STORM DRAINAGE MASTER PLAN

FOR

PROVO CITY, UTAH

DRAINAGE DESIGN POLICY MANUAL

VOLUME II

January 1986

JAMES M. MONTGOMERY, CONSULTING ENGINEERS, INC.

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STORM DRAINGE MASTER PLAN
FOR
PROVO CITY, UTAH

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PARKER, MC MONTGOMERY, COOK & PRING ENGINEERS, INC.

STORM DRAINAGE MASTER PLAN
FOR THE
CITY OF PROVO, UTAH

DRAINAGE DESIGN POLICY MANUAL
VOLUME II

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CHAPTER 1

STATEMENT OF POLICY

The provision of adequate drainage for urban areas is necessary to preserve and promote the general health, welfare, and economic well being of the region. Drainage is a regional feature that affects all governmental jurisdictions and all parcels of property. This characteristic of drainage makes it necessary to formulate a program that balances both public and private involvement. Over all coordination and master planning must be provided by the governmental units most directly involved, but drainage planning must be integrated on a regional level, and should be concurred with by state and national agencies if optimum results are to be achieved.

When planning drainage facilities, certain underlying principles provide direction for the effort. These principles are made operational through a set of policy statements. The application of the policy is in turn facilitated by technical criteria and data. When considered in a comprehensive manner, on a regional level with public and private involvement, drainage facilities can be provided in an urban area in a manner that will avoid uneconomic water damage and disruption, will enhance the general health and welfare of the region, and will assure optimum economic and social relationships.

The principles and policies for urban storm drainage are summarized below.

PRINCIPLES

- Drainage is a sub-system of the total urban system
- Drainage is a space allocation problem
- Stormwater runoff is a resource out of place
- An urban drainage strategy should be a multi-purpose, multiple-means effort

BASIC KNOWLEDGE

A program for collecting and analyzing storm runoff and flood data shall be undertaken in order that intelligent and orderly planning may be developed in the future in regard to storm drainage facilities.

A program shall be instituted to delineate flood hazard areas along all waterways in the region which are urbanized, or which soon may be. This program shall make full use of the city's Flood Insurance Study. This information shall be regularly reviewed and updated to reflect changes due to urbanization, changed channel conditions, and the occurrence of extraordinary hydrologic events.

Before commencing design of any drainage project, comprehensive facts and data shall be collected and examined for the particular basin and area under consideration. With the basis for the design then agreed upon with the governmental entities affected, detailed plans and specifications can be prepared that will provide the required drainage facilities.

PLANNING

Storm drainage is a part of the total urban environmental system. Therefore, storm drainage planning and design must be compatible with comprehensive regional plans. A Master Plan for storm drainage shall be developed and maintained in an up-to-date fashion at all times for each urbanizing drainage basin in Provo City.

The planning for drainage facilities shall be coordinated with the planning for open space, the planning for solid waste disposal, the planning for transportation, and the planning for other public utility systems. By coordinating these efforts, new opportunities will be identified which can assist in the solution of drainage problems.

Natural drainage channels shall be used for storm runoff conduits wherever possible. Major consideration must be given to the flood plains and open space requirements of the area. Planning and design of stormwater drainage systems shall not be based on the premise that problems can be transferred from one location to another.

Stormwater runoff can be stored in detention basins. Such storage reduces the drainage capacity required, thereby reducing the land area and drainage facilities expenditures required downstream. Acquisition of park land having a relationship to detention basins will provide areas where storm runoff can spread out and be stored for slower delivery downstream.

TECHNICAL SERVICES

Storm drainage planning and design shall follow the criteria developed and presented in following chapters of this report.

The determination of the magnitude of the stormwater runoff shall be found by utilizing one or more of the following hydrologic methods; the Rational Formula, the Soil Conservation Service Technical Release 55 (TR-55), the ILLUDAS stormwater model, or on analyses based on actual measured flood occurrences and/or synthetically developed unit hydrographs.

Use of streets for urban drainage shall fully recognize that the primary use of streets is for traffic. Streets shall not be used as floodways for storm runoff. Urban drainage design shall have as an objective the reducing of street repair and maintenance costs to the public.

The significant cost of handling storm runoff water, coupled with the significant social benefits to be derived from proper storm drainage facilities, points

towards the advent of selected detention basins for storage of storm water in Provo City.

Flood plain management programs should be initiated by the various governmental units within Utah County. Flood plain management must encompass comprehensive criteria designed to encourage, where necessary, the adoption of permanent state or local measures which will lessen the exposure of property and facilities to flood losses, improve the long-range land management and use of flood prone areas, and inhibit, to the maximum extent feasible, unplanned and economically unjustifiable future development in such areas.

FLOOD INSURANCE

The Flood Insurance Program should be an integral part of a strategy to manage urban drainage. Provo City will seek to participate in the Federal Flood Insurance Program set forth in the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973.

IMPLEMENTATION

This Drainage Design Policy Manual should be adopted by all departments operating within Provo City. Problems in urban drainage administration should be reviewed by Provo City to determine if equity or public interest indicate a need for drainage policy, practice, or procedural amendments. The financing of storm drainage improvements is fundamentally the responsibility of the affected property owners - both the person directly affected by the water and the person from whose land the water flows.

CHAPTER 2

APPROVAL PROCEDURE

INTRODUCTION

Provo City finds that it is necessary to adopt a formal procedure for approving all necessary and proposed drainage modifications, improvements or additions. This is necessary in order to protect property owners adjacent to or downstream of developing land from increased runoff rates which could cause erosion and flooding of abutting property, to promote sound development policies which respect and preserve the city's natural drainage channels, to insure the safety of the city's roadways, bridges and rights-of-way, and to decrease surface water drainage to public and private property. The following are definitions that will be utilized to describe the city's approval procedure:

- "Computations" shall mean calculations, including coefficients and other pertinent data, made to determine the drainage plan with flow of rates of water given in cubic feet per second (cfs)
- "Department" shall mean the Provo City Engineering Department
- "Developmental Coverage" shall mean all developed surface areas within the subject property including, but not limited to, rooftops, driveways, carports, accessory buildings, and parking areas
- "City Engineer" shall mean the Provo City Engineer and/or his designated representative
- "Drainage Area" shall mean the watershed (acreage) contributing surface water runoff to and including the subject property
- "Drainage Plan" shall mean a plan for receiving, handling, and transporting surface water within the subject property
- "Peak Discharge" shall mean the maximum surface water runoff rate (cfs) determined for the design storm frequency
- "Receiving Bodies of Water" shall mean natural drainage channels, creeks, rivers, lakes and other bodies of water into which surface waters are directed, either naturally or in manmade channels and pipelines or open systems
- "Detention Facilities" shall mean facilities designed to hold runoff for a short period of time and then releasing it to the natural watercourse or adequately sized drainage facilities
- "Subject Property" shall mean the tract of land which is the subject of the permit and/or approval action

GENERAL APPROVAL PROCEDURE

All persons applying for any of the below-listed permits and/or approvals shall submit, for the review and approval of the City Engineer; a "Grading and Drainage Plan/Permit", "Comprehensive Drainage Plan/Study", and/or a "Flood Plain Use Permit":

- o Building Permit Application
- o Site Plan Review
- o Subdivision Plat
- o Development Plan
- o Use Permit
- o Variance

Each of the above-listed permits and/or approvals, generally, require the submission of a "Grading and Drainage Plan/Permit", except as waived by the City Engineer, and several may also require a "Comprehensive Drainage Plan/Study" and/or a "Flood Plain Use Permit." Each applicant should check with the department to determine which of the above three submittals will be required for each specific permit and/or approval. The data requirements and the approval process for each of these three required submittals are discussed in subsequent sections of this chapter. For reference purposes, copies of the application form for a "Building Permit", Figure 2-1, the application form for a "Site Plan Review", Figure 2-2, and the application form for a "Land Use, Variance, Subdivision Plat and Development Plan Permit," Figure 2-3, are contained on the following pages.

Materials and data submitted with a "Grading and Drainage Plan/Permit", a "Comprehensive Drainage Plan/Study", and/or a "Flood Plain Use Permit" during one permit/approval process may be subsequently submitted with further required applications. The materials submitted shall be supplemented with additional information at the request of the department. The plan requirements established herein will not apply when the department determines that the proposed permit and/or activity;

- o Will not seriously and adversely impact the natural drainage channels, drainage facilities, or receiving bodies of water
- o Will not alter the drainage patterns, increase the peak discharge, or cause any other adverse effects in the drainage area of the designated flood plains or floodways controlled by the city

Sample forms of the "Grading and Drainage Permit", Figure 2-4, and the "Flood Plain Use Permit", Figure 2-5, are found in their respective sections of this Chapter. These permits shall be utilized in conjunction with the specific

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BUILDING PERMIT APPLICATION

Issued By _____

Dist.	Application Date	Plans	Survey	Plot Plan	Type Con.	Permit Number
						PR № 8177

To be Filled in by Applicant — PLEASE PRINT OR TYPE

Owner _____ Phone No. _____

Owner's Mailing Address _____ City _____ Zip _____

JOB SITE ADDRESS _____ CITY _____ Sec. _____ Twn. _____ Rng. _____

Lot No. _____ Subdivision _____ Tax Serial No. _____

Existing Use of Parcel		Intended Use of Parcel	
☐ Vacant	☐ Commercial / Specify Type	☐ Agriculture	☐ Commercial / Specify Type
☐ Agriculture	☐ Industrial / Specify Type	☐ Single Family	☐ Industrial / Specify Type
☐ Single Family	☐ Other / Specify Type	☐ Duplex	☐ Other / Specify Type
☐ Duplex		☐ Multiple Units	
☐ Multiple Units			

No. Dwell. Units	Owner Occupied or Rental	No. Bedrooms	No. Stories	Occupant Load

Bldg. Dimensions	Carport/Garage Dim.	Attached	No. Parking Spaces	Fire Place
X	X	No Yes		Yes No

Lot Dimensions	No. Dwell. Units Now on Lot	Other Buildings now on lot and use

Contractor	Arch./Eng.	Phone No.

Contractor's Mailing Address	City	Zip	Phone No.

FLOOR	EXT. WALLS	INT. WALLS	CEILING	ROOF	HEATING	SEWAGE
☐ Conc.	☐ Masonry	☐ Masonry	☐ Open Beam	☐ Wood Sh.	☐ Elect.	☐
☐ Wood	☐ Frame	☐ Frame	☐ Plaster	☐ Comp. Sh.	☐ Nat. Gas	☐ Public
	☐ Stucco	☐ Plaster	☐ Sheetrock	☐ Built-up	☐ L.P.G.	☐ Private
	☐ Siding	☐ Sheetrock	☐ Wood	☐ Metal	☐ Oil	
	☐ Metal	☐ Wood	☐ Fiber Board	☐ Shake	☐ Solid	

APPLICANT PLEASE READ CAREFULLY

I agree to comply with all City, County and State Building Laws and Ordinances, and that the representations in this application for a building permit are true and accurate, and any misrepresentations or errors herein, are the sole responsibility of applicant, and shall in no way incur or accrue liability or obligation to enforcing officers or agents.

This permit becomes null and void if work on construction authorized is not commenced within 120 days, or if construction or work is suspended or abandoned for a period of 120 days at any time after work is commenced.

OCCUPANCY OF STRUCTURE IS PROHIBITED UNTIL AFTER FINAL INSPECTION AND ZONING AND OCCUPANCY COMPLIANCE CERTIFICATE IS ISSUED.

