One such area that is subject to flooding almost every year is the residential neighborhood of Colonia Solana, which is listed on the National Register of Historic Places.

Consideration of various flood control alternatives indicated that utilization of the existing Randolph South golf course (located immediately upstream of Colonia Solana) as a detention basin is the best alternative which will satisfy the above mentioned constraints and provide the necessary reduction in peak flood flow in the downstream areas. An innovative approach for the design of the detention basin was necessitated because of the following two factors: the need to preserve the golf course function of the Randolph Park which provides significant economic benefit to the community; and the prohibitive cost for a single detention basin which required high embankment and a Probable Maximum Flood (PMF) spillway under state dam safety criteria. The innovative design consists of a series of six interconnected basins excavated within the golf course. Individual basins were designed such that PMF spillway will not be required under dam safety criteria, and were configured to fit into areas between fairways and greens to preserve the use of the site as a golf course. The project was a cooperative effort between the City of Tucson Department of Parks and Recreation, the Pima County Department of Transportation and Flood Control District, and the U.S. Army Corps of Engineers, Los Angeles District.

The Randolph South detention basin is a multi-objective project, that provides flood protection, recreation, and environmental enhancement to the city of Tucson. In terms of flood control, the basin directly impacts 225 structures downstream by preventing flooding from events up to the 100-year storm. It will combine with another detention basin project downstream (currently under design) to provide protection to another 750 residential and commercial structures in the central part of downtown Tucson. All of these structures will be eventually removed from the 100-year regulatory floodplain. In terms of recreation, the Randolph South detention basin not only preserves the existing use of the land as a revenue producing municipal golf course, it actually enhanced the golf experience. The flat, relatively uninteresting golf course, that was once characterized as a "pool table", was replaced by a completely redesigned PGA-level course that includes interesting and challenging topography, with new turf, lakes, and cart paths. In terms of environmental restoration, the project was designed to limit the impact to the many mature Eucalyptus and Alleppo Pine trees, and over 1100 new trees were added.

The interconnected design of multiple detention basins was the key to providing flood protection and recreation in the same space. Preliminary design attempts looked at storing floodwater above ground by placing a single embankment at the downstream end. This concept was rejected since it would back water onto the golf course, damaging tees and greens, during relatively frequent flow events, and would also be classified as a jurisdictional dam by the Arizona Department of Water Resources - Dam Safety Division, requiring construction of PMF spillway. Subsequent design focused on a combination of excavated basins designed to work with a new layout of the golf course. Because of the relatively steep 2% slope of the overland area, it was possible to construct a cascade of basins through which flood flows were conveyed by gravity via pipes and weirs. A non-jurisdictional embankment at the downstream end collects flows off of the main watercourses, and also serves as the final control point for remainder of the basin. The final outflow is metered to the existing downstream watercourse via a single 5' wide by 3' high concrete box culvert. Given a total storage volume of almost 500 acre feet, the without project design peak discharge of 3100 cfs is reduced to 240 cfs at the outlet. The six interconnected basins are located within the fairways and out-of-play areas of the course. Tees and greens, which are expensive and easily damaged by the floodwaters, were located in the high ground areas, above the 100-year flood stage. Concrete cart paths with small bridges, and careful design of the fairways through the basins, make golf play possible during the frequent flow events. State of Arizona dam safety requirements were avoided by distributing the required storage volume over the six basins, and keeping it predominantly below ground.

The Randolph South golf course is one of the busiest municipal courses in the United States, and provides significant revenues to the Tucson Department of Parks and Recreation. The adjacent Randolph North golf course, is frequently used for PGA and local golf tournaments. Construction of the project, which began in May of 1995, was carefully planned in order to minimize loss of revenue, avoid disruption of scheduled golf events during the spring of 1996, and minimize impact to the existing mature trees. The rough earthwork and hauling away of 400,000 cubic yards of excess material took place on an overnight schedule during the summer months. Installation of structures, finished grading, irrigation, and sodding took place in phases during late 1995 and early 1996. The completed project, dedicated as the "Dell Urich Golf Course", was open to the public in April 1996, and has received excellent reviews from local golfers. It was also chosen as the site of the 1996 NCAA Men's and Women's Cross Country Championship, which were held in November.

The project has been tested by its first significant flood event. In the early morning hours of September 3, 1996, 1.6 inches of rain fell over a 2-hour period (roughly a 5-year event), and an estimated peak inflow of 420 cfs (which is greater than the downstream channel capacity) was reduced to a peak outflow of approximately 65 cfs, with roughly 60 acre feet of storage within the detention basin. The storm ended at 8:00 a.m. and the course was open for play at noon.

PHOTOGRAPHS

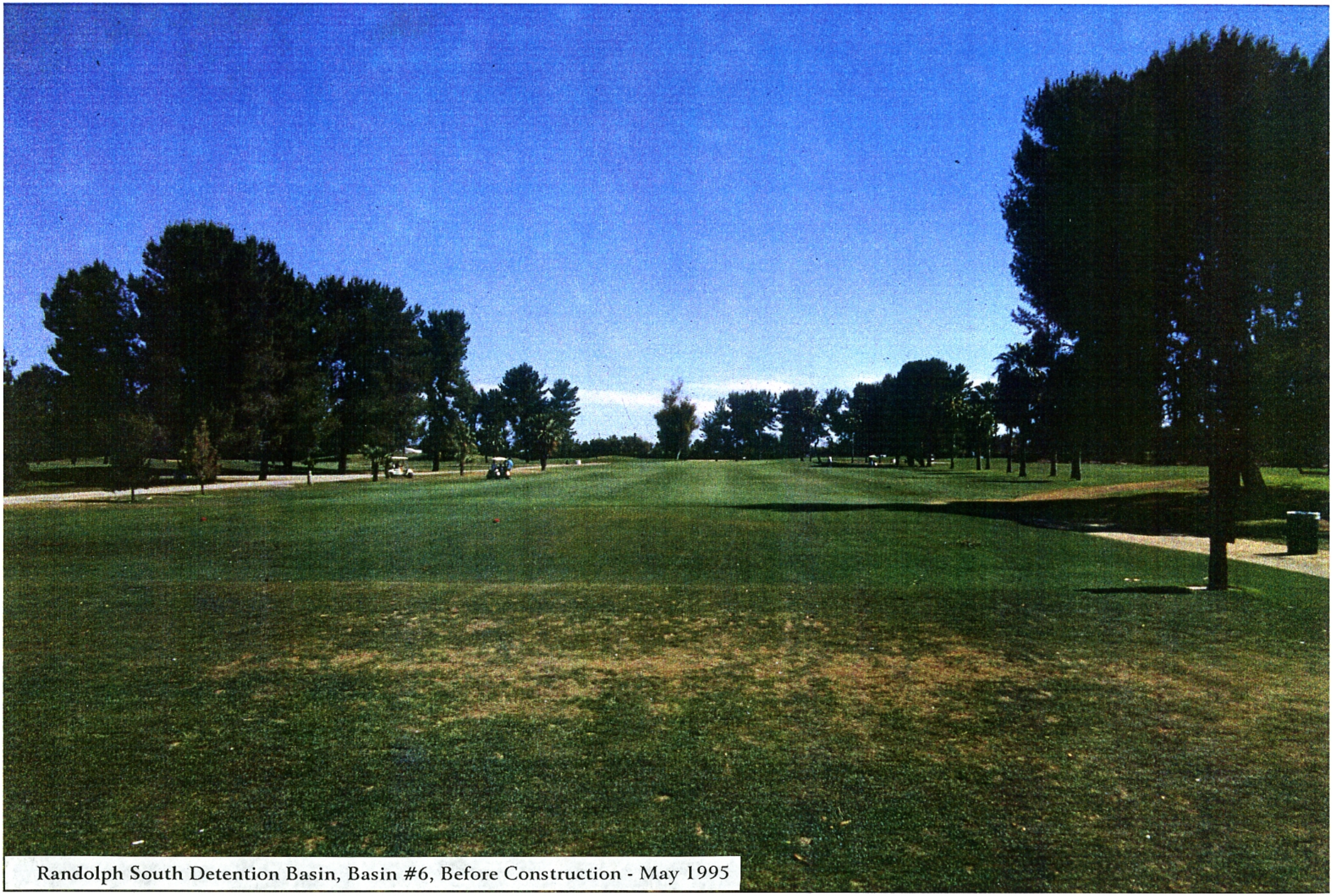
Randolph South Detention Basin, Basin #3, Before Construction - May 1995

Randolph South Detention Basin, Basin #3, After Construction - March 1996


Randolph South Detention Basin, Basin #3, Flood of September 3, 1996

Randolph South Detention Basin, Basin #5, Before Construction - May 1995

Randolph South Detention Basin, Basin #5, After Construction - May 1996



Randolph South Detention Basin, Basin #6, Before Construction - May 1995

Randolph South Detention Basin, Basin #6, After Construction - April 1996

Randolph South Detention Basin, Basin #6, NCAA Cross Country Championship - November 1996

PAPERS

Innovative Approach for Peak Discharge Reduction In an Urban Environment Using Multipurpose Detention Basin

Douglas Lantz, Zbigniew Osmolski and Fazle Karim
Pima County Department of Transportation and Flood Control District

Presented to the 20th Annual Conference of the Association of State Floodplain Managers
June 10-14, 1996
San Diego, California

Introduction

Flood flows from the Arroyo Chico and its tributaries cause severe and frequent flood damages to the central part of the City of Tucson in Arizona. One particular area which is subjected to flooding almost every year, because of the limited capacity of the stream channel passing through the area, is the residential neighborhood of Colonia Solana which is listed on the National Register of Historic Places. As the watershed is urbanized, urban encroachment into floodplain has occurred over the years severely limiting the rights-of-way needed for implementation of traditional flood control measures like channel improvement, levee, structure relocations, etc. Another important constraint is imposed by the desire of the residents and elected public representatives for preserving the historic character of the neighborhood.

Consideration of various flood control alternatives indicated that utilization of the Randolph South golf course, located immediately upstream of the historic neighborhood, as a detention basin is the best alternative which will satisfy the above mentioned constraints and provide the necessary reduction in peak flood flow in the downstream areas including the historic neighborhood of Colonia Solana. An innovative approach for the design of the detention basin was necessitated because of the following two factors: the need to preserve the golf course function of the Randolph Park which provides significant economic benefit to the community; and the prohibitive cost for a single detention basin which required high embankment and a Probable Maximum Flood (PMF) spillway under state dam safety criteria. The innovative design consists of a series of six interconnected basins excavated within the Randolph South golf course. Individual basins were designed such that PMF spillway will not be required under dam safety criteria, and were configured to fit into areas between fairways and greens to preserve the use of the site as a golf course. The project was designed in cooperation with the Corps of Engineers, Los Angeles District, and the City of Tucson.

Hydrology

The Randolph South detention basin is part of the larger Tucson Drainage Feasibility Study, currently underway by the U.S. Army Corps of Engineers, which covers the 11.35 square mile watershed for Arroyo Chico at the

Santa Cruz River (Figure 1). As part of the study, an HEC-1 rainfall- runoff model was constructed and calibrated for this watershed. The basic runoff criteria for the model (S-graph, n-values, and loss rates) were determined by reconstituting six observed runoff events on High School Wash, which had rainfall and runoff gages operated by the University of Arizona. The model included the Phoenix Valley S-graph, a lag equation in which Manning's n- value ranged from 0.035 - 0.050, and uniform loss rates ranging from 0.5 in/hr to 2.0 in/hour. A 6-hour summer thunderstorm was chosen for the design storm. The 6-hour duration provides almost all of the volume produced by summer thunderstorms that will be contained in the detention basin, but also contains the intense rainfall for shorter durations and is thus the critical storm in producing peak discharges as well. The 6-hour rainfall depths were developed using the NOAA Atlas II -Volume 8 for Arizona (NOAA, 1973). The temporal distribution was adapted from the August 1954 thunderstorm centered over Queen Creek, Arizona, east of Phoenix. The HEC-1 model was calibrated by adjusting loss rates and n-values to reproduce discharge frequency curves for three gages on the watershed, and volume frequency curves for two gages on the watershed.