I HAVE CHECKED THE SEWER DEPTH OF ABOVE LOT AND WILL TAKE ALL RESPONSIBILITY FOR SETTING BUILDING ACCORDINGLY.

Owner's Signature _____

Contractor's Signature _____ License No. _____

FOR DEPARTMENT USE ONLY

Date Permit Issued _____

Bldg. Insp. Signature _____

ZONE _____

Fire Zone 1 2 3 4 5 6 7 8 9 9a 9b 10

TYPE	FEE
Temp. Power	
Sewer Fee	
Water Fee	
Plan Ck. Fee	
Constr. Fee	
Elect. Fee	
Plumbing Fee	
Heating Fee	
Off Site Fee	
Bldg. Permit Fee	
TOTAL FEE	$
Total Valuation	$

Receipt No. _____

Cash _____

Check No. _____

FLOORS	Sq. Ft.
1	
2	
3	
Carport/Gar.	

Minimum Property Setback Distances

_____ Front Setback from P.L. _____

_____ Rear Setback from property line

_____ Side Street Setback from P.L. _____

_____ Side Setback from property line

_____ Side Setback from property line

COMMENTS

N

W E

S

APPROVAL OF SEWAGE FACILITY
(Private System Only)

The above applicant agrees to construct sewage facilities in conformity with Utah County and Utah State regulations.

Septic Tank _____ gallons.

Absorption field _____ lineal ft. of 3 ft. wide trench.

Seepage pit _____ Absorption bed _____ sq. ft.

Water Supply _____

Date _____, 19 _____

Approved: _____

Utah County Health Department

TO BE FILLED IN BY PLANNING OFFICE			
TRAFFIC ZONE	CENSUS TRACT	CENSUS BLOCK NO.	SLU CODE

Distribution List: White - Office Green - C.O.G. Yellow - Office Duplicate Pink - Assessor Gold - Customer

Rev. '76

PROVO CITY CORPORATION

COMMUNITY DEVELOPMENT DEPARTMENT

APPLICATION

FOR THE FOLLOWING ACTION:

- ☐ VARIANCE
- ☐ USE PERMIT
- ☐ DEVELOPMENT PLAN APPROVAL
  - ☐ PRELIMINARY
  - ☐ FINAL
- ☐ SUBDIVISION
  - ☐ PRELIMINARY PLAT
  - ☐ FINAL PLAT

Application No:

Zone:

Received By:

Date Received:

CHECKED

- ☐ FEE
- ☐ PLANS AND PLATS
- ☐ DESCRIPTION
- ☐ DISTRIBUTION
- ☐ SIGNATURE

HEARING DATE:

TYPE OR PRINT IN INK

NAME OF APPLICANT (PROPERTY OWNER)

APPLICANT'S ADDRESS | TELEPHONE NO.

NAME OF AGENT

AGENT'S ADDRESS | TELEPHONE NO.

PROPERTY ADDRESS

LEGAL DESCRIPTION (LOT, BLOCK & TRACT - OR ATTACH METES AND BOUNDS)

PRESENT USE OF PROPERTY

USE, PROJECT, OR TYPE OF VARIANCE BEING REQUESTED

STATEMENT OF JUSTIFICATION
VARIANCE ONLY

STATE THE EXCEPTIONAL CIRCUMSTANCES OF THIS PROPERTY THAT DO NOT APPLY TO OTHER PROPERTIES IN THIS ZONE.

WHEN WERE THESE CIRCUMSTANCES CREATED, AND BY WHOM?

OVER

requirements found in the "Grading and Drainage Ordinance" and the "Floodplain Management Ordinance."

GRADING AND DRAINAGE PLAN/PERMIT REQUIREMENTS

Proposed alteration of any existing land surface within Provo City requires a Grading and Drainage Plan submittal to the Department. This includes, but is not limited to, any proposed grading, filling, excavating, surfacing, landscaping, or erecting of structures.

The developer must obtain plan approval and a Grading and Drainage Permit from the department prior to issuance of a Building Permit.

Basic Data Requirements

Single Residential Structure Development, such as single family, duplex, triplex, fourplex, etc., which is freestanding with a common-finish floor.

Submit an 8" X 11" or 8" X 14" reproducible drawing (24" X 36" size is also acceptable) prepared by a Registered Engineer containing the following information:

- Title block entitled "Grading and Drainage Plan" with a legal description of the site, the owner/developer, the engineer's name and signature, license number, date, and scale
- Current survey information by a Registered Land Surveyor in the State of Utah, including retraceable corner monumentation bearing his RLS number, and/or existing corner monumentation found
- Existing and proposed elevations tied to the Provo City benchmark datum in sufficient quantity to allow adequate review by staff (i.e., property, structural, setback, driveways, parking, etc.)
- Location of any existing improvements within fifteen feet (15') of the property or which may be affected by grading operations, including street lights, fire hydrants, driveways, etc.
- North Arrow
- Approval by Provo City - approval line to read "Provo City Engineer" and date
- Onsite drainage runoff calculations

Multiple Unit Residential Structure Development, such as single family subdivisions, planned unit developments, townhouses, condominiums, apartment complexes, trailer estates, churches, commercial, or industrial developments, etc.

Submit a 24" X 36" original drawing suitable for microfilming and blueline reproduction containing the following information:

- All of the requirements in Section A above
- A soils report, if required
- Specifications, if required
- Onsite detention design together with drainage calculations
- Earthwork quantities separated into offsite and onsite cut and fill for permit estimating purposes; any other quantity which pertains to drainage structures referred to below
- Locations of disposal areas for deleterious or excess materials resulting from grading and drainage operations
- Detailed plans of all surface and subsurface drainage devices, walls, cribbing, detention facilities, dams and other protective devices to be constructed with, or as a part of the proposed work, together with a map showing the drainage area and the estimated runoff of the area served by any drainage system - provide calculations
- Any additional plans, drawings, calculations or specifications reasonably required by the City Engineer

The Supervising Engineer (or Surveyor in the instance of single residential grading and drainage plans) in charge of the survey control shall certify, in writing, that the finish floor elevation, when completed, conforms to the approved Grading and Drainage Plan.

A Performance Bond or other form of acceptable security may be required to insure compliance to the approved Grading and Drainage Plan.

Approval Procedure

The developer or his agent may submit the Grading and Drainage Plan to the department prior to submittal of the architectural plans to the Building Department. This allows approvals to be obtained simultaneously. However, copies of the Grading and Drainage Plan must also be included with the architectural plans because these are routed to several other departments for review. The Engineering Department forwards its comments to the Building Department and to the developer and his engineer/surveyor. When all corrections are made to the satisfaction of the City Engineer, the plan is signed and a Grading and Drainage Permit is issued. When the Building Department approves the architectural plans, a Building Permit may be issued. The Engineering Department inspects grading and drainage operations and the Building Department is in charge of the remainder of the development. Prior to final inspection of the project, the completed grading and drainage construction requires approval by the Engineering Department.

Offsite Improvement Requirements Adjoining Proposed Development

The City Engineer has the authority to require offsite improvements for any development to the standards set forth in the Provo City Code. Specific provisions are not addressed herein but will be considered as a part of the overall development including an Offsite Improvement Permit, if required.

Sample of Grading and Drainage Plan

Figure 2-4 is a sample of the "Grading and Drainage Permit." It must be properly completed and submitted with the data described above.

COMPREHENSIVE DRAINAGE PLAN/STUDY

All persons applying for any of the permits and/or approvals contained in this chapter shall provide a drainage plan for surface water flows entering, flowing within, and leaving the subject property. The detailed form and contents of the drainage plan shall be described in procedures listed below. The developer must obtain plan approval from the Engineering Department prior to issuance of the requested permit or project approval.

Basic Data Requirements

A "Subdivision Plat" requires the development of the below listed materials for a "Comprehensive Drainage Plan."

- Background computations for sizing drainage facilities:

  1. Depiction of the drainage area on a topographical map, with acreage indicated.

  2. Indication of the peak discharge and amount of surface water currently entering and leaving the subject property.

  3. Indication of the peak discharge and amount of runoff which will be generated within the subject property if development is allowed to proceed.

  4. Determination of the peak discharge and amount of water that will be generated by 10 and 25-year frequency storm events at various points on the subject property.

- Proposed improvements for handling the computed runoff:

  1. Where open ditch construction is used to handle drainage within the tract, a minimum of 15 feet will be provided between any structures and the top of the bank of the defined channel.

  2. Where a closed system is used to handle drainage within the tract, all structures will be a minimum of 10 feet from the closed system.

PROVO CITY

ENGINEERING DEPARTMENT

GRADING AND DRAINAGE PERMIT

APPLICANT _____ DATE _____

ADDRESS OR LEGAL DESCRIPTION _____

_____

DESCRIPTION OF PROPOSED DEVELOPMENT _____

_____

ESTIMATED EARTHWORK QUANTITIES: ONSITE: _____ OFF SITE: _____

EXCAVATED WASTE DISPOSAL AREA: _____

GRADING AND DRAINAGE PLANS REQUIRED: YES ___ NO ___ DATE APPROVED _____

ONSITE DETENTION REQUIRED: YES ___ NO ___ DATE APPROVED _____

SPECIFICATIONS REQUIRED: YES ___ NO ___ DATE APPROVED _____

SOIL REPORT REQUIRED: YES ___ NO ___ DATE APPROVED _____

AIR POLLUTION CONTROL PERMIT REQUIRED: YES ___ NO ___ DATE APPROVED _____

P.E. CERTIFICATION REQUIRED: YES ___ NO ___ DATE APPROVED _____

BOND REQUIRED: YES ___ NO ___ DATE APPROVED _____

BOND AMOUNT _____ BOND TYPE _____

OTHER REQUIREMENTS PER GRADING AND DRAINAGE ORDINANCE: _____

_____

_____

REMARKS: _____

_____

_____

_____
SIGNATURE OF APPLICANT (PERMITTEE)

FEE $ _____

_____
APPROVED BY

I WISH TO MEET A CONSTRUCTION INSPECTOR ON _____ AT _____ AM PM

FINAL APPROVAL BY CONSTRUCTION INSPECTOR ON _____, 19 _____

BY _____

FIGURE 2-4

3. Where detention facilities are proposed within the development, such facilities are to be designed in accordance with the parameters of this Manual, with the operation and maintenance responsibilities assumed by the property owner, unless otherwise approved by the department.

The following items are required as mandatory elements of the Drainage Plan:

- Surface water entering the subject property shall be received at the naturally occurring location, and surface water exiting the subject property shall be discharged at the natural location, with adequate energy dissipators to minimize downstream damage and with no diversion at any of these points

- The peak discharge from the subject property may not be increased due to the proposed development - in other words, the peak discharge from the property after development occurs must be equal to or less than the predicted discharge from the property in its natural condition

- Detention basin facilities must be provided and maintained by the property owner in order to handle all surface water in excess of the peak discharge of the property in a natural state

Exceptions from any or all of the foregoing requirements may be permitted only after a determination by the department, employing the following criteria:

- Capacity of downstream facilities

- Acceptability of receiving bodies of water

- Possibility of adverse effects of detention basins

- The utilization of regional detention basin facilities

Approval Procedure

All Comprehensive Drainage Plans that are submitted must be in compliance with, and in general conformity to, the recommendations of the "Storm Drainage Master Plan for Provo City." All plans must be approved in writing by the department. After approval of the Comprehensive Drainage Plan and prior to the issuance of any building permits, the Owner and/or Developer shall, at his own expense, prepare and submit for review and approval by the department detailed construction drawings, including plans, profiles and specifications for the construction and installation of channels, conduits, reservoirs, culverts, bridges, easements and all other drainage facilities necessary for the control and drainage of all storm and flood waters within said parcel of land, or the part thereof to be approved and the conveyance of such drainage to the discharge or outflow point, all in conformity with the Drainage Plan for the parcel of land. The Owner and/or Developer shall also prepare and submit an estimated construction cost estimate and schedule for implementation of the required improvements.

All Comprehensive Drainage Plans must be prepared by a licensed professional engineer, licensed by the State of Utah. All municipal corporations and government entities shall be required to submit a Comprehensive Drainage Plan and comply with the terms and conditions of this Chapter when developing and/or improving land including, but not limited to, road building and widening within the incorporated limits of Provo City.

Offsite Improvement Requirements Adjoining Proposed Development

The City Engineer has the authority to require offsite improvements for any development to the standards set forth in the Provo City Municipal Code. Specific provisions are not addressed herein but will be considered as a part of the overall development including an Offsite Improvement Permit, if required.

FLOOD PLAIN USE PERMIT

Any person or company who undertakes any construction or development in the floodplain, (i.e., erection, addition, alteration, or change in use of any building, groundcover, or land, on any land within the Provo City) shall be required to obtain a Flood Plain Use Permit from the department before a building permit can be obtained or construction initiated. This requirement shall include the placement of mobile homes or other mobile structures so that it may be determined whether such construction or other development is proposed within flood-prone areas.

The purpose of the Flood Plain Use Permit is to determine whether proposed building sites and development activities will be reasonably safe from flooding. If the proposed building sites and development activities are located within the 100-year flood plain, or flood-prone areas, all new construction and substantial improvements, including the placement of pre-fabricated buildings and mobile homes, shall be designed or modified to prevent flotation, collapse, or lateral movement of the structures and be constructed with materials and utility equipment resistant to flood damage and be constructed by methods and practices that minimize flood damage.

If a subdivision proposal or other proposed new development is in a flood-prone area, any such proposal shall be reviewed to assure that:

- All such proposals are consistent with the need to minimize flood damage
- All public utilities and facilities such as sewer, gas, electrical, and water systems are located and constructed to minimize or to eliminate flood damage
- Adequate drainage is provided to reduce exposure to flood hazards
- All water supply systems are designed to minimize or to eliminate infiltration of flood waters into the systems

- Provide elevations to certify that all new construction and substantial improvements of residential structures within Zones A1 to B0 on the city's Flood Insurance Rate Map (FIRM) have the lowest floor (including basement) elevated to or above the base flood elevation.

- Provide elevations to certify that all new construction and substantial improvements of non-residential structures within Zones A1 to B0 on the city's FIRM have the lowest floor (including basement) elevated to the base flood elevation plus one (1) foot allowance for sediment and future development, or, together with attendant utility and sanitary facilities shall:

  1. Be flood-proofed so that below the Flood Hazard level plus an allowance for sediment and for future development, the structure is watertight with walls substantially impermeable to the passage of water, and protected from erosion.

  2. Have structural components capable of resisting hydrostatic and hydrodynamic loads and effects of buoyancy.

  3. Be certified by a registered professional engineer that the standards of this subsection are satisfied. Such certifications shall be provided to the City Engineer as set forth in the applicable portions of this Ordinance.

- Provide proof that where flood-proofing is utilized for a particular structure that it is done in accordance with the requirements established by the Federal Emergency Management Agency (FEMA) for the National Flood Insurance (FIS) Program. A registered professional engineer shall certify that the flood-proofing methods are adequate to withstand the flood depths, pressures, velocities, impact, and uplift forces and other factors associated with the base flood.

- Provide proof, within Zones A1 to B0 on the city's FIRM, for new mobile home parks and mobile home subdivisions, for expansions to existing mobile home parks and mobile home subdivisions, and for existing mobile home parks and mobile home subdivisions where the repair, reconstruction or improvement of the streets, utilities, and pads equals or exceeds 50% of the value of the streets, utilities and pads before the repair, reconstruction or improvement has commenced, that: (a) stands or lots are elevated on compacted fill or on pilings so that the lowest floor of the mobile home will be at or above the base flood level, (b) adequate surface drainage and access for a hauler are provided, and (c) in the instance of elevation on pilings; lots are large enough to permit steps, piling foundations are placed in stable soil no more than ten feet apart, and reinforcement is provided for pilings more than six feet above the ground level.

- Provide proof, within Zones A1 to B0 on the city's FIRM, for all mobile homes not located in a mobile home park or mobile home subdivision

that: (a) stands or lots are elevated on compacted fill or on pilings so that the lowest floor of the mobile home will be at or above the base flood level, (b) adequate surface drainage and access for a hauler are provided, and (c) in the instance of elevation on pilings; lots are large enough to permit steps, piling foundations are placed in stable soil no more than 10 feet apart, and reinforcement is provided for piers more than 6 feet above ground level.

- Provide proof, within any A0 Zone on the city's FIRM, that all new construction and substantial improvements of residential structures have the lowest floor (including basement) elevated above the crown of the nearest street to or above the depth number specified on the city's FIRM.

- Provide proof, within any A0 Zone on the city's FIRM, that all new construction and substantial improvements of non-residential structures (a) have the lowest floor (including basement) elevated one (1) foot above the crown of the nearest street to or one (1) foot above the depth number specified on the FIRM, or (b) together with attendant utility and sanitary facilities be completely flood-proofed to or above that level so that any space substantially impermeable to the passage of water and with structural components having the capability of resisting hydrostatic and hydrodynamic loads and effects of buoyancy.

- The floodway designated on the city's FIS maps shall be regulated by the following requirements:

  1. Permitted Uses: Uses having a low flood damage potential may be permitted to the extent that they are not prohibited by other regulation, code, or ordinance provided that they do not require permanent structures, fill or other obstructions to the flow of flood water in the Floodway District and provided that they do not adversely affect the capacity of the channels or floodways of any tributary to the main system, drainage ditch, or any other drainage facility or system. These uses may be permitted only upon application to the City Engineer and issuance of a Flood Plain Use Permit. Permits for these uses do not preclude the appropriate requirement for flood insurance.

  2. Prohibit encroachments, including fill, new construction, substantial improvements, and other development within the adopted regulatory floodway that would result in any increase in flood levels within the community during the occurrence of the base flood discharge.

  3. Prohibit the placement of any mobile homes, except in an existing mobile home park or mobile home subdivision, within the adopted regulatory floodway.

  4. Certification: Any application for a Flood Plain Use Permit must be certified by a registered professional engineer that the proposed

development shall not result in any increase in flood levels during the occurrence of the flood hazard discharge, any deflection of flow, or any erosion or sediment hazard.

- The Floodway Fringe District shall be regulated by the following requirements:

Floodway Fringe District

1. Permitted Uses:

   a. Any use specified in the Floodway District may be permitted in the Floodway Fringe District.

   b. Any other use may be permitted if it is elevated above the Flood Hazard Elevation and a determination is made by the City Engineer that the use will not unduly restrict the capacity of the channels or floodways of tributaries to the main watercourse, drainage ditches, or other drainage facilities or systems.

   c. Structures or buildings, including dwellings, may be erected on fill material, provided the lowest habitable floor is above the Flood Hazard Elevation. The fill may be used at locations where the ground elevation is no lower than two feet below the Flood Hazard Elevation and shall extend at such elevation for at least 25 feet beyond the limits of any structure or building erected thereon. Bank protection, if approved by the City Engineer, may be used in lieu of the twenty-five (25) feet of fill.

   The above uses may be permitted only if a Flood Plain Use Permit is obtained, except that in the Floodway Fringe District, encroachment is allowed only to the extent that it will not raise the Flood Hazard Elevation more than one (1) foot at the time of delineation.

2. Certification: The applicant shall provide a certification by a registered professional engineer that the encroachment does not raise the Flood Hazard Elevation more than one (1) foot and the flood-proofing methods for any structure are as defined under FIRM. The City Engineer will maintain a record of all certifications along with the permit applications.

3. Permitted Uses Below the Flood Hazard Elevations: If the City Engineer determines, after reviewing the Flood Plain Use Permit application, that the proposed use can be readily removed from flood hazard areas during times of flood, he may allow such uses to be located at an elevation below the Flood Hazard Elevations.

- In areas of shallow flooding, as designated on the Flood Zoning District Maps, all new structures or substantial improvements shall have the lowest habitable floor elevated above the crown on the nearest street to or above the depth number specified on the FIRM, and all nonresidential structures shall have the lowest floor elevated or shall be flood-proofed to or above the depth number specified on the FIRM.

Review and Approval Procedure

The City Engineer shall review all applications for Flood Plain Use Permits to determine that all the requirements of this Ordinance are met, and that the structure would be reasonably safe from flooding.

The review shall determine if the proposed development adversely affects the flood and sediment-carrying capacity of the area of special flood hazard. For this purpose, "adversely affects" means that the cumulative effect on the proposed development, when combined with all other existing and anticipated development, will not increase the water surface elevation of the base flood more than one (1) foot.

Prior to occupancy or use of any structures or areas in the Flood Hazard Zone, a Certificate of Compliance for Flood Plain Use will be obtained from the City Engineer. The Floodplain Ordinance contains specific details regarding the methods and procedures to be utilized to obtain a variance or to submit an appeal concerning all aspects of the Flood Plain Use Permit.

Sample of Flood Plain Use Permit

Figure 2-5 is a sample of the "Flood Plain Use Permit." It must be properly completed and submitted with the data described above. Figure 2-6 is a schematic representation of the 100-year flood plain that is being regulated by the issuance of a Flood Plain Use Permit.

PROVO CITY

ENGINEERING DEPARTMENT

FLOOD PLAIN USE PERMIT

APPLICANT _____ DATE _____

ADDRESS OR LEGAL DESCRIPTION _____

_____

DESCRIPTION OF PROPOSED DEVELOPMENT _____

_____

DETERMINATION: THIS PROPERTY IS IN A(N) _____ ZONE AND (IS) (IS NOT) WITHIN A 100-YEAR FLOOD HAZARD AREA AS DETERMINED BY THE NATIONAL FLOOD INSURANCE PROGRAM AND SHOWN ON ITS OFFICIAL FIRM AND/OR FLOODWAY MAPS.