The subwatershed for the Randolph South detention basin is drained by Arroyo Chico, Naylor Wash, and Paseo Grande Wash, and has a total drainage area of 3.51 square miles (Figure 1). The 100-year inflow hydrograph produced by the calibrated model at Randolph South had a peak discharge of 3100 cfs and a runoff volume of approximately 430 acre feet. For detailed hydraulic modeling, the 100-year inflow hydrograph was broken into six subwatershed hydrographs, each of which entered the detention basin complex at a different point (Figure 1). The two main flows are from Arroyo Chico (subwatershed AC), which drains a 1.13 square miles to the east, and the combined Grande Wash (subwatershed GW) and Naylor Wash (subwatershed NW) which together drain 1.9 square miles to the east and southeast. The remaining hydrographs contributed runoff from the golf course area itself (subwatersheds ACRN, RNE, and ACRS) and from a highly urbanized area to the northeast (subwatershed RNELC).

Design of Randolph South

The project area includes two existing 18 hole municipal golf courses: Randolph North, and Randolph South (Figure 2). By virtue of location, relatively low user fee's, and year round weather, they are reportedly two of the busiest municipal courses in the country. Arroyo Chico generally bisects the two courses, while Naylor Wash flows through the south course to its confluence with Arroyo Chico just upstream of Randolph Way. The basin outflow was constrained by the Arroyo Chico channel immediately downstream of Randolph Way (Figure 1). The existing channel is small, having a bank full capacity of approximately 300 cfs (less than the 2-year flood), and is surrounded by heavy desert riparian vegetation on both sides. Since the wash, and the Colonia Solana neighborhood through which it flows, are listed on the National Register of Historic Places, channel improvements through the neighborhood were not a practical option.

Preliminary design attempts for the basin looked at a single embankment along Randolph Way. This concept was rejected for two reasons. One, it would back water onto the golf course, damaging tees and greens, during relatively frequent events. Two, it would be classified as a jurisdictional dam by the Arizona Department of Water Resources - Dam Safety Division, requiring construction of PMF spillway. Subsequent design focused on a combination of excavated basins designed to work with a new layout of the golf course (Figure 2). Because of the relatively steep 2% slope of the overland area, it was possible to construct a cascade of basins through which flood flows were conveyed in both in parallel and in series. As an example of parallel storage, flows from Naylor Wash are intercepted by Basin 1 while flows from Arroyo Chico are intercepted by Basin 3. In terms of series flow, Basin 1 drains directly to basins 2, 3, and 6, which drain through basins 4 and 5 before reaching Randolph Way. Basin 3 drains directly to basin 4, which in turns drains to basin 5 and to Randolph Way. Interbasin conveyance is via weirs, and culverts ranging from a single 18" reinforced concrete pipe (RCP) to a 3 barrel 60" RCP. A non-jurisdictional embankment along Randolph Way collects and detains the runoff from the urban area to the northeast, and also serves as the final control point for remainder of the basin. The final outflow is metered to the Arroyo Chico channel via a single 3' x 5' concrete box culvert under Randolph Way.

This overall combination of below ground storage in six interconnected basins and an embankment at Randolph Way served the mulitipurpose objective of the project without requiring an expensive PMF spillway needed under jurisdictional dam classification. It also allowed for design of a rather unique and challenging golf course, especially when compared to the previous course, which was often referred to as the "pool table".

Modeling and Reservoir Routing

The HEC-1 rainfall-runoff model is not appropriate for modeling interconnected detention ponds. The model is not capable of adjusting the stage-discharge curve as tailwaters of the individual basins fluctuate. The "Advanced Interconnected Channel and Pond Routing (ADICPR) Program" from Streamline Technologies was written specifically to rout flows through a number of storage nodes (basins) that are connected by various reaches (pipes, open channels, or weirs), and was used for routing flows through the six interconnected basins. The water surface elevations at each node, and the discharge in each reach are computed for each time increment based on: (1) a downstream boundary condition, (2) stage-storage relations for each node, (3) stage-discharge relations for each reach, and (4) incoming flows.

Each node in the ADICPR model represents a control volume. Water enters and leaves each node by the links connected to it, and by runoff hydrographs flowing into it. Storage at each node is provided by specified stage/storage relationships (i.e. stage-volume, or stage-area). The change in storage in each node is based on the differences in inflows and outflows at each time step during a simulation, and is used to determine the watersurface elevation at each node. Flows through each link (i.e. pipes, channels, or weirs) are calculated from known elevations at the ends of the link and the hydraulic properties of the link (slope, roughness, and geometry). Simultaneous solution of the elevations, flows and storage is done by iteration. The computation time step is variable and can be reduced to fractional seconds to minimize numerical inaccuracies.

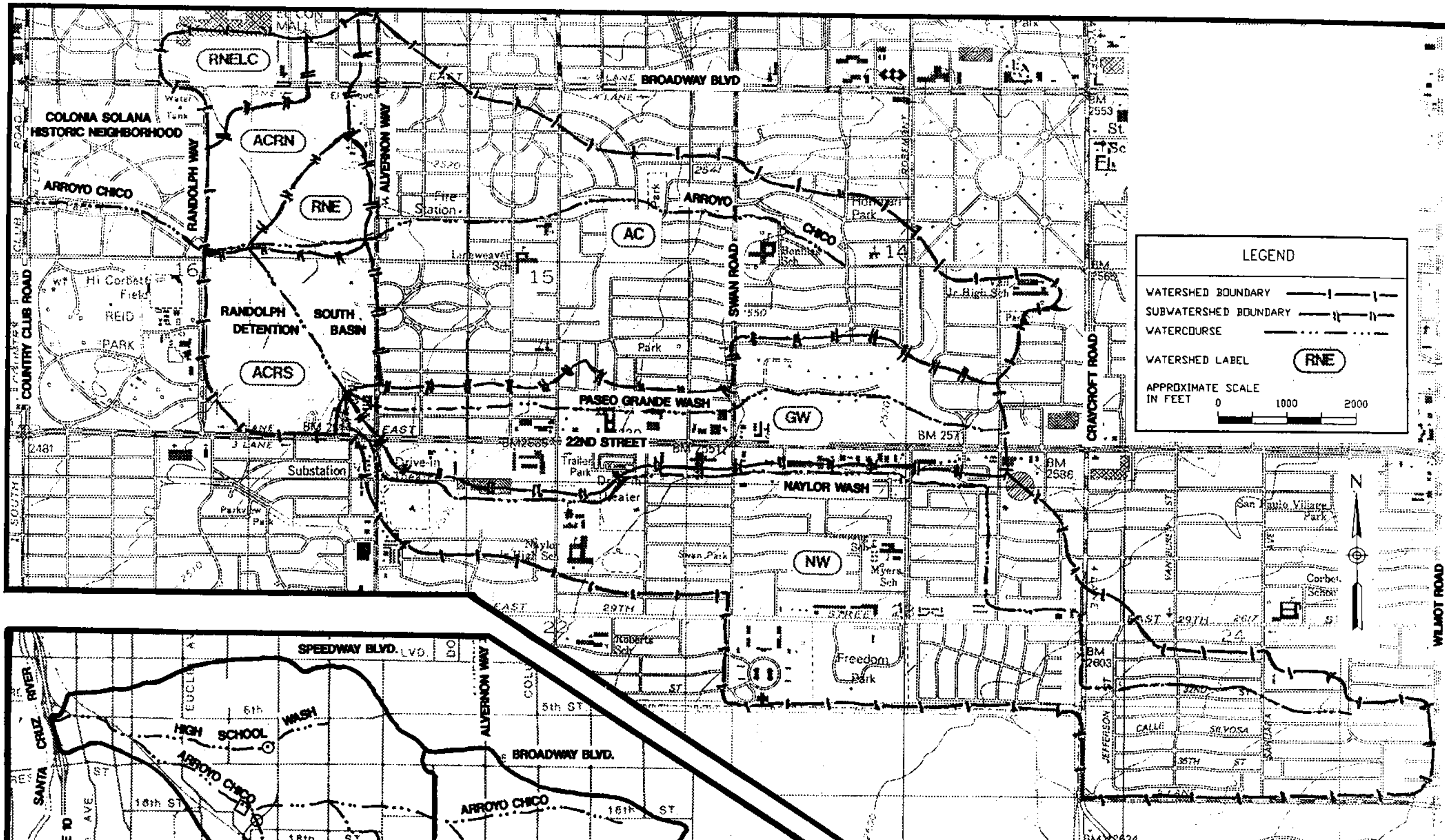
A schematic routing diagram for the Randolph South model is shown in Figure 3. The downstream boundary condition was chosen as critical flow depth through the low flow outlet, which was approximately the same as normal depth in the downstream channel. Stage-storage relations were computed by measuring storage volumes at one foot contour intervals from the final grading plans. Stage-discharge relations were computed internally by the ADICPR program, based on the elevations of both the headwater and tailwater during the time increment of interest. Incoming hydrographs were entered at the appropriate nodes as shown in the schematic routing diagram.

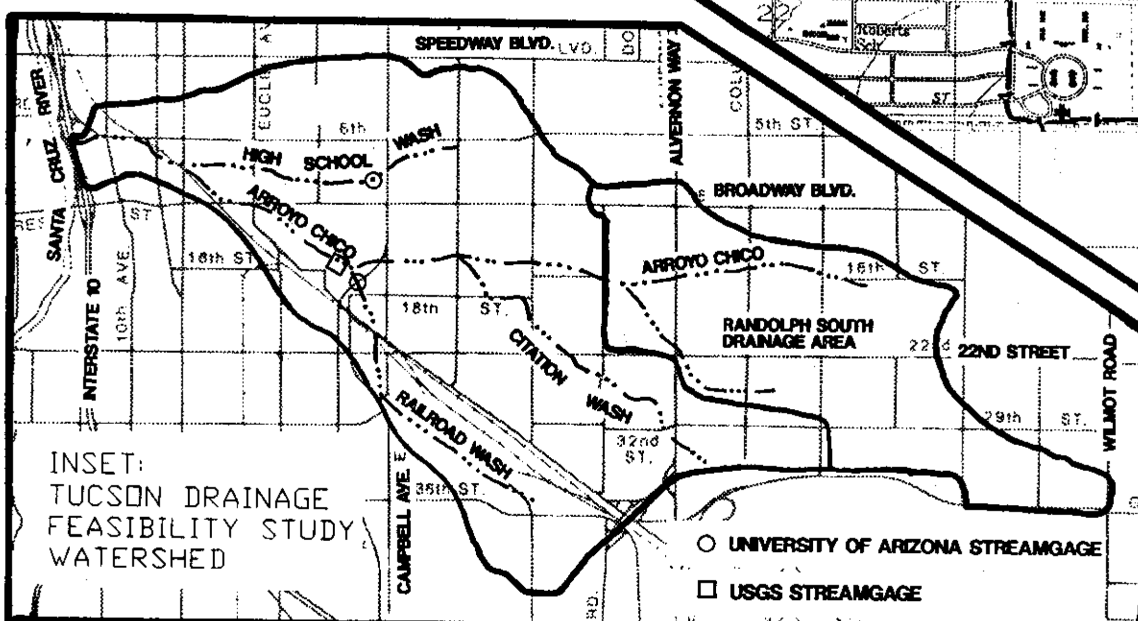
Acknowledgment

The project was designed and constructed under a cooperative agreement between the Pima County Flood Control District, City of Tucson Department of Transportation, City of Tucson Department of Parks and Recreation, and the U.S. Army Corps of Engineers, Los Angeles District. Construction was completed in April 1996 by the City of Tucson Parks and Recreation, with major funding provided by the Pima County Flood control District, to be reimbursed by the Corps of Engineers under Section 104 of the Flood Control Act.

References

National Oceanic and Atmospheric Administration.
1973. Precipitation Frequency Atlas of the Western United States, Volume 8 - Arizona, NOAA Atlas 2. National Weather Service. Silver Springs, MD.



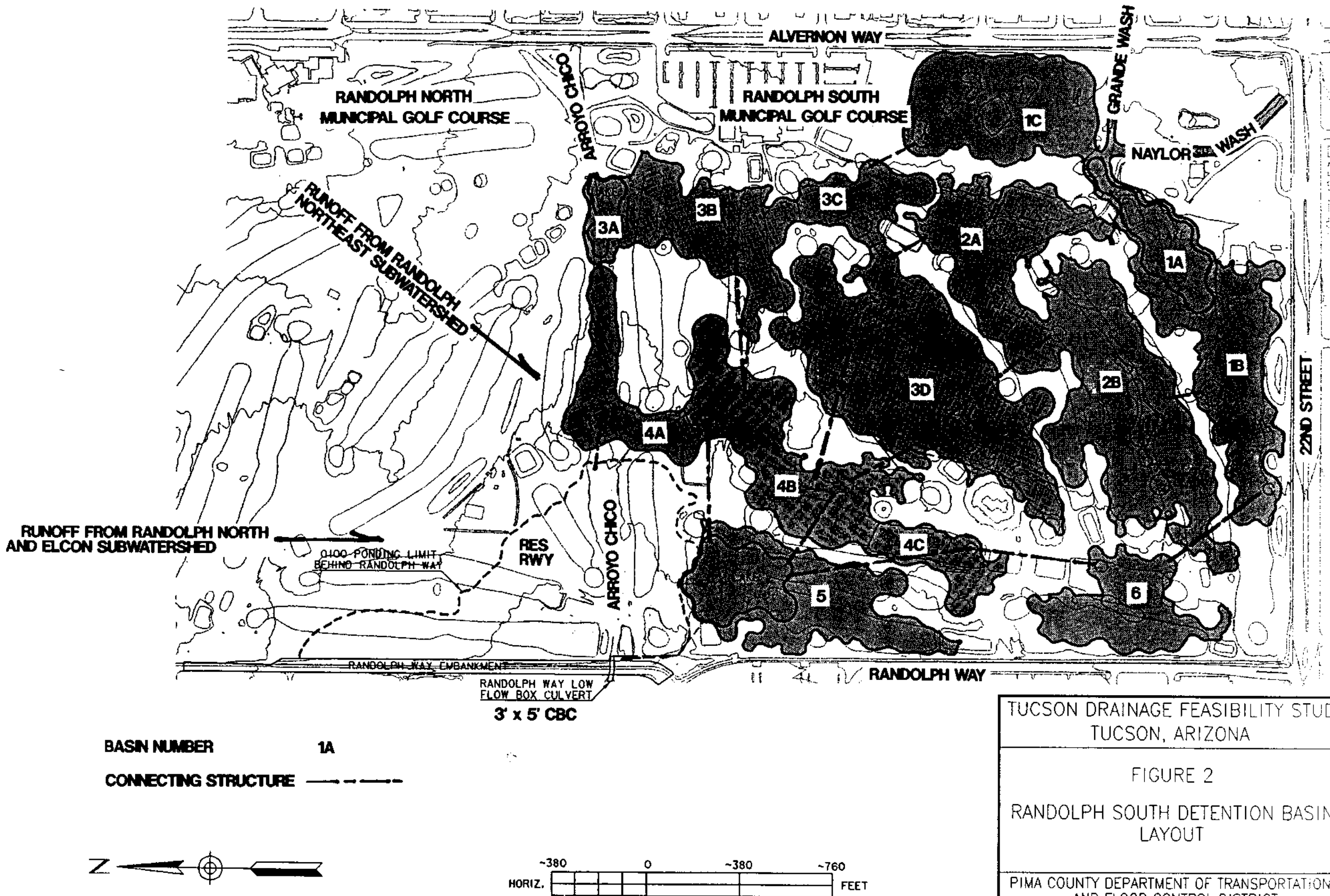


TUCSON DRAINAGE FEASIBILITY STUDY
TUCSON, ARIZONA

FIGURE 1

RANDOLPH SOUTH DETENTION BASIN
WATERSHED AND LOCATION MAPS

PIMA COUNTY DEPARTMENT OF TRANSPORTATION
AND FLOOD CONTROL DISTRICT

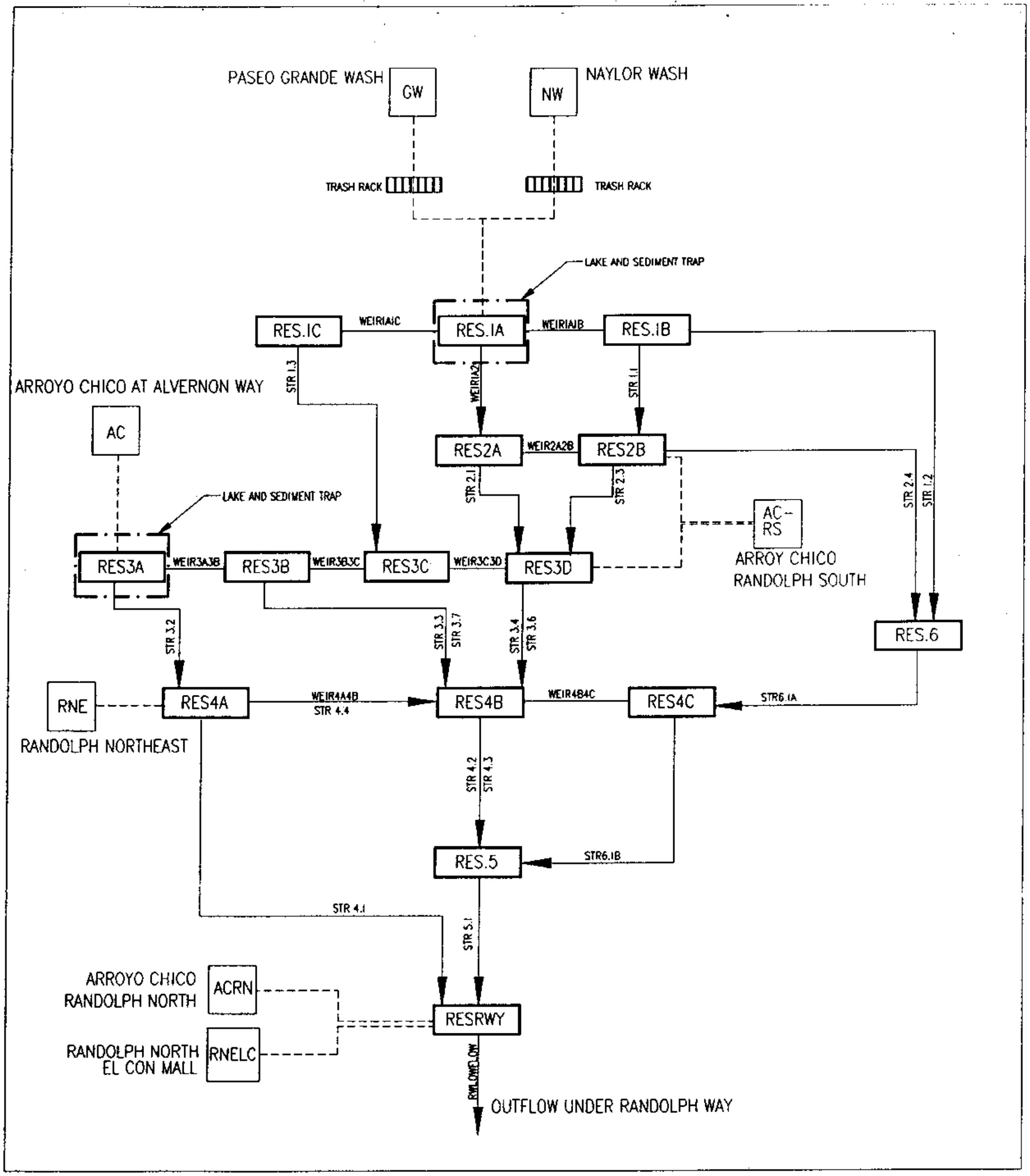


TUCSON DRAINAGE FEASIBILITY STUDY
TUCSON, ARIZONA

FIGURE 2

RANDOLPH SOUTH DETENTION BASIN LAYOUT

PIMA COUNTY DEPARTMENT OF TRANSPORTATION AND FLOOD CONTROL DISTRICT



LEGEND	
SUBWATERSHED	------- AC
DETENTION BASIN	RES.2
CONNECTING STRUCTURE	⟶

TUCSON DRAINAGE FEASIBILITY STUDY
TUCSON, ARIZONA

FIGURE 3

RANDOLPH SOUTH DETENTION BASIN
SCHEMATIC ROUTING DIAGRAM

PIMA COUNTY DEPARTMENT OF TRANSPORTATION
AND FLOOD CONTROL DISTRICT

DESIGN

1996 Annual Meeting Proceedings

American Society of Landscape Architects

5. THE PROFESSION: DESIGN

TUCSON'S BUSIEST GOLF COURSE: IT DOESN'T LOOK LIKE A FLOOD CONTROL PROJECT

Karen Novak, and Doug Lantz
Additional speakers: Eldon Gatwood, Zbignew Osmolski, Raul Pina, Greg Shinn, Boyd Winfrey

Introduction

The Tucson Arroyo/Arroyo Chico is an ephemeral watercourse that drains about 11 square miles of urban and suburban Tucson. (It is referred as "the Tucson Arroyo" in the downstream areas and "Arroyo Chico" in the upstream areas). Summer thunderstorms that are characteristic of the southwest cause frequent flash flooding. Plans for reducing flood damages for thousands of residential and commercial properties along Arroyo Chico and its tributaries are being undertaken in a two-phase project, as a joint effort between the Los Angles District of the U.S. Army Corps of Engineers, Pima County Flood Control District and the City of Tucson. A flood control plan that is compatible with urban development is the major objective of the project team.

The Problem

The Tucson Arroyo/Arroyo Chico runs through heavily developed areas in the central part of Tucson. Urbanization has resulted in increased storm water runoff while at the same time reducing open space. Parts of the Tucson Arroyo/Arroyo Chico do not have the capacity to convey the two-year storm without flooding surrounding areas. In the lower part of the watershed, two concrete box culverts totaling almost a mile in length convey flows underground through the downtown part of Tucson. The capacity of these culverts is less than a ten-year flood (which would occur, on average, ten times in 100 years). When the capacity of the culverts is exceeded (which happened as recently as 1990) floods continue overland through residential and commercial areas. Enlarging or replacing these culverts is not feasible or cost effective because the culverts are located under downtown Tucson and have multistory buildings and major roadways above them. A cooperative and innovative design approach was needed to solve the problem.

The selected approach for solving the flooding problem was to construct regional detention basins, upstream of the culverts, to reduce the peak discharge to value that could be conveyed by the existing channels and structures. Since the watershed is almost completely urbanized, locating enough vacant land to accommodate the required storage (approximately 900 acre/feet in the 100-year event) was a daunting proposition. Additionally, the idea of constructing a massive single-purpose detention facility was not in concert the more progressive concept of multi objective design. It was clear that any new detention facility had to be integrated into the existing urban fabric in a manner that would be an asset for the community.

The Process

Early attempts to address the urban flooding problem began in 1987 with a basin management study by the City of Tucson. In 1990, the City asked the U.S. Army Corps of Engineers - Los Angeles District to do a Reconnaissance Study of flooding problems throughout Tucson. In 1991, the Corps completed their study and identified Arroyo Chico as one of the problem areas in which there would be a federal interest, i.e., the benefit/cost ratio for a flood control project appeared to be greater than one. In 1992, the City and the Pima County Flood Control District agreed to work together as the "Local Sponsor" in a cost-shared feasibility study with the Corps. The resulting Tucson Drainage Feasibility

Study analyzed the problems and solutions in detail, and has identified the "National Economic Development (NED) Plan." The NED plan is the proposed flood control solution that maximizes the net benefits (benefits minus costs) to "the nation."

This particular project is a hybrid of federal and local government design processes. The Tucson Drainage Feasibility Study for the entire project is still underway. The hydrologic, hydraulic, and design documentation for the project elements was prepared by the local sponsor and submitted to the Corps in July 1996. The documents will be reviewed by the Los Angeles District, the South Pacific Division in San Francisco, and at Corps headquarters in Washington, D.C. Once the review process is complete and the feasibility study is approved, the Preconstruction Engineering and Design (PED) phase will begin in earnest. However, while the feasibility study was underway, the local sponsor elected to design and construct one of the project elements. Under a provision of the Flood Control Act (which authorizes the Corps to participate in flood control projects) the local sponsor can construct a portion of the project during the feasibility study. The cost of constructing that element can be applied toward the local cost share of the total project, if and when it is constructed.

The Project

Early in the design process it became obvious there was not sufficient area within the watershed to create one detention basin with enough capacity to solve the flooding problems without negative impacts to existing development. Furthermore, the flooding problem extends throughout the watershed. Locating a single basin just upstream of the undersized culverts (the main problem) would do nothing for the upper watershed. Likewise, if the single basin were located in the upper watershed, the area between the basin and culverts would still generate enough flow to exceed the culvert capacity. Consequently, the concept of multiple detention basins was proposed and proved more feasible to implement.