REMARKS: _____

_____

_____

_____

_____

_____

_____

_____

_____

DETERMINATION OF ZONE MADE BY: _____

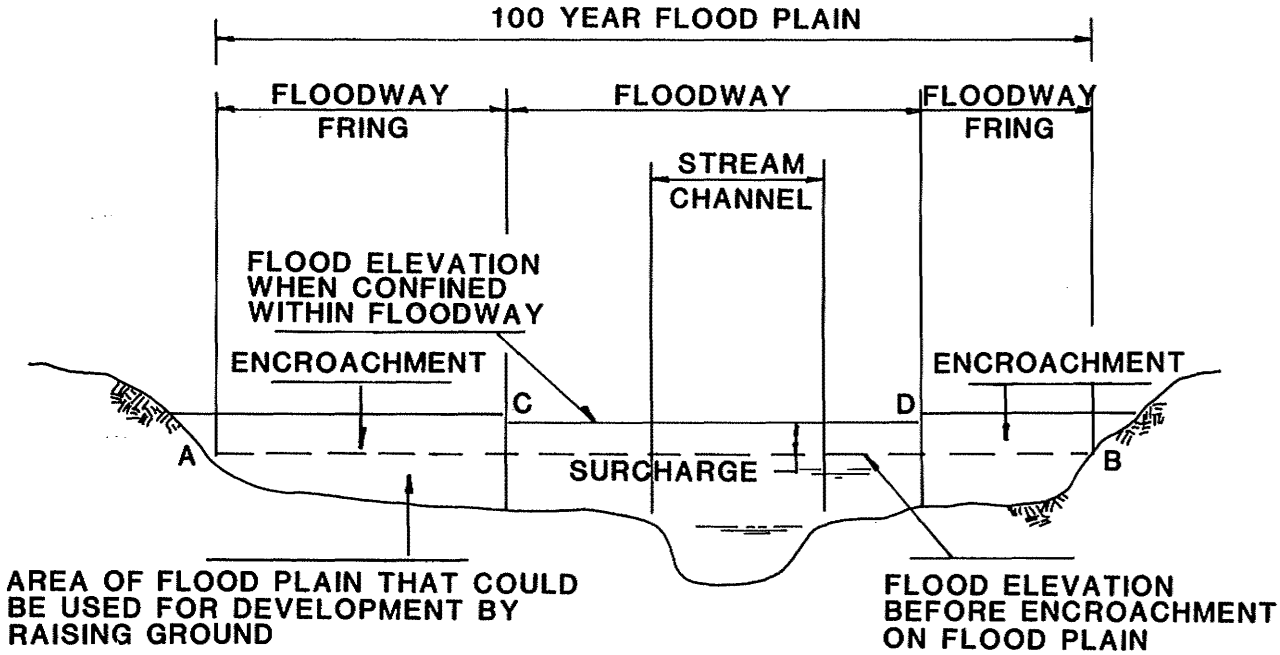
CERTIFICATION BY: _____ P.E. _____

AS REQUIRED IN THE FLOODPLAIN MANAGEMENT ORDINANCE

FEE $ _____ DATE OF APPROVAL _____

SIGNED BY: _____

FIGURE 2-5



LINE AB IS THE FLOOD ELEVATION BEFORE ENCROACHMENT
LINE CD IS THE FLOOD ELEVATION AFTER ENCROACHMENT
"SURCHARGE" NOT TO EXCEED 1.0 FEET

PROVO CITY
STORM DRAINAGE MASTER PLAN
SCHEMATIC REPRESENTATION
of the
100-YEAR FLOOD PLAIN

FIGURE NO. 2-6

CHAPTER 3

DESIGN CRITERIA FOR FLOOD CONTROL SYSTEMS

INTRODUCTION

The term "flood control system," as utilized in this chapter, refers to the system of inlets, conduits, manholes, detention basins, and other appurtenances which are designed to safely collect, store, and convey storm runoff from the design storm to a point of discharge.

The term "natural water course" as utilized in this chapter refers to the historical major flow path taken by stormwater and/or snowmelt runoff.

FREQUENCY OF DESIGN RUNOFF

The frequency of design runoff, or rainfall return period, to be utilized for a local storm drainage system should be once in ten years. Adjustments can be made to this design frequency as follows:

- Establish a storm frequency of 10 years for projects, 1) not located in natural existing watercourses, 2) draining important sump areas, or 3) restricted by outlet conditions.

- Establish a storm frequency of 25 years for projects, 1) concerning major trunk lines and collection facilities, or 2) located in natural existing watercourse or sump areas.

- Establish a storm frequency as approved by Provo City where such circumstances exist to warrant an adjustment.

The rainfall intensities for the design storm frequency to be used in the computation of runoff shall be obtained from the rainfall intensity-duration-frequency curves for Provo City as shown in Figures 3-1 and 3-2.

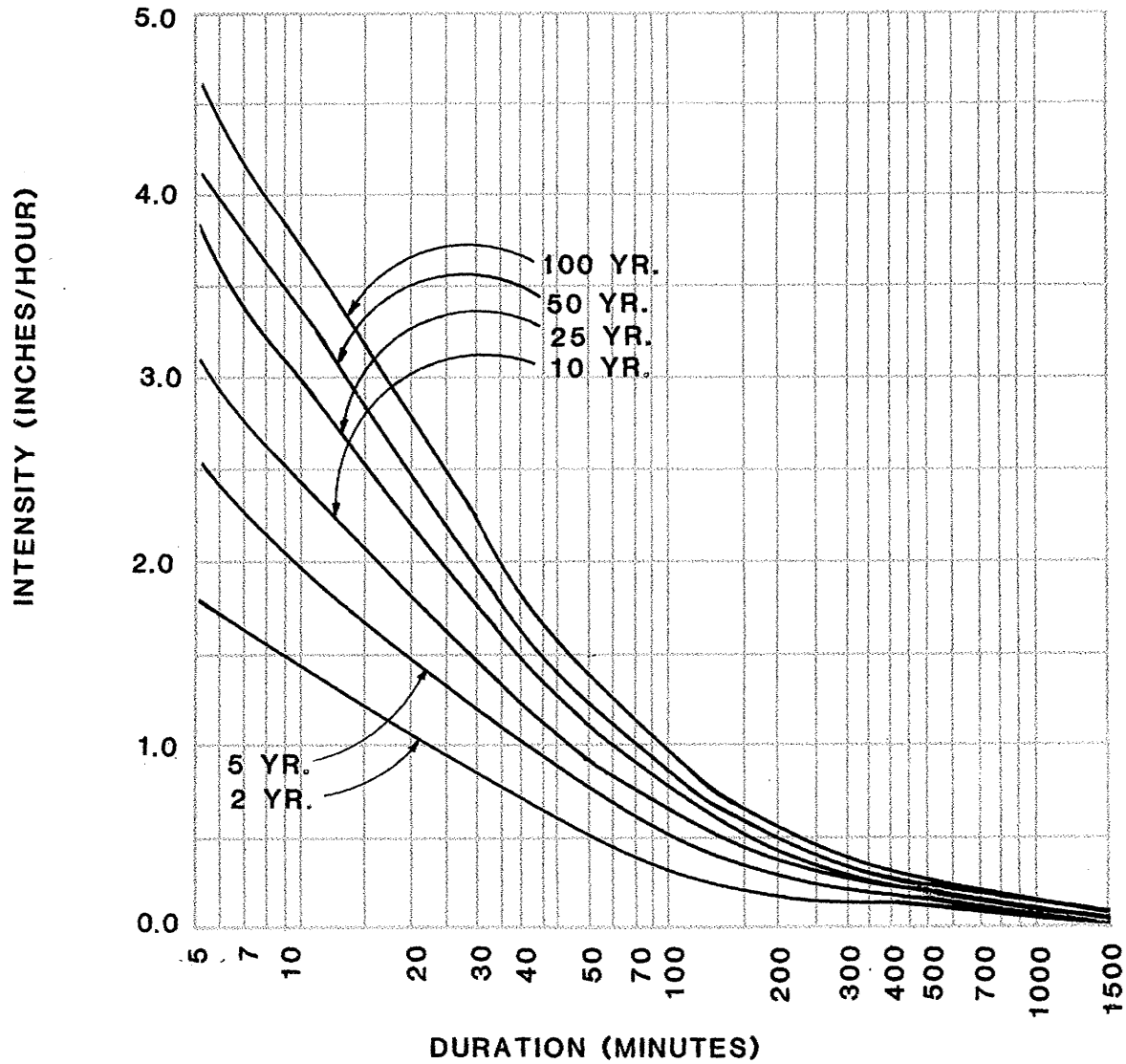
DESIGN PROCEDURES

The design engineer shall get the facts before commencing design work. This is particularly important in drainage work. After having the facts, a logical and technically-thorough procedure can be carried out to design a hydraulically balanced storm drainage system. Generalized procedures for designing such a storm drainage system are presented here as an aid to those who do not regularly do storm drainage design.

Basic Data Requirements

The design engineer shall prepare, furnish, establish, or develop the following:

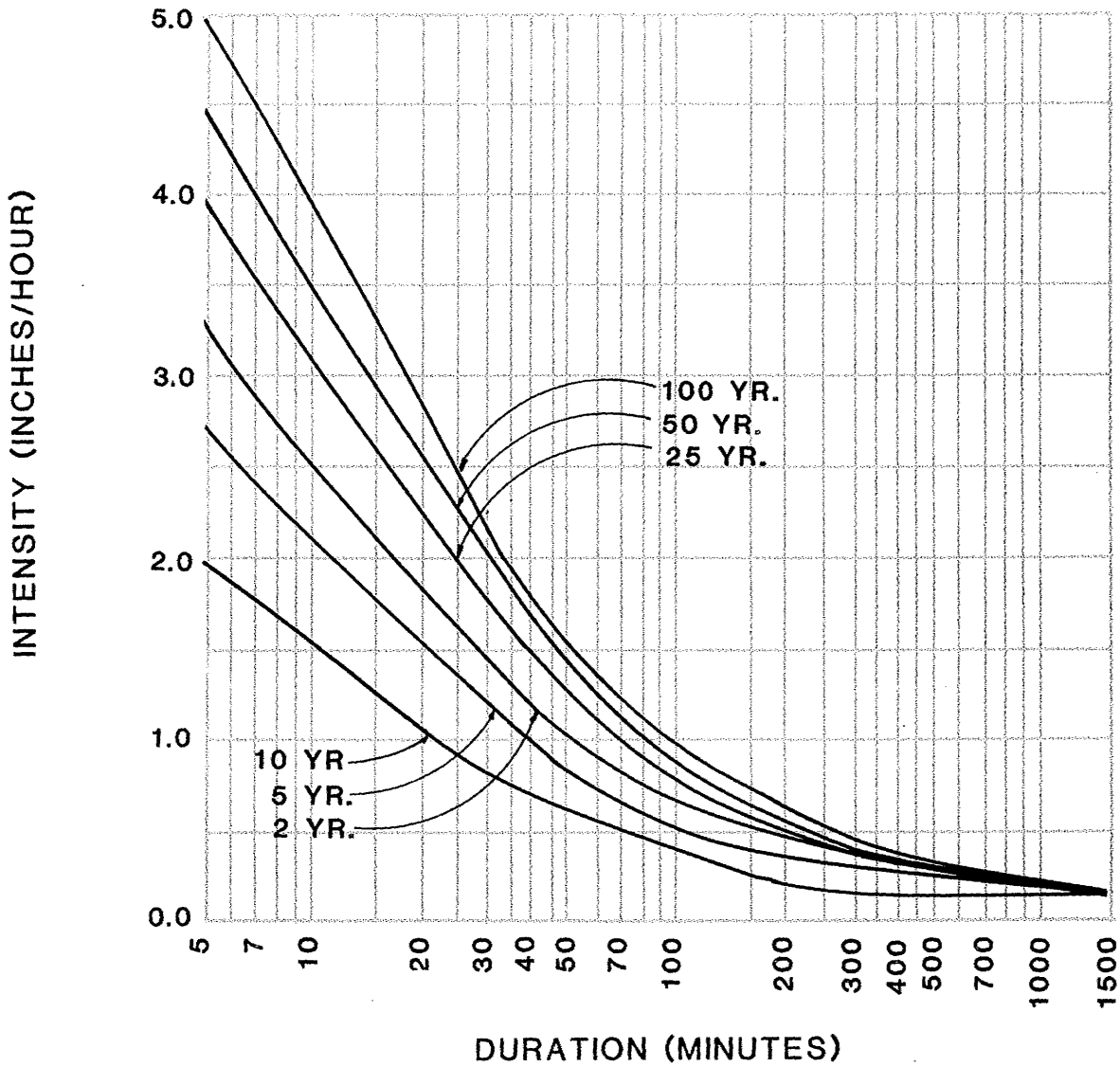
- A map of the area to be serviced by the storm drain. The map generally should be at a scale of 1 inch to 100 feet or 1 inch to 50 feet, having 2 foot contours.