The search for suitable sites within the urbanized watershed for the proposed basins yielded only a limited selection, including an unlikely candidate, the existing and very popular thirty-six-hole Randolph Municipal Golf Course, figure 1. The idea of using the golf course as a detention basin facility was first proposed as part of a 1987 basin management study for the City of Tucson. The idea was rejected at that time as too disruptive to the golf course. However, its location immediately upstream of one of the worst flooding problems made it an attractive option from a purely flood control viewpoint. Almost a decade later, the increased need for the flood control project, coupled with the limited available land, justified using the golf course. Another unlikely candidate was a City park (Reid Park), located just downstream of the Randolph Golf Course. While it offered significant open space for detention, it did not provide enough flood peak reduction to justify its proposed cost, and was dropped from consideration. The final candidate was a collection of private and City owned parcels just upstream of the undersized box culverts, at Park Avenue. The final NED plan identified by the Tucson Drainage Feasibility Study includes detention basins at the eighteen-hole Randolph South portion of the golf course, and at the Park Avenue site.

Phase I. The first phase of this project became the redesign and reconstruction of the City of Tucson's Randolph South Golf Course to include a detention basin. The support of the City of Tucson for using the golf course was solidified by the demonstration that most of the existing trees on the golf course could be preserved through sensitive design and the quality of the golf course could be improved while providing the required flood water storage.

As specified in the request-for-proposal put out by the City of Tucson Parks and Recreation Department, a Landscape Architect served as the prime consultant for a multi-disciplinary team that included engineers, hydrologists, arborists and a nationally recognized golf course architect. The common concern of preserving hundreds of existing trees, many of which were more than sixty feet tall, required all members of the design team to understand each other's perspective, and to craft solutions to fit site specific conditions. With diligence, attention to detail, and considerable argument on the part of the design team, the basins were designed with undulating side slopes to preserve significant vegetation and create challenging golf play. A state-of-the-art hydraulic modeling computer program was used to quickly evaluate all of the changes and "what ifs" while ensuring the flood control function was not compromised. Grading was the key to this phase as the successful function of the interconnected basins depended on meeting specific design grades with a very low tolerance. Grading around existing trees was limited to areas beyond the drip line. The new tees and greens were elevated to avoid being flooded in all but the largest storms. The layout of the course, and the inclusion of a driving range was done with consideration to minimize maintenance and interference to playing time due to flooding.

Construction began in May 1995. The driving range (which itself provides about 10% of the flood storage) was open in January 1996. The completed project, which was renamed the del Urich Municipal Golf Course, was open for public use in April 1996. It is estimated that more than 50 percent of the twelve million dollar cost of construction is attributable the extra efforts required to preserve the trees and develop the golf course. The result is a new spectacular municipal golf course which has retained its previous park-like character and become a showcase of design excellence and interagency cooperation. At the same time, the 450 acre-feet of flood storage reduces the incoming peak discharge of 3100 cubic feet per second (cfs) to roughly 240 cfs, a value that is within the downstream channel capacity.

Phase II. The second phase of this project will be the design and construction of a detention basin just upstream of Park Avenue. It will consist of a series of four interconnected detention basins, whose combined flood storage capacity is also 450 acre-feet, figure 2. Three of the four basins are "inline", i.e., they are located along the existing Tucson Arroyo/Arroyo Chico drainage way. The fourth basin, which will occupy a high school athletic field, is separated from the other proposed basins by a weir and is thus "offline." The three inline basins are sufficient to control flood waters up to the twenty-five-year storm. For events larger than the twenty-five-year storm, flood waters will fill the inline basins first, and will then spill over the weir into the fourth basin.

With the successful implementation of the first phase of the project, expectations are high for the second phase. While the program elements and existing conditions are vastly different, the approach and commitment to designing the basins to meet several objectives are constant. Design of these detention basins includes environmental mitigation, environmental restoration and enhanced recreational features in addition to replacement of existing recreational facilities such as a paved bike trail and high school athletic fields.

Environmental mitigation includes the identification of existing desert riparian habitat that can be preserved in place as well as replacing the riparian habitat that will be impacted through the construction of the project. Environmental restoration includes the development of a specialized wetland habitat for migratory shorebirds. The need for this habitat was identified by the Arizona Department of Game and Fish. A feasibility study is being conducted and design guidelines for development of this specialized wetland habitat are being developed. Funding for this aspect of the project was provided by Game and Fish through a grant from the Heritage Fund Program, which uses revenues from the Arizona Lottery to fund efforts that benefit wildlife. The recreational enhancements include a perimeter bike path around each of the basins, and a proposed neighborhood park in second inline basin. The park features included in the design were promised to the area residents more than ten years ago as part of a rezoning in their neighborhood. The rezoning project was never implemented, but the residents' desires for a neighborhood park, have been incorporated in the current plans

The existing conditions of the first three basins include desert riparian habitat and vacant land. The fourth basin is currently a high school athletic facility with baseball, softball, and football fields, locker rooms and maintenance buildings. The use of the high school athletic facility became necessary due to a new commercial development on a formerly vacant piece of land initially identified for inclusion in the project. At first, there was concern on the part of the school district about agreeing to the use of their facility, but the successful reconstruction of the golf course in the first phase demonstrated the feasibility of modifying an existing recreational facility to include flood control uses while preserving or enhancing the original use.

As with the golf course, landscape architects are involved in the planning and programming of the environmental mitigation, restoration and recreational features of the basins, as well as working closely with the engineering and hydrology members of the team to design the grading for the basins to accommodate the required flood storage while creating optimal areas for recreation and wildlife habitat.

The cost estimate for the second phase is approximately twelve million dollars. The one year design phase will follow completion of the flood control feasibility study and is expected to begin in May 1997. Construction should begin in the fall of 1998.

Conclusion

The Tucson Arroyo/Arroyo Chico project demonstrates that a large scale urban flood control project can be incorporated into a heavily developed area with positive results. A strong commitment by a design team willing to respond to community concerns, preserve existing vegetation and work in a collaborative manner can lead to solutions to urban flooding problems that don't look like flood control projects.

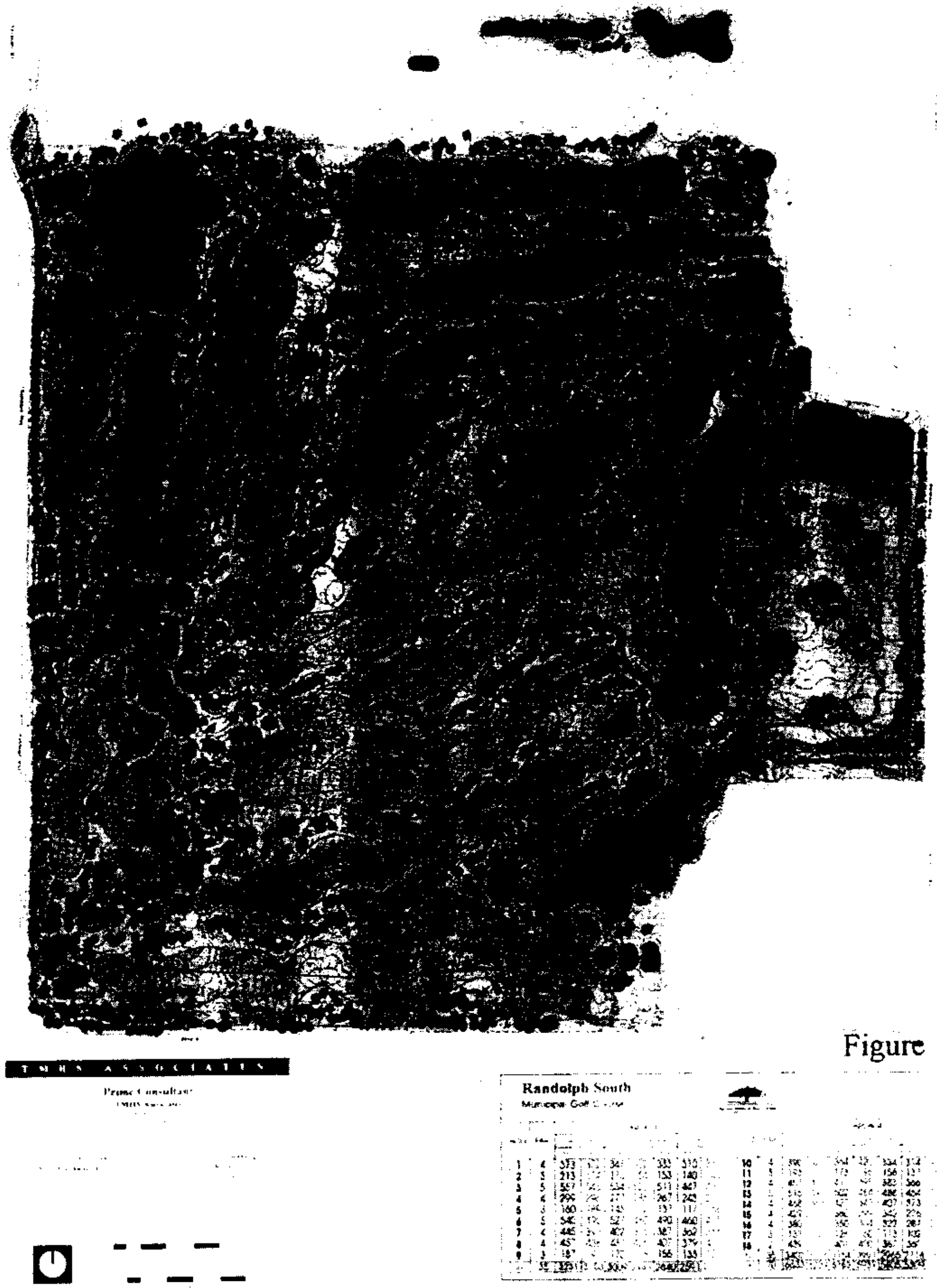
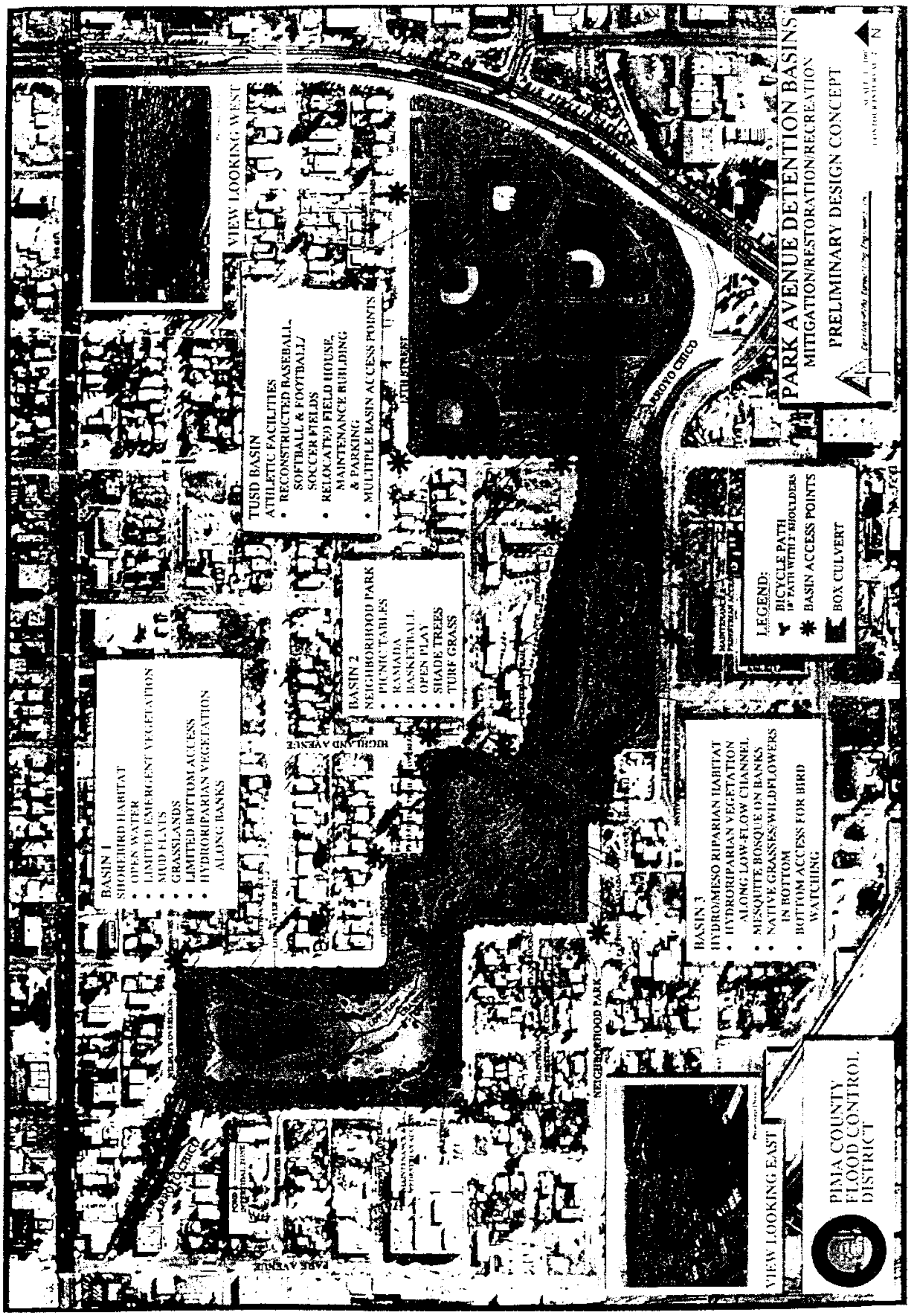