PROVO CITY
STORM DRAINAGE MASTER PLAN

RAINFALL INTENSITY-DURATION-FREQUENCY CURVES
FOR AREAS LESS THAN 5000 FEET ELEVATION

FIGURE NO. 3-1



PROVO CITY
STORM DRAINAGE MASTER PLAN

RAINFALL INTENSITY-DURATION-FREQUENCY CURVES
FOR AREAS GREATER THAN 5000'

FIGURE NO. 3-2

- A map of the drainage basin containing the area being studied. This map is usually a USGS map at 1 inch to 2000 feet.

- A layout of the area to be storm drained showing existing or proposed streets, intersections, and development type. The engineer should advise the planner in street layout and major drainage ways to reduce drainage problems.

- Typical street cross sections.

- Street and intersection elevations or street profiles of the subject areas.

- Soil and water table data.

- Location and elevation of the outfall point of the storm drainage system for the proposed project.

- Rainfall curves as shown in Figures 3-1 and 3-2.

- Information on existing and proposed utilities.

Development of Alternate Concepts

In many cases, numerous potential layouts are possible. Here the engineer should review the reasonable alternatives and concepts, selecting those that appear most practical from an intuitive standpoint. The most promising concepts should be selected for analysis.

Preliminary Conduit Alignments

Several preliminary layouts should be considered. Alignments should coincide with collector or arterial streets since it will be necessary to preclude cross street flow on these streets.

Divide Basin into Sub-basins

Separate the basin into relatively homogeneous and hydrologically independent sub-basins. The definition of a sub-basin requires that each sub-basin have only one discrete point of discharge, whether that be into a storm drain, a channel or other drainage facility. When dividing a basin into sub-basins, it should be remembered that at various inlets on a continuous grade only a portion of street flow will be removed to the storm drainage system. At intersections of collector streets or arterial streets, it will be necessary to remove 100% of the storm drainage from the road surface to preclude cross street flow.

Design of the Storm Drainage System

The following is a general outline of the procedure that should be followed to design a storm drainage system. The method of determining design runoff values is developed in Chapter 4 entitled "Hydrologic/Hydraulic Computational Methods."

- Obtain or develop preliminary street grades and cross sections. The allowable carrying capacity for these streets can then be calculated.

- Beginning at the upper end of the basin in question, the designer should calculate the quantity of flow in the street until the point is reached at which the allowable carrying capacity of the street matches the design runoff.

- Initiation of the storm drain system would start at this point if there is no alternate method of removing runoff from the street surface. It is not necessary to remove 100% of the flow from the street surface at the beginning of the storm drainage system, or at any given location along the system unless the intersection of streets causes termination of cross street flow. It is, however, necessary for the allowable street capacity plus the storm drain capacity to equal or exceed the design flow.

  The designer must note that once the storm drain system is started, only small portions of the street flow should flow across intersections with local streets, and none where collector or arterial streets are encountered.

- Prepare a cost estimate for each of the proposed systems and list the pros and cons of each system. Unbiased attention to all good and bad points of various systems is necessary to arrive at the decision as to which system is actually most desirable.

- Review the alternative plans with the people responsible for the final decision. If any potential problems exist with reference to the system, such as effects on downstream entities, they should be thoroughly analyzed and resolved.

  Note: The preceding steps constitute the preliminary design portion of the total design procedure for a storm drain system. Up to this point, we have been compiling the information necessary to make a correct decision on which system to utilize for the final design.

- Review all of the preliminary work done up to this point. This includes all hydrological assumptions, basin boundaries, sub-basin boundaries, street classification and cross section, and any other preliminary design values which will subsequently be used in the final design.

- Often it will be necessary for the drainage design engineer to revise street construction details to facilitate drainage. This may include eliminating cross fall on streets, raising required ground elevation of houses adjacent to streets, or increasing street grade to achieve sufficient stormwater carrying capacity within the street.

- The hydraulic design of a system should be based on the procedures set forth in this manual. A realistic "n" value for final design should be determined and applied as necessary, treating the conduits as either open

channels or pipes flowing full, as the case may be. For open channel flow, the energy grade line should be used as a base for calculation. For conduits flowing full, the hydraulic grade line should also be calculated.

- The design of inlets and detention basins should be carried on simultaneously with the design of the remainder of the storm drainage system. The allowable street carrying capacity and storm drain capacity should be continuously equated to the design runoff to determine where inlets and detention basins will be necessary.

- The structural aspects of pipe and appurtenances to be utilized in the storm drainage system should be designed by thorough methods to insure that they are both adequate and economical.

  Certain of these decisions must be made prior to hydraulic design of the system since the geometry of junctions, the type of inlets to be utilized, and the pipe material will influence the design.

- Final construction plans and specifications should be of sufficient accuracy and clarity to guarantee that the designer's ideas are carried to completion by field installations.

DESIGN CRITERIA

The final hydraulic design of a storm drainage system should have as its objective the design of a balanced system in which all portions will be used to their full capacity without adversely affecting the drainage of any area.

Hydraulic calculations will usually be based upon the design runoff. It may be advisable also to analyze lower flows for sediment carrying capacity and higher flows for the possibility of the hydraulic grade exceeding the ground elevation with resulting discharge from the storm drain. For storm drainage systems on natural channels a bulking factor may be required by the City Engineer.

The following sections describe the design criteria needed in order for the hydraulic design to be carried out.

Design Procedures

General procedures for establishing quantities of flow and horizontal layout are the same for both open channel and pressure conduits. With the criteria discussed in this chapter, the following procedure allows computations for required pipe size and appurtenance construction to be pursued with the degree of accuracy justified by the cost of subsequent construction.

In storm drain systems flowing full, all losses of energy through resistance to flow in pipes or by changes in momentum and interference with flow patterns at manholes must be compensated by an accumulative series of rises of pressure along the system from its outlet to its initial upstream inlet or until open channel flow conditions interrupt the calculations. Losses due to pipe flow

resistance may be calculated by any of a variety of methods, so long as an appropriate roughness factor for the conduit is used (see Chapter 4).

Since the elevation to which water rises in a manhole, or the internal pressure on the conduit for structural purposes, is the factor most important in design, the changes are expressed in terms of the total energy head line. The change in hydraulic grade line may be either positive or negative at a given manhole, while the total head must always drop due to losses. Therefore, the total head, although not necessary for calculations, may be a desirable calculation to carry along as a check.

Pipelines

Closed conduit sections (pipe, box, etc.) shall be designed as flowing full, whenever possible, and may be allowed to flow under pressure in peak flow conditions. It is evident that if the hydraulic grade line rises above the ground surface, storm inlets will not function, and storm water will actually be discharged from the storm sewer to the street surface via the inlets and manholes.

Based on the assumption that Manning's "n" varies with depth, the capacity of a circular conduit at a given grade is the same at 91% and 100% ratios of d/D. Since it is impractical to design for the theoretical range where capacity exceeds that for the full conduit, open channel flow should only be assumed below d/D = 90%. Capacity calculations should be carried out as described in Chapter 4 of this manual.

Pipe Size. The minimum diameter of any storm drainage conduit shall be 15 inches, unless otherwise approved by the city.

Pipe Slope. The slope of the pipe is controlled by the velocity of the flow. Slopes are calculated so that when the pipe is flowing full or partially full, the velocity will be at least 3.0 feet per second. This criteria is based on the assumption that these minimum slopes will produce self-cleaning velocities and prevent sedimentation. Pipe slope shall be designed so that neither silting nor excessive velocities resulting in scour can occur.

Alignment. Storm drains shall be straight between manholes insofar as possible. Where long radius curves are necessary to conform to street layout, the radius of curvature shall be not less than 100 feet. Radius of curvature specified should coincide with standard curves available for the type of material utilized wherever possible.

Crossings. Crossings with other underground utilities except at intersections shall be avoided. Crossings, if necessary, should be at an angle greater than 45 degrees.

The storm drain pipeline and/or the utility must be structurally reinforced if insufficient vertical clearance is available. Standard allowable clearance without reinforcing between storm drains and sanitary sewers is 24 inches.

Cover. Storm drain grade shall be such that a minimum of 1 foot, 6 inch cover over the crown of the pipe is maintained. Uniform slopes shall be maintained between manholes unless specifically approved otherwise.

Materials of Construction. Storm drains may be constructed of any suitable material acceptable to the city, as long as it is capable of matching requirements set forth in this manual. Soils tests shall be conducted when there is a possibility that conditions exist which would cause premature failure of certain materials. Structural calculations must be carried out on any material to verify that it is acceptable. CMP pipe should not be allowed on any natural drainage subject to a debris load.

Box Culverts

The use of poured in place box culverts for underground outfall conduits of larger capacity can have cost advantages over large-diameter pipe. Furthermore, because they are poured in place, advantages accrue in being able to incorporate conflicting utilities into the floor and roof of the structure. Box culverts as used here refer to long, boxlike conduits similar to long pipes.

Major disadvantages of box culverts for long conduits are:

- The fact that the capacity drops significantly when the water surface reaches the roof. The capacity drop is 20 percent for a square cross section, and more for a rectangular cross section where the width is greater than the height.

- Normal structural design, because of economics, usually does not permit any signficant interior pressures, meaning that if the conduit reached full capacity, there could be a failure due to increased interior pressures caused by a choking of the capacity.

It is apparent that the use of long box culverts for outfall conduit purposes requires a high standard of planning and design involving complex hydraulic considerations and major utility interference reconciliation.

Hydraulic Design. Box culverts are often considered to be a covered free-flow conduit (open channels with a cover).

The structural design of precast culverts shall conform to those methods and criteria recommended by the manufacturer for that culvert type and for the conditions found at the installation site. However, the design shall adhere to the minimum standards set forth in the current American Association of State Highway and Transportation Officials (AASHTO) "Standard Specifications for Highway Bridges".

Computational procedures for flow in box culverts are essentially the same as for canals and lined channels, except that special consideration is needed in regard to rapidly increasing flow resistance when the conduit reaches full capacity.

Typical roughness coefficients for a box culvert are presented in Table 3-1.

TABLE 3-1

ROUGHNESS COEFFICIENTS FOR LARGE CONDUITS

Type of Pipe	Manning's n
Concrete	
Precast concrete pipe, good joint alignment	0.012
Precast concrete pipe, ordinary joint alignment	0.013
Poured in place, steel forms, projections 1/8" or less	0.013
Poured in place, smooth wood forms, projections 1/8" or less	0.013
Poured in place, ordinary work with steel forms	0.014
Poured in place, ordinary work with wood forms	0.015
Steel	
Structural plate corrugated, 2"x6" corrugations, 5' to 20' diameter	0.033 - 0.0298
Corrugated pipe, 1"x3" corrugations, 3' to 8' diameter	0.028 - 0.026

Catch Basins

Certain specific design procedures are necessary when designing catch basins for storm-water inlets.