Figure 1

RANDOLPH SOUTH GOLF COURSE



PARK AVENUE DETENTION BASINS
MITIGATION/RESTORATION/RECREATION
PRELIMINARY DESIGN CONCEPT
VIEW LOOKING WEST
TUSD BASIN
ATHLETIC FACILITIES
• RECONSTRUCTED BASEBALL, SOFTBALL & FOOTBALL/ SOCCER FIELDS
• RELOCATED FIELD HOUSE, MAINTENANCE BUILDING & PARKING
• MULTIPLE BASIN ACCESS POINTS
BASIN 2
NEIGHBORHOOD PARK
• PICNIC TABLES
• RAMADA
• BASKETBALL
• OPEN PLAY
• SHADE TREES
• TURF GRASS
BASIN 1
SHOREBIRD HABITAT
• OPEN WATER
• LIMITED EMERGENT VEGETATION
• MUD FLATS
• GRASSLANDS
• LIMITED BOTTOM ACCESS
• HYDRORIPARIAN VEGETATION ALONG BANKS
LEGEND:
BICYCLE PATH
BASIN ACCESS POINTS
BOX CULVERT
BASIN 3
HYDRO/MESO RIPARIAN HABITAT
• HYDRORIPARIAN VEGETATION ALONG LOW-FLOW CHANNEL
• MESQUITE BOSQUE ON BANKS
• NATIVE GRASSES/WILDFLOWERS IN BOTTOM
• BOTTOM ACCESS FOR BIRD WATCHING
HIGHLAND AVENUE
PARK AVENUE
ARROYO CHICO
NEIGHBORHOOD PARK
VIEW LOOKING EAST
PIMA COUNTY FLOOD CONTROL DISTRICT

Multi Objective Flood Control and Recreational Enhancement in an Urban Environment

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Abstract

The watershed of the Arroyo Chico and its tributaries, which flow through the central part of the city of Tucson Arizona, is fully urbanized and experiences severe and frequent flood damages. Urban encroachment into floodplain has occurred over the years, severely limiting the opportunities and the rights-of-way needed for implementation of traditional flood control measures like channel improvement, bank protection/levee, structure relocation, etc. Another important constraint is imposed by the desire of the residents and public representatives for preserving the historic character of the residential neighborhood of Colonia Solana which was inundated frequently by flood flows from the Arroyo Chico. Flood protection to this historic neighborhood and downstream areas in the city center required substantial reduction in peak flood discharges of the Arroyo Chico and its tributaries.

Because of limited capacity of the stream channel passing through the Colonia Solana area, flood control alternatives involved detention of almost the entire flood volume of the design 100-year flood event. Due to lack of suitable detention sites in the densely populated urban area, utilization of the existing 18-hole Randolph South Golf Course, located immediately upstream of the historic neighborhood, as a detention basin was found to be the best alternative which satisfied the above-mentioned constraints and provided the necessary reduction in peak flood flows. The need to preserve the golf course function of the Randolph Park, which provides significant economic and recreation benefits to the community, required an innovative approach for the design of a multi purpose facility combining the golf course and detention basin functions. A single detention basin was not feasible because of prohibitive cost due to the need for a Probable Maximum Flood (PMF) spillway required under federal and state dam safety criteria. A series of six interconnected basins was designed such that PMF spillway was not required under State of Arizona dam safety criteria.

The Randolph South Detention Basin was designed to function within a redesigned 18-hole Randolph South Golf Course. The design team included engineers, hydrologists, landscape architects and a golf course designer. The interconnected basins were configured to fit within the fairway and "out-of-play" areas between the new tees and greens. Design of both the basins and the golf course were constrained by the desire to save the numerous mature trees that were already in place. The project significantly improved the quality of the course by providing new and interesting topography, new turf on fairways, tees and greens, new lakes, additional landscaping, concrete cart paths, and a new irrigation system. The course was open to

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the public in April 1996 and has been extremely well received. The innovative design for the interconnected basins required the use of a state-of-the-art routing program specially coded for this purpose. The design and construction of the multipurpose project were carried out as a cooperative effort between the County, City and Federal governments.

Introduction

Arroyo Chico (also known as the Tucson Arroyo) drains an 11.35 square mile watershed in the central part of the city of Tucson Arizona. Its tributaries include Naylor Wash, Paseo Grande Wash, Citation Wash in the upper watershed; and Railroad Wash and High School Wash in the lower watershed. The watershed is fully urbanized and includes residential areas, commercial areas (downtown Tucson), and industrial areas (railroad yards). In addition to increasing storm water runoff, urbanization has reduced the open space, leaving the 36-hole Randolph Golf Course and a municipal park near Arroyo Chico and Citation Wash, and the fewer than 40 acres of vacant land just downstream of the confluence of Arroyo Chico and Railroad Wash as the only significant open areas that would be available for flood control purposes.

Urbanization has also encroached into the floodplain and resulted in limited channel capacities. In the upper watershed, parts of the Tucson Arroyo/Arroyo Chico cannot convey the two-year storm without flooding surrounding areas. Channel improvements are not feasible because of a lack of right-of-way, and more important, because of a desire of the neighborhoods and their public representatives to keep the existing channels, which contain significant riparian areas, in their present condition. In the lower part of the watershed, the primary watercourse consists of two sections of double barrel, ten foot by ten foot, concrete box culverts totaling almost a mile in length, which convey flows underground through downtown Tucson. The capacity of these culverts is less than a 10-year event, and when exceeded (which happened as recently as 1990) flows continue overland through residential and commercial areas. Enlarging or replacing these culverts is not feasible or cost effective because of their location under multistory buildings and major roadways. Consequently, the selected approach for solving the flooding problem was to construct regional detention basins, upstream of the culverts, to reduce the peak discharge to a value that could be conveyed by the existing channels and structures.

Early in the design process it became obvious that there was not sufficient available area within the watershed to create one detention basin with enough capacity to solve the flooding problems without negative impacts to existing development. Furthermore, since the flooding problem extends throughout the watershed, locating a single basin just upstream of the undersized culverts (the main problem) would do nothing for the upper watershed. Likewise, if the single basin were located in the upper watershed, the area between the basin and culverts would still generate enough flow to exceed the culvert capacity. Consequently, the concept of two basins, one in the upper watershed, and one on the lower watershed, was proposed and proved more feasible to implement. In the first phase of a two-phase project, flows on the upper watershed will be controlled by a multiple interconnected detention basin complex located within the City of Tucson's Randolph South Golf Course. In the second phase, flows on the lower watershed will be controlled by another multiple interconnected detention basin complex that will be located on the aforementioned vacant area just downstream of the Railroad Wash confluence. The first phase reduces the 100-year peak discharge to a level that can be conveyed by the existing channels in the upper watershed. The second phase, working in conjunction with the first, reduces the 100-year peak discharge to a level that can be conveyed by the existing concrete box culverts through downtown Tucson.

The first phase, which includes the Randolph South Detention Basin and is the subject of this paper, was designed and constructed over a two-year period beginning in the spring of 1994. Construction was complete and the course was open for play in April of 1996. The second phase is currently under design, and is expected to be constructed sometime in 1998. The design and construction of the multipurpose project were carried out as a cooperative effort between the County, City and Federal governments.

Hydrology

The Randolph South detention basin is part of the larger Tucson Drainage Feasibility Study, which covers the entire 11.35 square mile watershed for Arroyo Chico at the Santa Cruz River (Figure 1). As part of the study, an HEC-1 rainfall-runoff model, using an S-graph unit hydrograph and a uniform loss rate, was developed and calibrated for this watershed. The model includes 13 subwatersheds, with drainage areas ranging 0.14 to 2.35 square miles, which were delineated based on the existing stream system and hydrologic characteristics. A 6-hour summer thunderstorm was chosen for the design storm. The 6-hour duration provides almost all of the volume produced by summer thunderstorms that will be stored in the detention basin, and also contains the intense rainfall for shorter durations and is thus the critical storm in producing peak discharges as well. The 6-hour rainfall depths were developed using the NOAA Atlas II -Volume 8 for Arizona (NOAA, 1973). The temporal distribution, in which the maximum rainfall intensities occur roughly four hours into the 6-hour storm, was adapted from a large historical event, the August 1954 thunderstorm centered over Queen Creek, Arizona, east of Phoenix.

The basic runoff criteria for the HEC-1 model include a dimensionless S-graph for the unit hydrograph, the Manning's n-value used to determine the lag time for the S-graph, and uniform loss rates to determine rainfall excess. These parameters were determined by reconstituting the eight largest (in terms of peak discharge) events on High School Wash, a tributary to the Arroyo Chico, with 16 years (1968-1983) of rainfall-runoff records collected by the University of Arizona. Reconstitution consists of reproducing the observed flood hydrographs with an HEC-1 model for the watershed (drainage area = 0.95 square miles) above the stream gage. The observed rainfall depth and pattern, and the observed hydrograph are coded into the model and the loss rate and unit hydrograph parameters are optimized by a subroutine within HEC-1 in order to produce the lowest root-mean-squared-sum of the difference between observed and computed hydrograph ordinates. The parameters that result in the lowest error over the eight events are adopted as the basic criteria. A "High School Wash" unit hydrograph was determined as the average of the ordinates of the eight optimized unit hydrographs. It was converted into a High School Wash S-graph and was compared against the "Phoenix Valley" S-graph already in use in Maricopa County (Sabol, 1987). Since two were very similar, the Phoenix Valley S-graph, which had already been approved in previous studies by the Corps, was considered to be verified for the Tucson urban area and was adopted for use in this study.

The HEC-1 model for the complete Tucson Arroyo/Arroyo Chico watershed (using the Phoenix Valley S-graph) was calibrated for both the peak discharge and runoff volume by adjusting the uniform loss rates and the Manning's n-value used in the lag equation such that the N-year (10-, 25-, 50-, and 100-year) storm (from NOAA Atlas II) produced the N-year runoff as determined by peak discharge frequency and volume frequency relations that were developed for runoff records on the watershed. The peak discharge calibration was based on the aforementioned High School Wash record plus a 14-year record from Railroad Wash (drainage area 2.35 square miles), which is another tributary that was gaged by the University of Arizona, and a 26-year record for Tucson Arroyo at Vine Avenue (drainage area = 8.2 square miles) which was collected between 1956 and 1981 by the U.S. Geological Survey. The largest flood peak in the Tucson Arroyo at Vine record was 5000 cfs and occurred in August 1961. It was known to be the largest flood peak since 1940 and thus the length of the record was extended to 40 years by historical adjustment in accordance with the procedures given in Bulletin #17B (Water Resources Council, 1981). The volume calibration was based on the High School Wash and Railroad Wash records. For each record, the hydrographs for the two or three largest events in each year were tabulated. In each hydrograph, the maximum runoff volumes for 1-, 2-, 3-, and 6-hour durations were determined. The maximum volume for each duration was converted to an average flow rate (cfs) by dividing the volume (cubic feet) by the duration (seconds), and the set of annual maximum average flow rates for each duration was selected. Note that the annual maximums for different durations did not necessarily come from the same storm. The annual maximum values for the peaks and the 1-, 2-, 3- and 6-hour average discharges were plotted on log probability paper using the median plotting position (m-0.3/n+0.4) where "m" is the rank of the event and "n" is the total number of events (Beard, 1962). Because of the high variability in skew values among the three gages and the limited data sets, a graphical approach was chosen over an analytical approach to develop the discharge and volume frequency curves.

The peak discharge and the 1-, 2-, 3-, and 6-hour average discharges, computed from the HEC-1 output hydrographs, were plotted against the respective frequency curves on log probability paper. It was found that adjustment of the loss rates strongly affected both the average discharge (volume) and peak discharge frequency relations. Conversely, adjustment of Manning's n-value strongly affected the peak discharge and 1-hour average discharge, but had a lesser effect on the 2-hour duration and almost no effect on the 3- and 6-hour durations. Thus, the optimal loss rates were determined by calibrating against the 2-, 3-, and 6-hour average discharge frequency curves, after which the Manning's n-values were determined by further calibrating against the peak and 1-hour discharge frequency curves. The calibrated parameters were different for each N-year storm, and ranged from 0.5 in/hr to 2.0 in/hour for the uniform loss rate, and from 0.035 to 0.050 for Manning's n-value.

The subwatersheds contributing to the Randolph South detention basin are drained by Arroyo Chico, Naylor Wash, and Paseo Grande Wash, and have a total drainage area of 3.51 square miles (Figure 1). The combined 100-year inflow hydrograph produced by the calibrated model at Randolph South had a peak discharge of 3100 cfs and a runoff volume of approximately 430 acre feet. For detailed hydraulic modeling, the HEC-1 model above Randolph South was further subdivided into six subwatershed hydrographs, each of which contribute runoff to the detention basin complex at a different point. The two main flows are from Arroyo Chico (subwatershed AC), which drains 1.13 square miles to the east, and the combined Grande Wash (subwatershed GW) and Naylor Wash (subwatershed NW) which together drain 1.9 square miles to the east and southeast. The remaining hydrographs contributed runoff from the golf course area itself (subwatersheds ACRN, RNE, and ACRS) and from a highly urbanized area to the northeast (subwatershed RNELC).

Hydrologic and Hydraulic Design of Randolph South

The project area includes two existing 18-hole municipal golf courses: Randolph North, and Randolph South (Figure 2). By virtue of location, relatively low user fees, and year round weather, they are reportedly two of the busiest municipal courses in the country. The existing course is characterized by flat terrain, large trees, broad fairways, somewhat monotonous hole layouts and short overall length. Of these characteristics, the flat terrain and broad fairways would necessarily change as a function of the excavation necessary for flood storage. There were approximately 900 large pine and eucalyptus trees on the existing course. These are considered a priceless resource within a desert community such as Tucson. As such, a high value was placed on their protection. The remaining criteria, hole layout and short length were considered attributes which could be changed with an innovative design solution. Arroyo Chico generally bisects the two courses, while Naylor Wash flows through the south course to its confluence with Arroyo Chico just upstream of Randolph Way. The basin outflow was constrained by the capacity of the Arroyo Chico channel immediately downstream of Randolph Way. The existing channel is small, having a bank full capacity of approximately 300 cfs (less than the 2-year flood), and is surrounded by heavy desert riparian vegetation on both sides. Since the wash, and the Colonia Solana neighborhood through which it flows, are listed on the National Register of Historic Places, channel improvements through the neighborhood were not a practical option.

Preliminary designs for the basin by the City of Tucson, Pima County, and the Corps looked at a single embankment at the downstream end, along Randolph Way. This concept was rejected for two reasons. One, it would back water onto the golf course, damaging tees and greens, during relatively frequent flow events. Two, it would be classified as a jurisdictional dam by the Arizona Department of Water Resources - Dam Safety Division, requiring construction of a spillway that could withstand the probable maximum flood. Subsequent design, by a design team that included engineers, hydrologists, landscape architects and a golf course designer, focused on a combination of excavated basins designed to work with a new layout of the golf course. Because of the relatively steep (in terms of drainage) 2% slope of the overland area, it was possible to construct a cascade of basins through which flood flows were conveyed both in parallel and in series. As an example of parallel storage, flows from Naylor Wash are intercepted by Basin 1 while flows from Arroyo Chico are intercepted by Basin 3. In terms of series flow, Basin 1 drains directly to Basins 2, 3, and 6, which drain through Basins 4 and 5 before reaching Randolph Way. Basin 3 drains directly to Basin 4, which in turns drains to Basin 5 and to Randolph Way. Interbasin conveyance is achieved through weirs, and culverts ranging from a single 18" reinforced concrete pipe (RCP) to a 3-barrel 60" RCP. A non-jurisdictional embankment along Randolph Way collects and detains the runoff from the urban area to the northeast, and also serves as the final control point for remainder of the basin. The final outflow is metered to the Arroyo Chico channel via a single 5' wide x 3' high concrete box culvert under Randolph Way. This overall combination of below ground storage in six interconnected basins and an embankment at Randolph Way served the mulitipurpose objective of the project without requiring an expensive PMF spillway needed under jurisdictional dam classification.

The water coming into the course from the three contributing washes is of extremely low quality. It contains trash, road debris and oils and large amounts of silt. As such, there were major concerns about the amount of trash and silt that would be deposited on the course during a storm event. To limit this, trash racks were installed upstream of the course. These have the capability to hold back the large trash and litter during high frequency events. The storm water is then routed into a lake, where the reduced velocity results in the settling out of the silt prior to moving the water through the course. It is anticipated that periodic removal of the silt from the lake will be required. To date, this combination of structures and routing has worked well to limit the impact of the urban flood water on the course.

Hydraulically, the performance of the basins and conveyance structures had to be considered in terms of: (1) frequent flow events during which the course would still be in use, (2) the 100-year design event, and (3) greater than design events. In the frequent events, conveyance from one basin to the next is primarily through the RCP's and is routed such that storage is limited to selected parts of the course. For example, in the two-year event, incoming flows from Naylor Wash will follow a path through Basin 1A, Basin 2A, Basin 3D, Basin 4B, and Basin 5, before reaching the outlet, while incoming flows from Arroyo Chico will go through Basin 3A and Basin 4A before reaching the outlet. The remaining basins are not used for detention at all, during frequent events. During the design event all basins are filled. Flows between sub-basins within the main basins (Basin 3A to 3B for example) are conveyed as submerged weir flow over turfed humps with 1% slopes on both sides. Flows between the main basins are via the RCP's and in some cases, concrete or rock protected weirs. During the greater than design events, the basins will fill and overflow their turfed embankments to the next basin downstream. The irrigated turf covering that is regularly maintained as part of the course is adequate as erosion protection since the fall from one basin to the next is generally limited to about four feet, the slopes are gradual (4:1 to 10:1), and the overflows are spread out over long embankments to limit the flow depth and unit discharge. The Randolph Way embankment is configured to control the design event and to provide relief in the greater than design event. The top of the embankment forms a 1500 foot long weir crest over which flows from a greater than design event will be distributed. By spreading the flows out, the depth of flow, unit discharge, velocity, and shear stress are reduced to a level that allows the use of an erosion control mat in place of concrete or riprap to protect the downstream slope of the embankment.

<u>Interconnected Basin Routing</u>

The HEC-1 rainfall-runoff model is not appropriate for modeling interconnected detention ponds. The model is not capable of adjusting the stage-discharge curve as tailwaters of the individual basins fluctuate. A commercially available program written specifically to rout flows through a number of storage nodes (basins) that are connected by various reaches (pipes, open channels, or weirs) was used for routing flows through the six interconnected basins. The water surface elevations at each node, and the discharge in each reach are computed for specified time increments based on: (1) a downstream boundary condition, (2) stage-storage relations for each node, (3) stage-discharge relations for each reach, and (4) incoming flows. Each node in the routing model represents a control volume. Water enters and leaves each node by the links connected to it, and by runoff hydrographs flowing into it. Storage at each node is provided by specified stage/storage relationships (i.e., stage-volume, or stage-area). The change in storage in each node is based on the differences in inflows and outflows at each time step during a simulation, and is used to determine the watersurface elevation at each node. Flows through each link (i.e., pipes, channels, or weirs) are calculated from known elevations at the ends of the link and the hydraulic properties of the link (slope, roughness, and geometry). Simultaneous solution of the elevations, flows and storage is done by iteration. The computation time step is variable and can be reduced to fractional seconds to minimize numerical inaccuracies.

A schematic routing diagram for the Randolph South model is shown in Figure 3. The downstream boundary condition was chosen as critical flow depth through the low flow outlet, which was approximately the same as normal depth in the downstream channel. Stage-storage relations were computed by measuring storage volumes at one foot contour intervals from the final grading plans. Stage-discharge relations were coded as multiple rating curves, or were computed internally by the routing program based on the elevations of both the headwater and tailwater during the time increment of interest. Incoming hydrographs were entered at the appropriate nodes as shown in the schematic routing diagram.

Aesthetic Design of Randolph South

The use of the site as a golf course has significant impact on the design criteria for the flood control basins, particularly the amount of land that can be utilized for flood storage. The available area for flood storage within the course was limited by the following four factors. First, the greens and tees need to be above the 100-year flood elevation. Typically, golf course greens have a subsurface drainage system consisting of 6" perforated pipe laid in a gravel layer. This is followed by sand and a specialized soil mix designed to provide high nutrients and fast drainage. The saturation of this specialized profile with high silt water clogs these layers reducing their drainage capacity and ultimately the quality of the turf. Likewise, the tees are generally laid over sand which will settle when saturated, creating a rough tee surface.

Second, the elevation at the base of the large trees cannot be altered. The excavation of soil or the placement of as little as 2" of fill material under the drip line of the trees can cause their death. Additionally, the use of any heavy equipment under the drip zone can cause compaction of the soils around the root tips damaging them and their ability to take up water and nutrients. To protect the trees, the design team employed a certified arborist to establish limits of earth work near the trees. Not only was no construction allowed within these limits but no equipment, traffic or materials were allowed within these zones. Because the existing fairways were lined with trees, this restricted the basins to the fairway areas and limited areas where pipes and structures could be placed.

Third, part of the project involved storage of water above the existing ground elevation. This means that some of the available land was taken up by fill slopes. The storage of flood water above existing elevations helped increase the volume of the basins. It also enhanced the character of the course by creating additional elevation differences, golf course features and visual interest. The creation of hills and levees above existing grade also reduced the amount of soil to be exported. Lastly, the location of structures like the comfort station, irrigation pump station, etc. had to be above the 100-year flood elevation. These four factors served to reduce the amount of land available for flood storage to 60-65% of the golf course area.

In addition to the inherent limitations of the flood control areas within the golf course, operational criteria further restricted the flood control aspect of the design. Because of the revenue and high demand for play on the course, the City required that the course be playable immediately after storm events up to the 10-year return interval. This meant that particular attention had to be paid to the function of the basins in high frequency storm events. The function of the basins in the 2- and 5-year events was carefully analyzed to assure that the course would be playable and that golf cart circulation was maintained. Several design solutions were explored and implemented to achieve this goal. Split level fairways were designed into some of the holes. A lower level, generally encompassing the right third of the fairway, serves as a grass bunker for the golfer and first level flood storage. As a golfer, this bunker represents a hazard, the penalty being a more difficult follow up shot. During high frequency events, these grass bunker areas would fill creating a fairway of reduced width, but still within acceptable fairway dimensions. On other holes, high frequency storm flooding concentrates in non-landing zone areas of the fairway, creating additional water hazards that enhance the golfing experience. Other holes provide high frequency flood storage in the out of play areas. The combination of golf course design solutions employed serves to meet the requirement for playability immediately after a high frequency storm event.

To fulfill the circulation requirement for golfers and carts immediately after a high frequency event, the routing of the cart path became critical. In some areas, low flows run under cart path bridges allowing circulation over the top. Because of the expense of these bridges, their use was somewhat limited. In other areas, cart paths run along the tops of the basins at the edges of the fairways. The cart paths were also constructed of concrete to provide a more permanent, all weather surface. By constructing the cart paths of concrete, these paths could also serve another important flood control feature. With the addition of stem walls up to 5' deep and structural reinforcing, these concrete paths serve as weir crests for movement of water between basins in large storms. The dual function of the cart paths as weir crests eliminated the need for introduction of large obtrusive structures into the golf course.

Turf management functions also provided limitations on the configuration of the flood control basins. They served to limit the slope of all grassed areas within the course. While 3:1 slopes are generally accepted as the maximum slope for growing turf in the southwest, mowing equipment cannot operate effectively on these slopes. Since the alternative, hand mowing is not desirable on a public course with limited maintenance personnel, slopes steeper than 4:1 were extremely limited on the course. Fairways themselves were often limited to 6:1 or flatter because of site lines to the greens and playability concerns. This further limited the amount of flood water storage on the course.

During the course of design, it became necessary to create a final embankment to control floodwaters from greater than design storm events. For this purpose, the Randolph Way roadway was selected. The roadway, located immediately adjacent to and downstream of the final project outlet, provided the additional space to construct this embankment without encroaching on either the golf course or adjacent residential development. In order to create a level embankment top, the grade had to be raised from zero top six feet for approximately 1500 linear feet.