The design water surface elevation should be at least 6 inches below the gutter grade at the inlet to allow the inlet to properly function. If there is any possibility of the hydraulic grade being above this level, the inlet should not be considered to accept any flow. Under unusual cases, the hydraulic grade may exceed the inlet elevation, allowing flow to escape from the system. Methods of dealing with this water must then be included in the design. Figures 3-3 to 3-5 show curves that are useful in the design of catch basins.

Manholes

The location of pipes in manholes shall be designed to insure maximum efficiency. Figure 3-6 presents details of the allowable manhole shaping and types of deflectors.

Spacing. Manholes shall be placed such that the maximum spacing between manholes is 450 feet.

Direction Changes. Short radius bends may be used on 24 inch and larger pipes when flow must undergo a direction change at a junction or bend. Reductions in headloss at manholes may be realized in this way. A manhole shall always be located at the end of such short radius bends.

Any local collector pipes that enter the storm drainage system shall enter the system at a manhole.

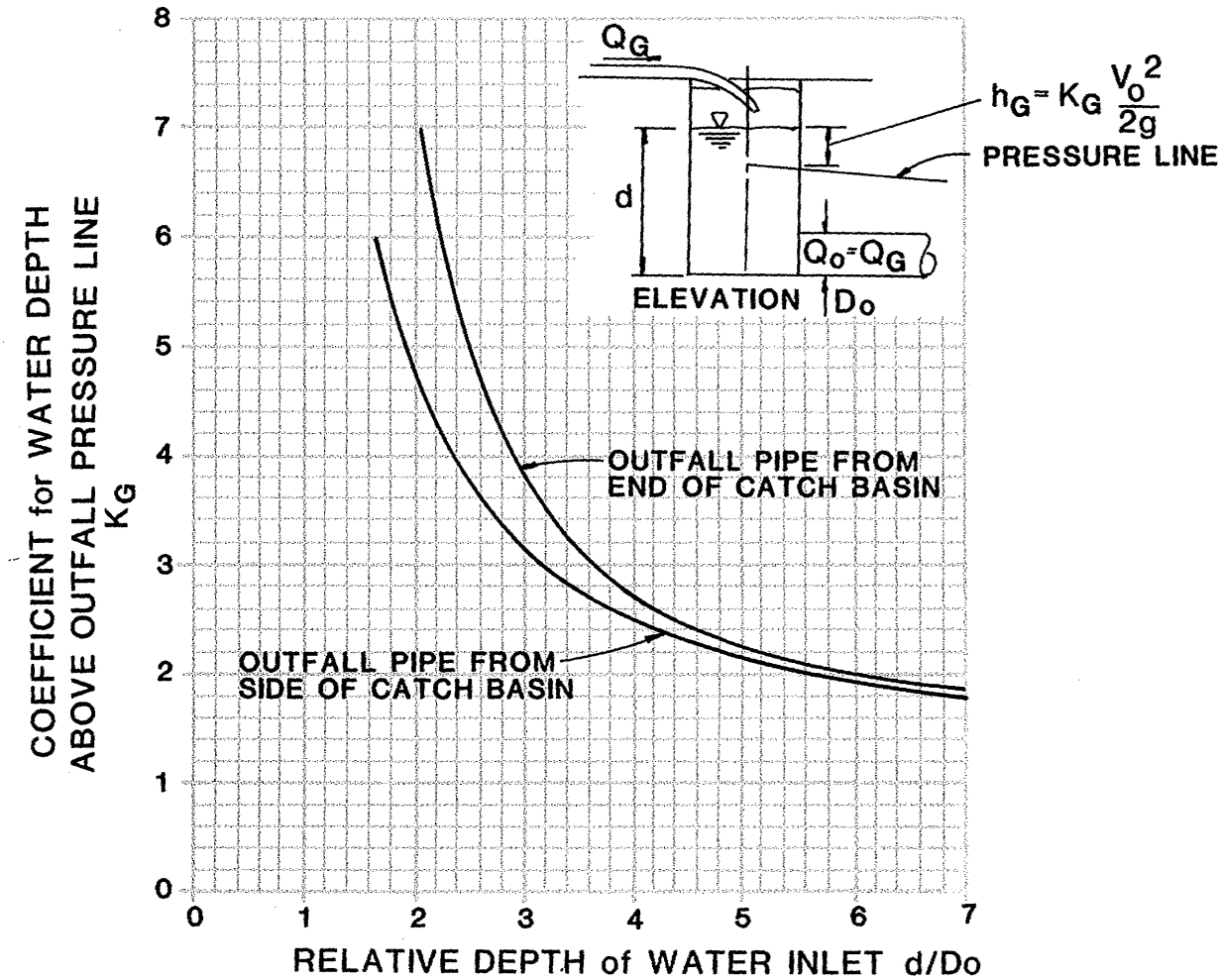
Outlets

The following discussion of outlets applies to the point at which a storm drain system discharges into an open channel or a major drainage conduit.

Outlet Location. Storm drain flows must in some way eventually reach a major drainage way such as the Provo River. Cases in which the major drainage is readily accessible by the storm drain are easily solved. However, when it is not readily apparent that the storm drain will discharge into a previously delineated major drainage, the question of an acceptable outlet point becomes important.

Hydraulic Design. The actual hydraulic design of an outlet can only proceed after the location has been approved.

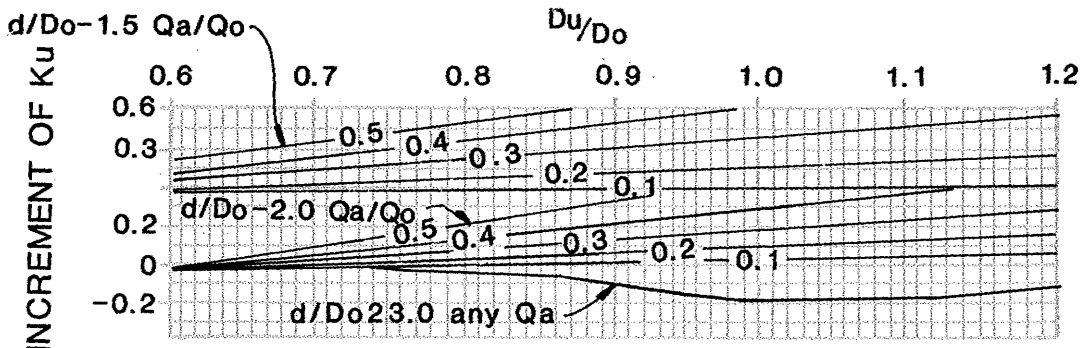
The water level in the receiving drainage way should be determined for the design storm frequency. If this elevation is above the crown of the sewer, it is unlikely that special outlet control devices will be necessary to prevent erosion. However, the outlet should be reviewed for possible erosion tendencies if the drainage way is flowing at less than the design depth.