The design of the Randolph Way embankment (Figure 4) carried another unique set of design challenges. First, large trees located within a few feet of the right of way line on the east side of the roadway had to be protected. Second, concerns of residents of large luxury and historic homes located immediately to the west of the roadway had to be considered. Third, a high use bicycle route had to be maintained. To preserve the existing trees, a retaining wall up to 6 feet in height was constructed along the property line. This retaining wall had a unique design which "bridged" potential root zone areas eliminating footing excavation in these root zone areas. A buttressed design provides the structural support in these bridged areas. The construction of this retaining wall was accomplished without loss of any of the adjacent large trees.

The view from the adjacent homes was also given primary consideration. In early designs, the roadway was set at the top of the spillway. This elevation, up to 6' above the adjacent property would have created unsightly views of the side slopes and cars above eye level from the homes. To avoid this, a split profile, they developed setting the roadway half way between the spillway and existing ground. The 3-foot maximum slopes between the roadway and adjacent properties present a visually manageable condition. The slope is well below eye level and could be landscaped with native trees and shrubs. The remaining 3 foot maximum slope between the roadway and bike path could likewise be landscaped. The result is an attractive tiered landscape integrating the roadway and bike path.

Construction Schedule and Challenges

Because of the course's revenue generating capacity for the City and its popularity, the City imposed a short construction window of 240 calendar days. The construction was to take place through the late spring, summer and early fall seasons and be complete in time for the busy winter golfing season. In addition, the construction project presented unique logistical and scheduling problems. The normal construction sequence for golf course construction was heavily disrupted by the exacting grading requirements and the time consuming construction of the structural elements. As a result, construction of this twelve million dollar project within the allotted construction window required allocation of major resources and constant attention to strict conformance with the schedule.

Whereas normal construction projects attempt to balance earthwork operations, this project required the export of approximately 400,000 cubic yards of soil. The contractor elected to perform this operation at night to reduce the impact of City traffic on the 16-mile round trip required to dispose of the soil. Local complaints about the noise and dust (which was highly visible under the artificial lighting) further restricted the Contractor's operations. Noise and dust problems aside, the export operation was completed in approximately three months. Concurrently with the export operation, the contractor performed many utility relocations. A 10" sanitary sewer required rerouting, a waste water treatment plant had to be closed, 24" reclaimed water lines with a regional customer base had to be lowered and other abandoned utilities had to be located and removed. Much of this work was done without benefit of accurate as-built information and survey.

Whereas a normal golf course grading plan serves as a guideline for construction, the precise storage requirements and hydraulic constraints that had to be met made it imperative that the grading plan on this course be closely followed. This increased the amount of construction staking required and the effort required for both rough and fine grading. The installation of the 20 different major pipe structures served to limit access during the rough grading operation, further complicating the effort. This impacted the grading contractor's ability to move dirt in an efficient manner. Additionally, the protected "islands" of existing trees further constricted the operation. During this operation, approximately 200,000 cubic yards of soil were relocated within the site in general conformance with the grading plans.

As the rough grading was completed, the inlet/outlet structures on the ends of the pipes, concrete cart paths and weir crests were constructed. Inlet/outlet headwalls were carefully tucked back into the hills so that they were not obtrusive visual elements. Each headwall was custom designed to fit the surrounding terrain. This custom design and field location process required significant extra effort by the contractor. Additional project elements included construction of approximately ½ mile of new 70' tall driving range fence, installation of a new 1.7 million dollar irrigation system, construction of over 5 miles of concrete cart path, reconstruction of 1/3 mile of City street, bike path and landscaping, 118 acres of sod, all in addition to the general construction requirements for a golf course facility.

<u>Performance in a Flood Event</u>

On the morning of September 3, 1996 widespread thunderstorms hit the Tucson area. The atmosphere around the Tucson basin was saturated due to continuing moisture flow from the Gulf of California. The storms were triggered by "outflow boundaries" from thunderstorms on the Mogollon Rim (north of Phoenix) and a perturbation in the upper atmosphere. On the watershed above Randolph South, rain began at approximately 5:45 a.m. and continued until 7:45 a.m., and had a total depth of 1.6 inches (roughly a five-year event). The rainfall peak, in which 0.17 inches fell in five minutes (a maximum intensity of 2.05 inches/hour), happened around 6:30 a.m..

The peak inflows at Naylor Wash and Paseo Grande Wash (Basin 1A), and Arroyo Chico (Basin 3A) occurred within 30-40 minutes after the peak rainfall. At Basin 1A, the inflow into the lake/sediment trap raised the water level nearly three feet. It crested over the weirs leading to Basins 2A, 1C (the driving range), and 1B by two feet, 8 inches, and one inch, in respective order. Flows continued through Basins 3C, 3D, 4B, and 5 before exiting at the Randolph Way outlet.

At Basin 3A, the inflow into the lake sediment trap raised the water surface nearly two feet. It first crested over the lip of the drop inlet at structure 3.2, which connects to Basin 4A, and then crested over the grass weir leading to basin 3B. From Basin 4A, flows continue directly to the Randolph Way outlet. From basin 3B, flows pass through Basins 4B and 5 en route to the outlet.

When the storm ended, members of the design team began touring the site with the golf course superintendent. Photos were taken, high water marks were noted, and the depth of the peak outflow was measured just downstream of the basin outlet. This information, along with the recorded rainfall was later entered into the calibrated HEC-1 rainfall-runoff model to estimate the inflow hydrographs to the basins. These in turn were entered into the hydraulic routing model. The resulting ponding elevations in the model were almost identical to the observed high water marks recorded the day after the storm. The combined peak discharge of the estimated inflows was 420 cfs. Based on the measured depth, the outflow was estimated to be approximately 65 cfs. Total storage, as estimated from the high water marks, was approximately 70 acre feet.

From the perspective of the City golf staff, the course functioned extremely well. Flood water was stored in the proper locations at the desired depths. This meant that the course was playable immediately after rain stopped. The maintenance staff was also pleased that the amount of debris and silt deposited on the course was minimal. The storm also allowed construction staff to identify several localized drainage problems so that they could further refine the performance of the course. Overall, the City has expressed high levels of satisfaction with the project's performance.

Conclusion

The design and construction of the Randolph South Detention Basin represent a cooperative effort between the City of Tucson, Pima County, and the U.S. Army Corps of Engineers. It proves that flood control, recreation, and aesthetics can coexist in a limited amount of open space surrounded by an urban environment. The key was an approach in which the design team came up with an innovative detention complex that functioned within a golf course, as opposed to trying to fit a golf course within a design for a detention basin. The redesigned golf course has been open for play since its dedication as the "Del Urich Golf Course" in April 1996. It has received an excellent response from the local golfing community. Use of the course has increased to record levels since redesign. Finally, the success of the integration of flood control and golf is most evidenced by the number of golfers who do not recognize the flood control function of the course.

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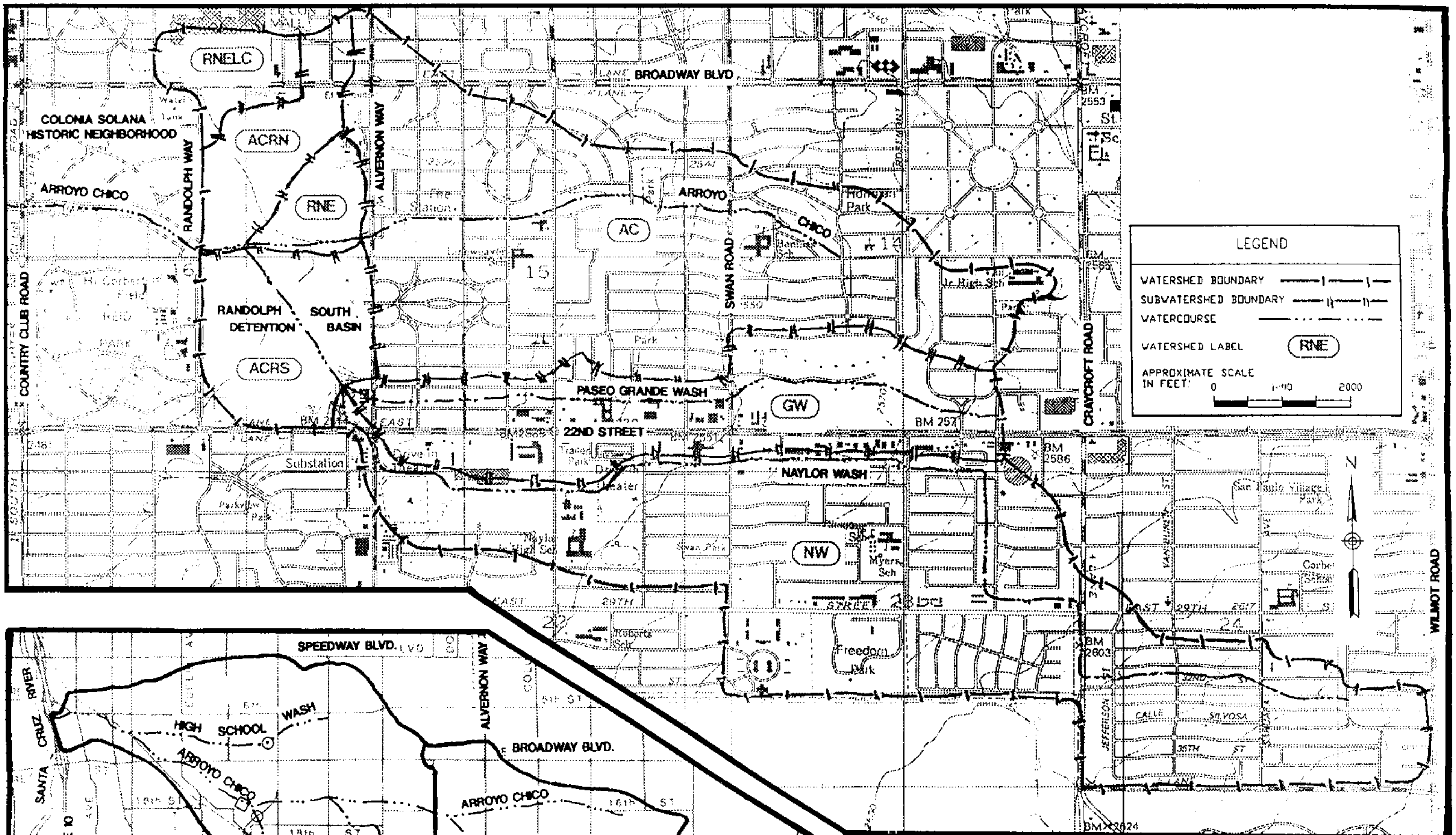
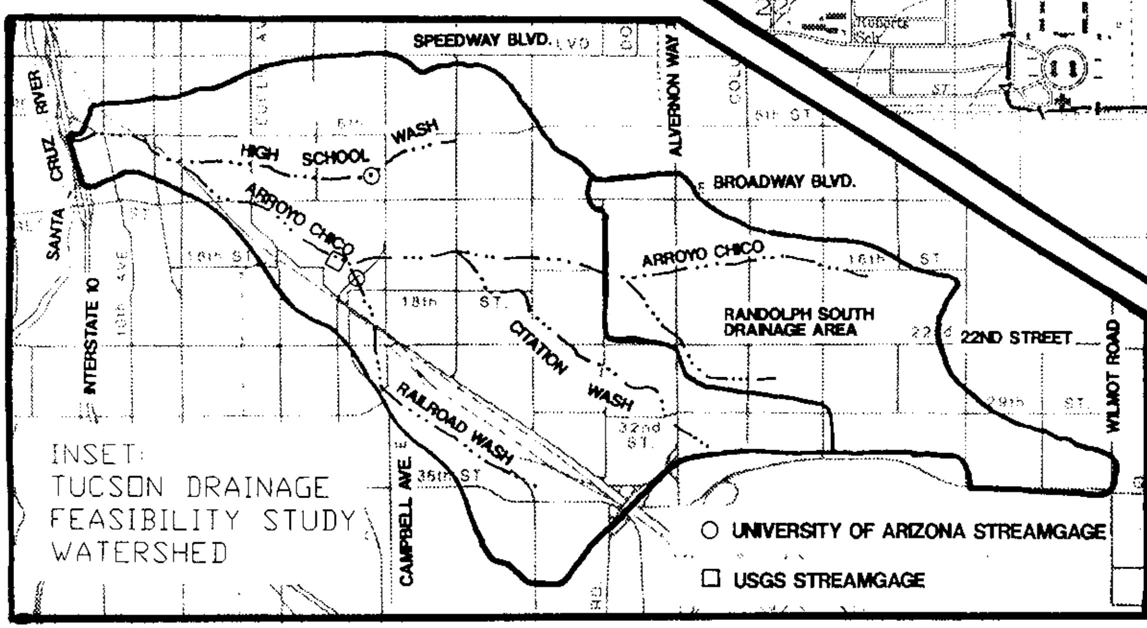


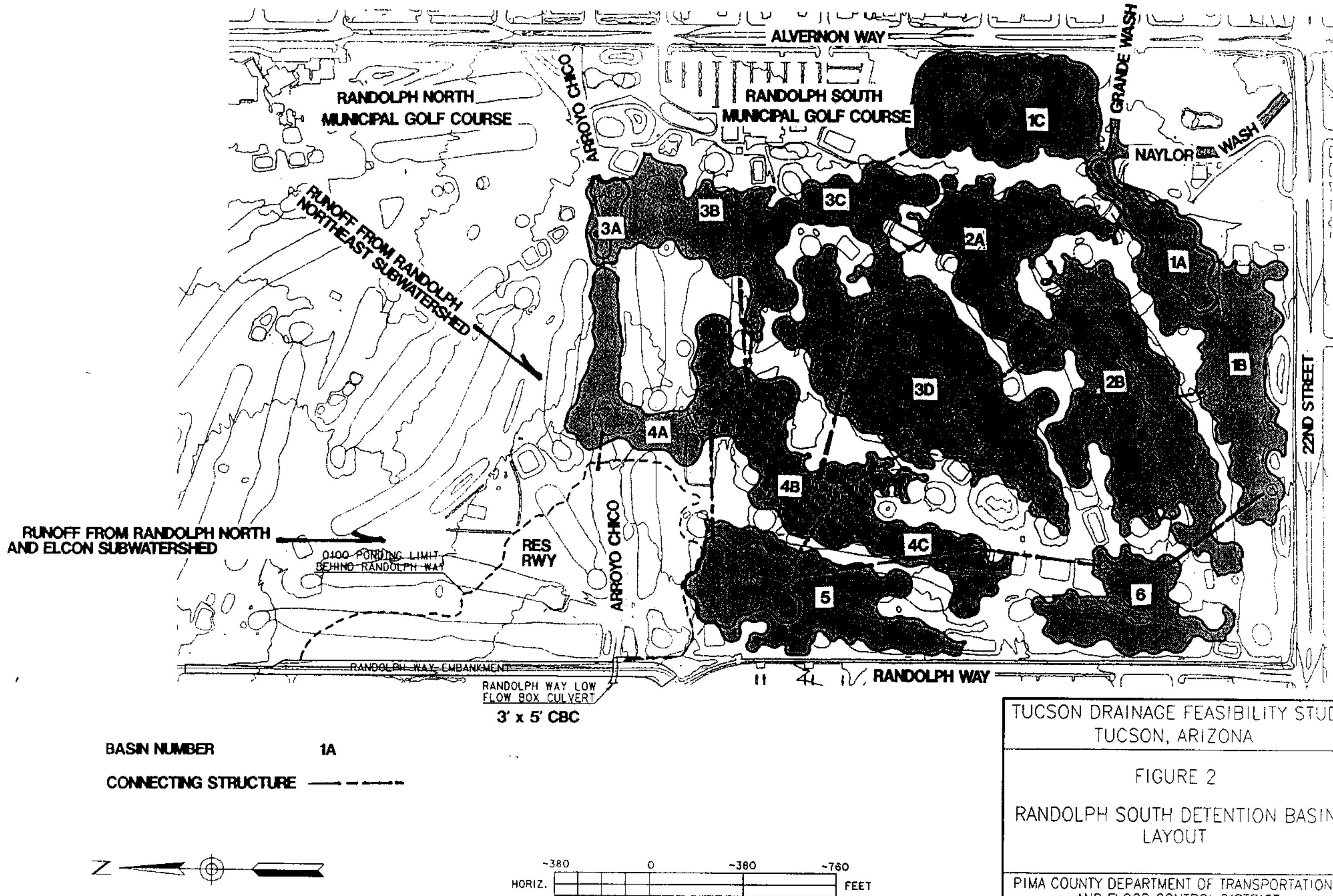


TUCSON DRAINAGE FEASIBILITY STUDY
TUCSON, ARIZONA

FIGURE 1

RANDOLPH SOUTH DETENTION BASIN WATERSHED AND LOCATION MAPS

PIMA COUNTY DEPARTMENT OF TRANSPORTATION AND FLOOD CONTROL DISTRICT

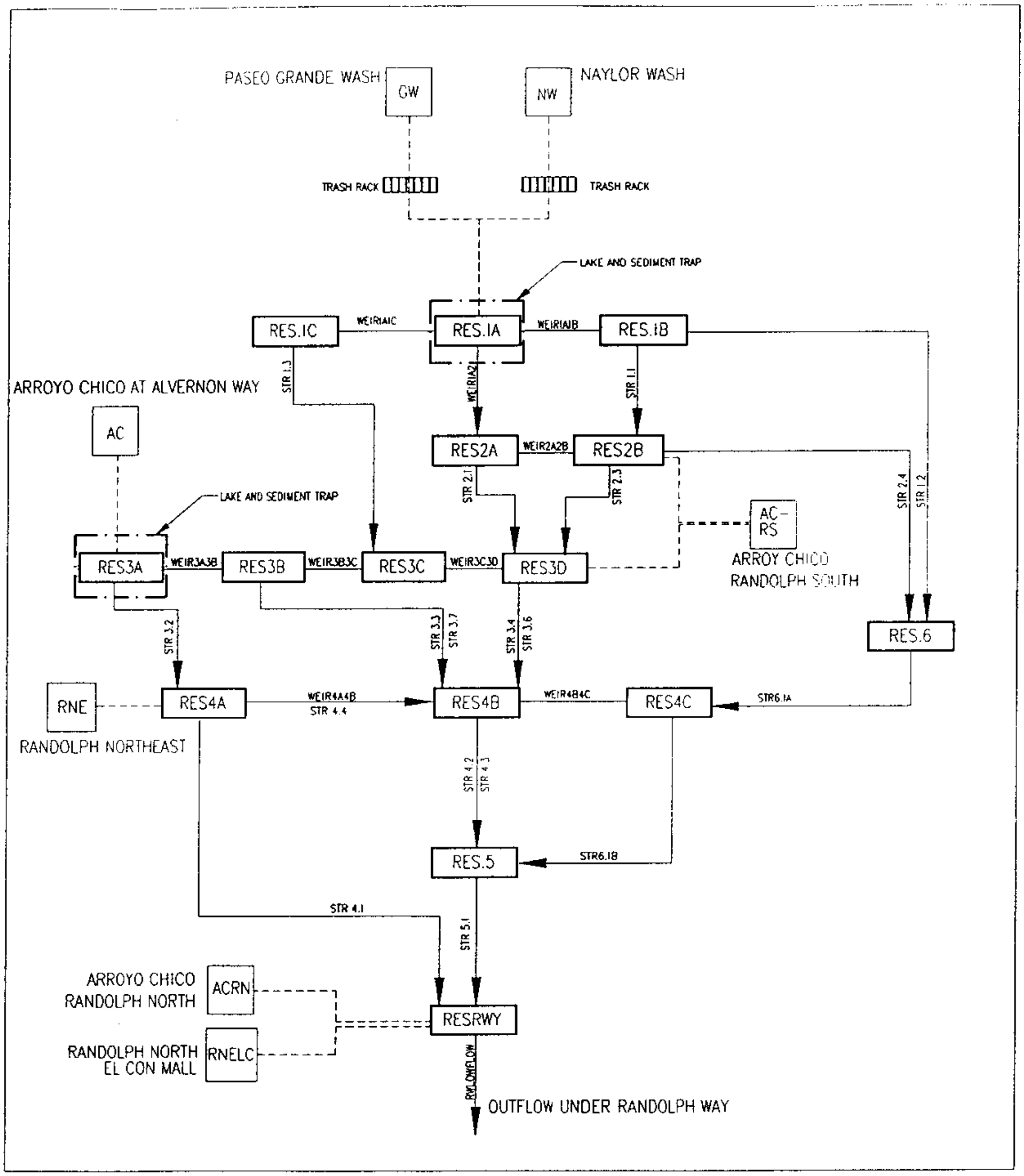


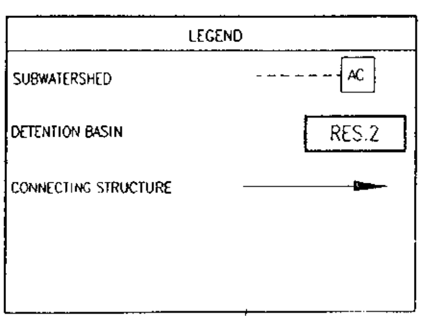
TUCSON DRAINAGE FEASIBILITY STUDY
TUCSON, ARIZONA

FIGURE 2

RANDOLPH SOUTH DETENTION BASIN LAYOUT

PIMA COUNTY DEPARTMENT OF TRANSPORTATION AND FLOOD CONTROL DISTRICT



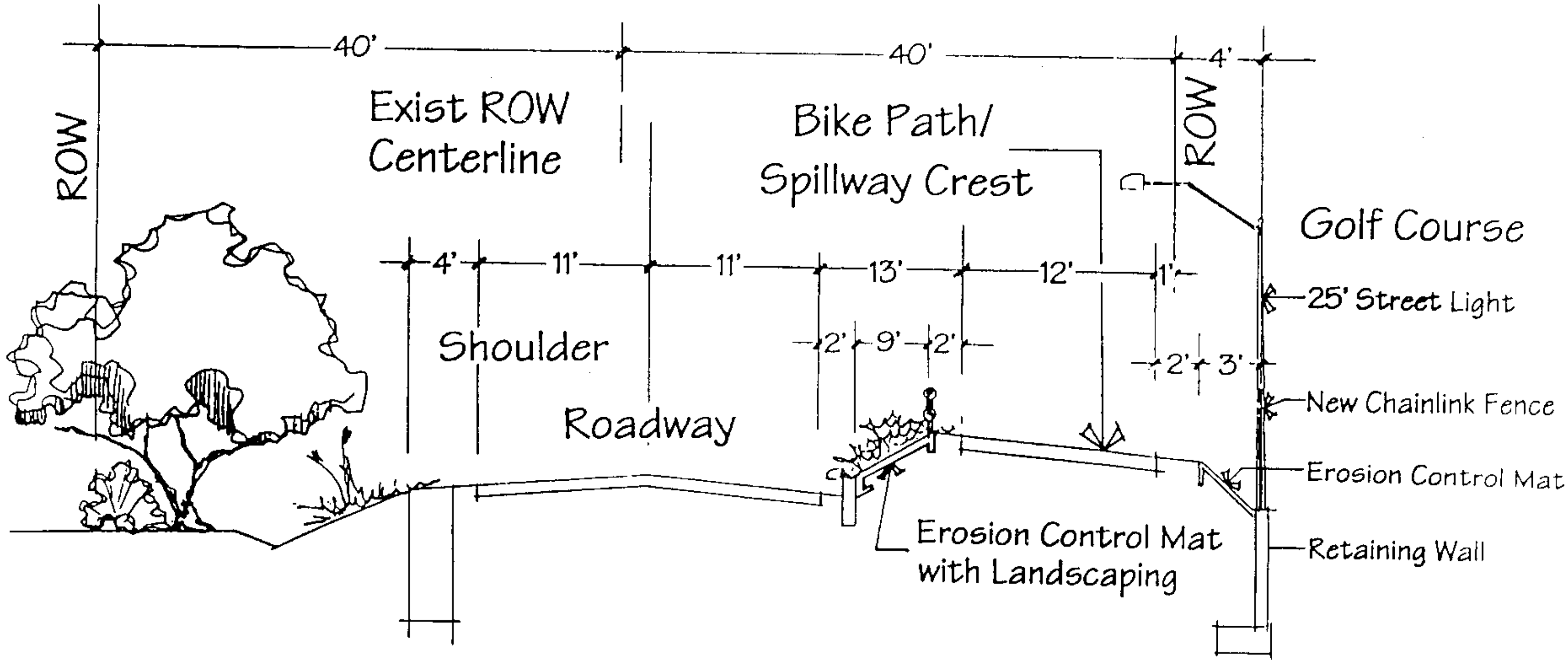


TUCSON DRAINAGE FEASIBILITY STUDY
TUCSON, ARIZONA

FIGURE 3

RANDOLPH SOUTH DETENTION BASIN
SCHEMATIC ROUTING DIAGRAM

PIMA COUNTY DEPARTMENT OF TRANSPORTATION
AND FLOOD CONTROL DISTRICT



RANDOLPH WAY ILLUSTRATIVE SECTION

FIGURE 4