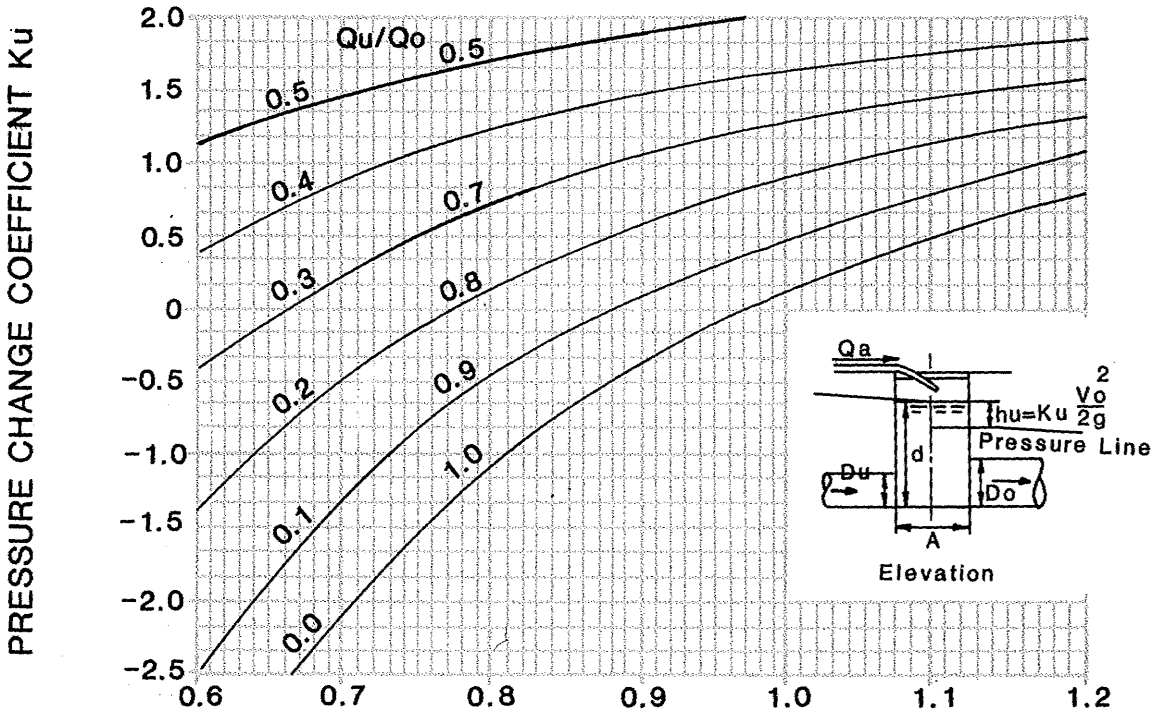
PROVO CITY
STORM DRAINAGE MASTER PLAN

DROP-INLET TYPE CATCH BASIN DESIGN CURVE
WITH SURFACE INFLOW ONLY

FIGURE NO. 3-3



SUPPLEMENTARY CHART FOR MODIFICATION OF Ku
FOR DEPTH IN INLET OTHER THAN 2.5Do

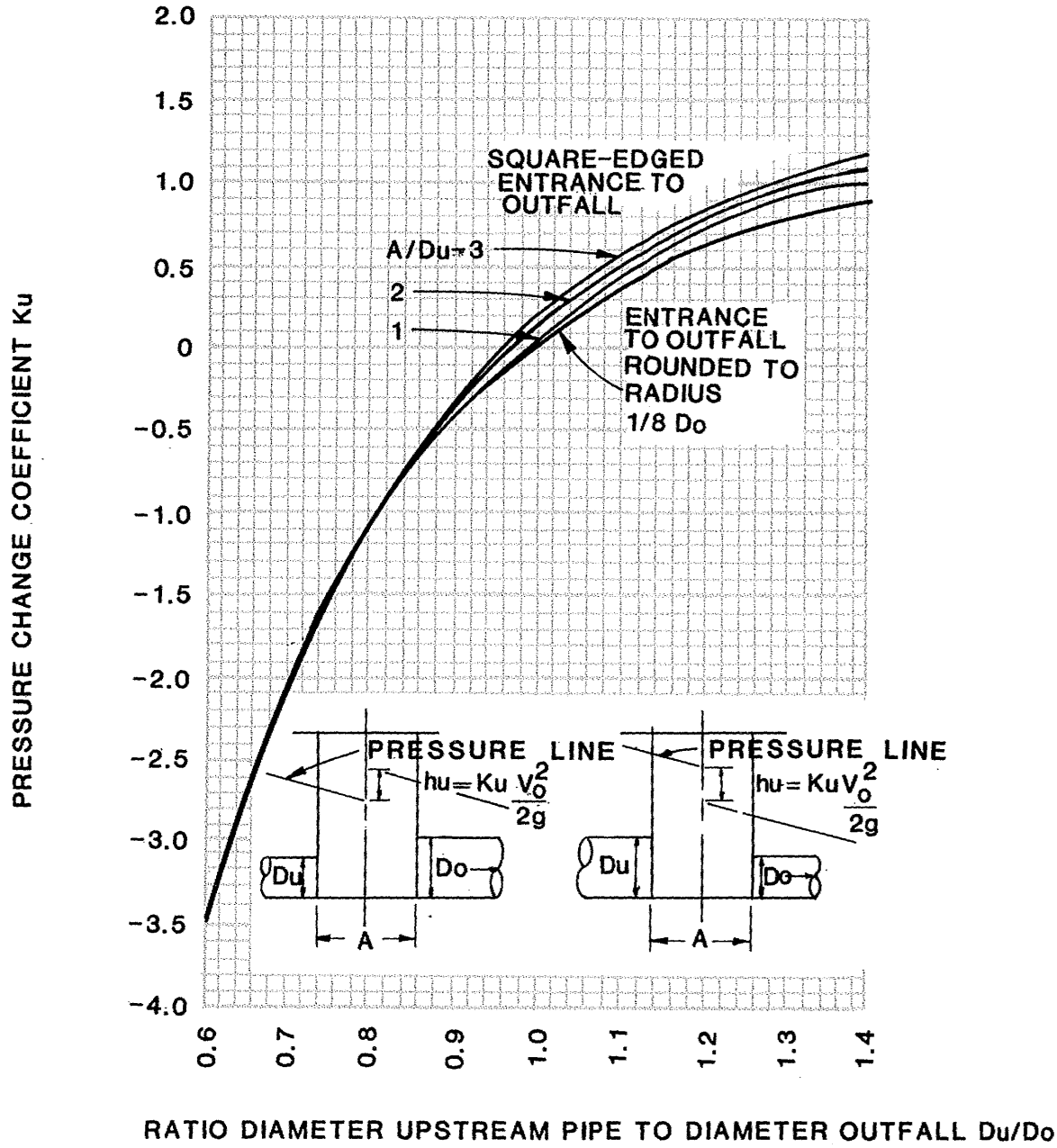


RATIO DIAMETER UPSTREAM
PIPE TO DIAMETER OUTFALL Du/Do

PROVO CITY
STORM DRAINAGE MASTER PLAN

DROP-INLET TYPE CATCH BASIN DESIGN CURVE
WITH SURFACE INFLOW AND FLOW THROUGH PIPELINE

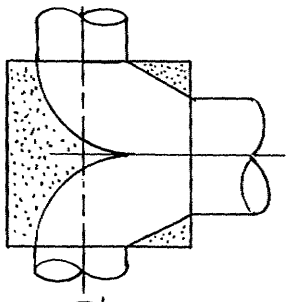
FIGURE NO. 3-4



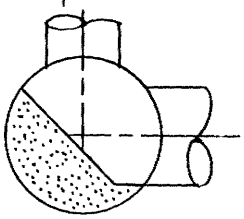
PROVO CITY
STORM DRAINAGE MASTER PLAN

MANHOLE DESIGN
WITH FLOW THROUGH PIPELINE

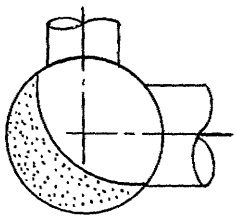
FIGURE NO. 3-5



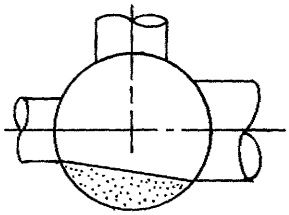
DIRECTLY OPPOSED TO LATERAL WITH DEFLECTOR (HEAD LOSSES ARE STILL EXCESSIVE WITH THIS METHOD, BUT ARE SIGNIFICANTLY LESS THAN WHEN NO DEFLECTOR EXISTS.)



BEND WITH STRAIGHT DEFLECTOR



BEND WITH CURVED DEFLECTOR



INLINE UPSTREAM MAIN & 90° WITH DEFLECTOR

PROVO CITY
STORM DRAINAGE MASTER PLAN

EFFICIENT MANHOLE SHAPING

FIGURE NO. 3-6

Design of headwalls and outlet structures is given considerable attention in the "Handbook of Concrete Culvert Pipe Hydraulics."

Open Channels

Open channels for use in the drainage system have significant advantages in regard to cost, capacity, multiple use for recreational and esthetic purposes, and potential for detention storage. Disadvantages include right-of-way needs and maintenance costs. Careful planning and design are needed to minimize the disadvantages and to increase the benefits.

The ideal channel is a natural one carved by nature over a long period of time. Desired characteristics of such a channel are that:

- Velocities are low, resulting in longer concentration times and lower downstream peak flows
- Maintenance needs are low because of the channel stability
- The channel provide a desirable green belt and recreational area, adding significant social benefits

The closer the artificial channel characteristics come to that of a natural channel, generally, the better will be the artificial channel.

Choice of Channel Characteristics. The choices of channel characteristics available to the designer are almost infinite, depending only upon good hydraulic practice, environmental design, sociological impact, and basic project requirements. However, from a practical standpoint, the basic choice is usually whether or not the channel is to be a lined channel, a grassed channel, or a natural existing channel.

The actual choice must be made upon a variety of multi-disciplinary factors and complex considerations which include, among others:

<u>Hydraulic</u>

- Slope of drainage way
- Right-of-way
- Required capacity
- Sediment deposition
- Erosion control
- Topography
- Ability to drain adjacent lands

<u>Structural</u>

- Costs
- Availability of material
- Areas for wasting fill

Environmental

- o Neighborhood character
- o Neighborhood esthetic requirements
- o Street and traffic pattern
- o Municipal or County policies

Sociological

- o Neighborhood social patterns
- o Neighborhood children population
- o Pedestrian traffic
- o Recreational needs

Concrete-Lined Channels. Where high velocities are present or steep side slopes must be used, an open channel shall be lined. If supercritical flow is unavoidable, all concrete channel sections shall be continuously reinforced, both longitudinally and laterally.

Grass-Lined Channels. Grass-lined channels may be considered to be the most desirable artificial channels. The channel storage, the lower velocities, and the sociological benefits obtainable create significant advantages over other types. The design must give full consideration to esthetics, to sediment deposition, and to scour, as well as hydraulics.

Natural Channels. Careful hydraulic analysis must be made of natural channels to deal with the highly active erosional tendencies resulting from urbanization. In nearly all cases some modification of the channel will be required to create a somewhat more stabilized condition.

Design Velocity. A maximum velocity should be selected that permits an economical cross section and yet keeps scour problems within reasonable limits. A typical maximum design velocity is 7.5 feet per second. Without a satisfactory grass cover established, however, the annual flows will cause serious channel cutting and bank cutting at bends.

Design Slopes. Grass-lined channels, to function well, normally have slopes of from 0.2 to 0.6 percent. Where the natural topography is steeper than desirable, drop structures should be utilized.

Curvature. In general, centerline curves should not have a radius of less than about twice the design flow top width, but not less than 100 feet.

Freeboard Requirements. Bridge deck bottoms and sanitary sewers often control the freeboard along the channel banks in urban areas. Where they do not control, the allowance for freeboard should depend somewhat upon the conditions adjacent to the channel. For instance, localized overflow in certain areas may be desirable because of ponding benefits. In general, a minimum freeboard of 1 to 2 feet should be allowed, though in certain cases as little as 8 inches might be satisfactory. However, it should be noted that freeboard requirements for natural drainage channels are specified by FEMA to be a minimum of 3 feet.

Channel Cross Sections. The channel shape may be almost any type suitable to the location and to the environmental conditions. Often the shape can be chosen to suit open space and recreational needs and to create other additional sociological benefits.

However, there are limitations within which the design must fall.

Side slopes -- The flatter the side slope, the better - 4:1 is a normal minimum. Under special conditions, the slopes may be as steep as 3:1, which is also the practical limit for mowing equipment.

Depth -- The maximum depth should be minimized - 3.5 feet through 4.0 feet are typical where good maintenance can be expected and where durations of peak flows are short lived.

Bottom width -- The bottom width should be at least 6 to 8 times the depth of flow - 20 to 30 times the depth is common.

Trickle channel -- Trickle channels or underdrain pipes are required on all urban grassed channels. These are required because of the maintenance problems created with nuisance water flows.

Water Surface Profile. A water surface profile must be computed for all channels and clearly shown on the final drawings. Computation of the water surface profile should utilize standard backwater methods, taking into consideration all losses due to changes in velocity, drops, bridge openings, and other obstructions.

Final Design Criteria. The final design criteria for open channels cannot be presented in cook book fashion because of the wide range of design options open to the engineer. Furthermore, no two channels nor any two conduits are exactly alike. Figure 3-7 illustrates some typical grassed channels.

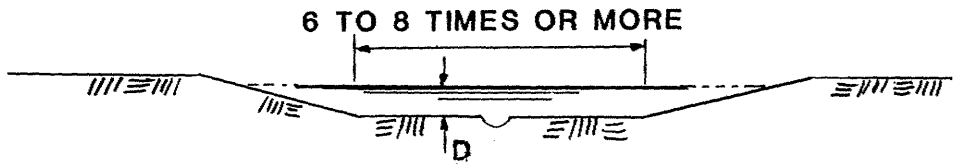
Detention Basins

The purpose of this section is to deal with criteria for design and methods of application of detention facilities. Included are: roof-top storage, parking lot storage, local recreation areas storage, and small detention basin and ponds constructed within the limits of development areas.

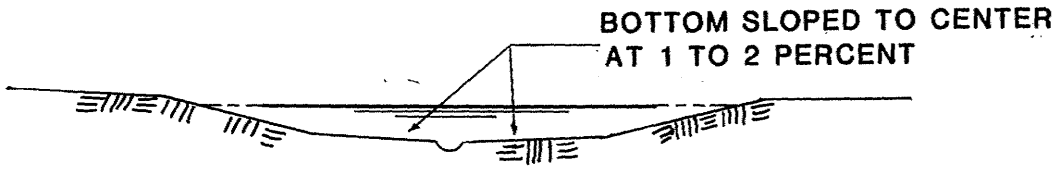
The objective of a detention facility is simply to regulate the runoff and to control the discharges to help reduce the impact of the new development on downstream drainage systems.

The important criteria which should be considered in the design of a stormwater detention facility, are as follows:

- Stormwater excess should be kept out of proposed habitable areas

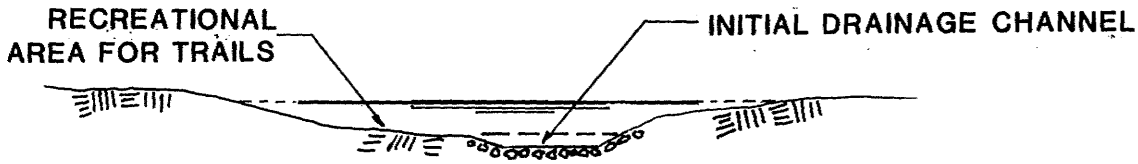


FLAT BOTTOM WITH TRICKLE CHANNEL



OVAL OR SLOPED BOTTOM WITH TRICKLE CHANNEL

INITIAL DRAINAGE CHANNEL WITH OVERFLOW FOR MAJOR DRAINAGE RUNOFF



RIPRAPPED INITIAL DRAINAGE CHANNEL
WITH OVERFLOW FOR MAJOR DRAINAGE RUNOFF

PROVO CITY
STORM DRAINAGE MASTER PLAN

TYPICAL GRASSED CHANNELS

FIGURE NO. 3-7

- Detention time should be as short as possible; typically it should be limited to a maximum of 18 hours

- Permanent "retention" facilities are not permitted

- Release into a sanitary sewer is not permitted

- The maximum depth of water shall not exceed 3 feet for a detention basin facility in a residential area and 1 foot for a commercial/industrial area

- The storage volume requirements should be capable of detaining a 10-year frequency rainfall event

- An overflow should be provided that will safely pass a 100-year frequency rainfall event without damage to the structure

- An underground piping system must be provided to bypass normal nuisance flows through any multi-use detention facility, such as a recreation park or parking lot, minimum pipe size requirements shall govern

Hydraulic Capacity of Streets

Although a typical street has the capability to convey stormwater, it should be noted that the main purpose of a street is for traffic. Hence, wherever possible, the stormwater should be removed to a separate storm drainage facility.

The hydraulic capacity of a street section to convey water can readily be calculated by the Manning Equation in the following form as developed by Izzard:

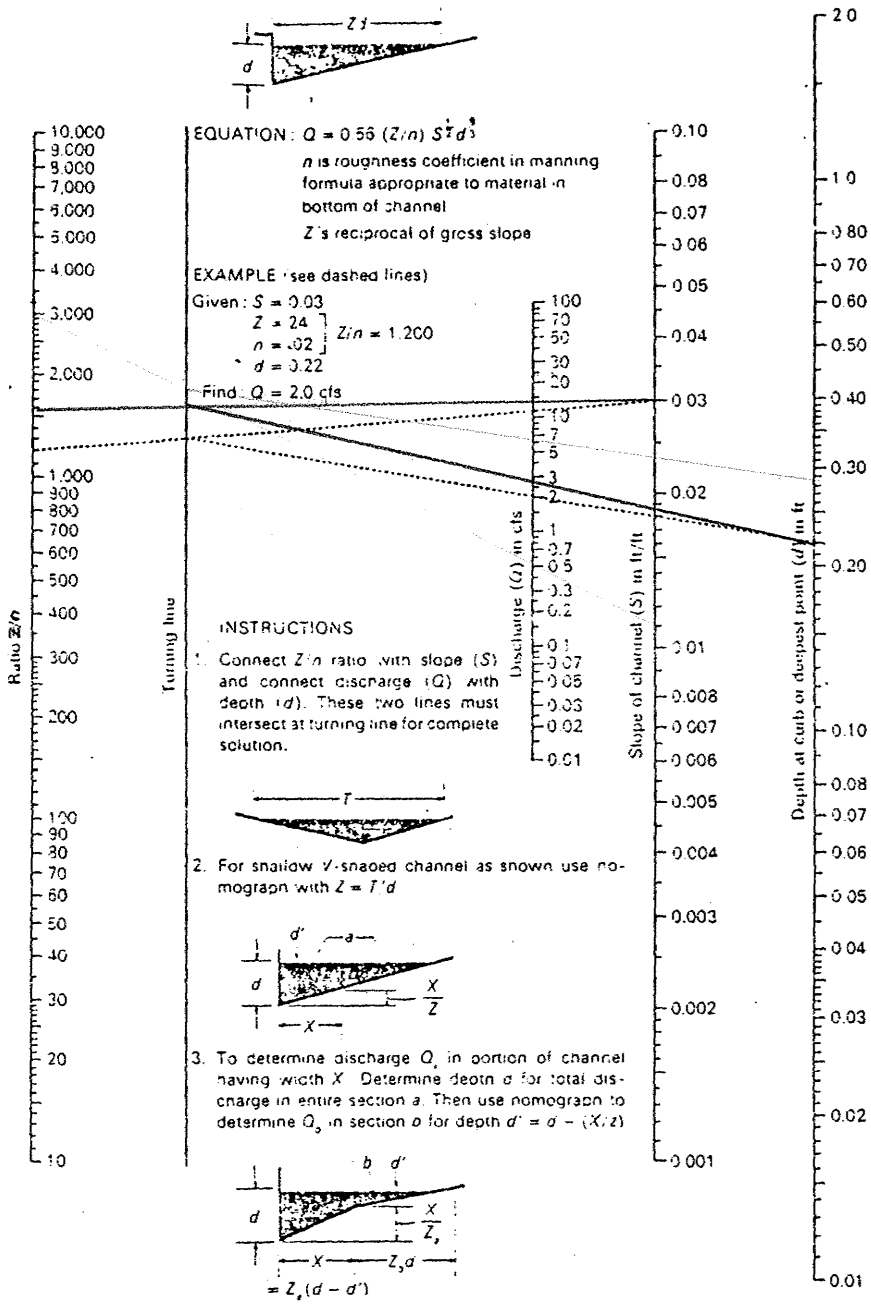
$$Q = 0.56 \frac{Z}{n} d^{8/3} S^{1/2}$$

In this equation the symbols are defined as follows:

Q = discharge in cfs
Z = $1/S_x$ where S_x is the cross slope of the pavement
d = depth of water in feet at face of curb
S = longitudinal grade of street
n = Manning's roughness coefficient

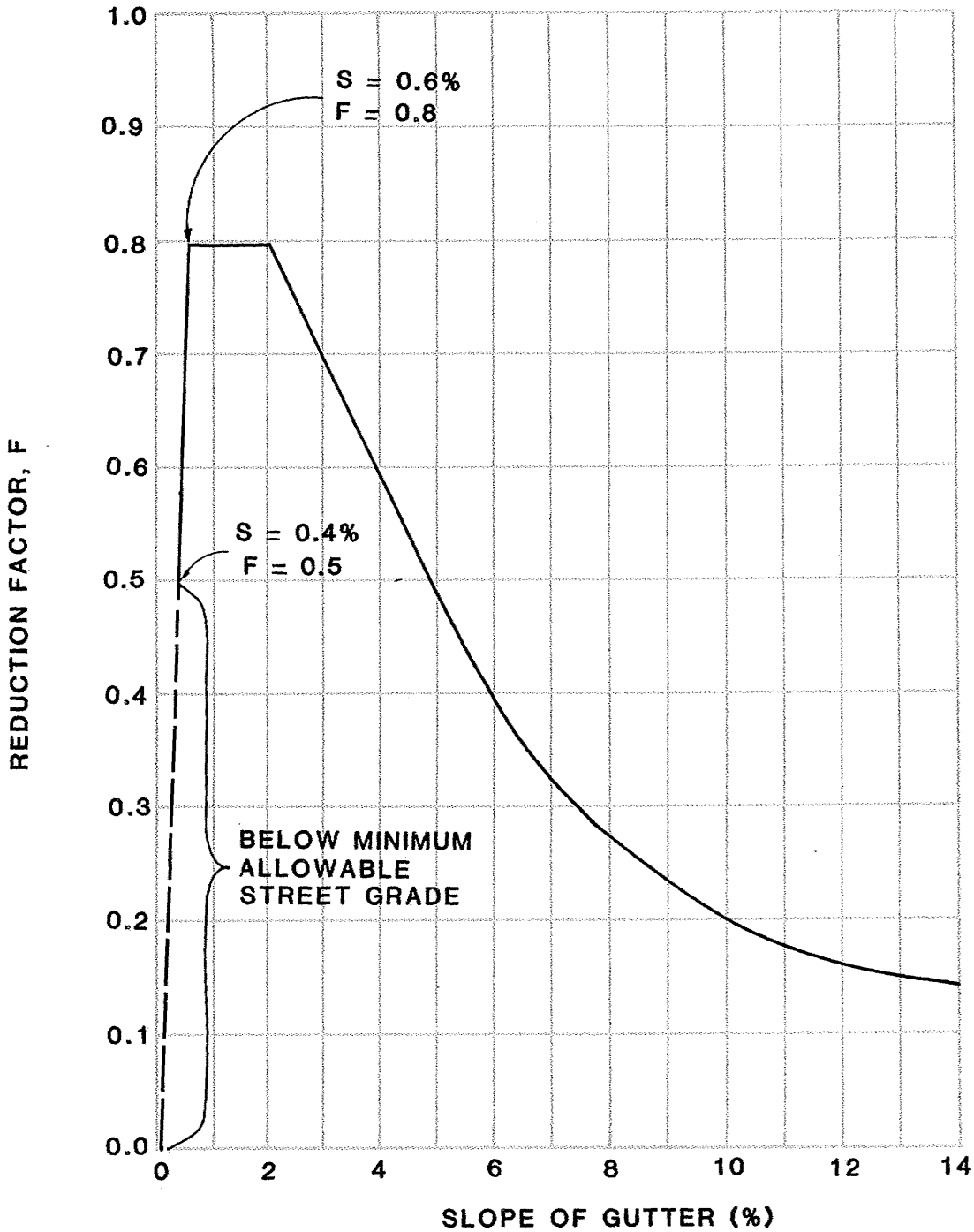
Experiments have proven that this form of the equation is more accurate than would be obtainable by computing the hydraulic radius based on the wetted perimeter and the area of the cross section. The equation applies directly to a section having a straight cross slope. An n value of 0.016 shall be utilized unless special considerations exist.

A nomograph has been developed based on the above equation (See Figure 3-8). The graph is applicable for all gutter configurations. In order to calculate the actual flow rate allowable, the theoretical capacity shall be multiplied by a reduction factor. These factors are determined by the curve in Figure 3-9.



PROVO CITY
STORM DRAINAGE MASTERPLAN
NOMOGRAPH FOR FLOW IN CURB AND GUTTER

FIGURE NO. 3-8



PROVO CITY
STORM DRAINAGE MASTER PLAN

REDUCTION FACTOR FOR ALLOWABLE GUTTER CAPACITY

FIGURE NO. 3-9

must be involved to establish the groundwater table for underdrain design purposes.

Field surveys may be necessary to supplement design maps with reference to utilities, test hole locations, and other items which are not accurately located on the maps.

Design Maps.

Mapping for use in final design shall be of sufficient accuracy to enable storm drain lengths to be set within 0.1 foot and elevations within 0.01 foot.

Elevation datum shall be USGS unless other datum is specifically required by the City.

Horizontal control shall be tied to state grid coordinates and section corners to allow matching of maps for different projects.

When alternate types of materials are being considered, hydraulic design profiles must be shown for each material to verify that both materials will be acceptable.

CHECK OF DESIGN SUBMITTAL

As an aid to the design engineer as well as to those reviewing drainage plan submittals, the following check lists are provided:

Preliminary Design

- Basic Data

  Map of total drainage basin
  Map of area to be storm drained
  Characteristics of streets
  Street grades and direction of slope
  Location and elevation of outfall points for initial and major drainage
  Rainfall curves
  Character of future development
  Degree of imperviousness
  Soil and water table data
  Utility information

- Hydrology

  Design criteria tabulation for major storm runoff
  Peak discharge computations for pipe sizing
  Peak discharge computations for storm runoff
  Assumptions as to upstream storage

- Layout

  Streets and street names
  Irrigation ditches
  Street drainage flow direction
  Drainage basin and sub-basin boundaries
  Storm drain layout with sizes
  Storm inlet locations
  Valley gutter locations
  Open drainage ways
  Layout of drainage system showing flows and direction
  Scale
  North arrow
  Signature blocks for review approvals
  Location map and subdivision names
  Conflicting utilities

- Cost Estimate

Final Design

- General

  Title block (lower right-hand corner preferred)
  Scale
  Date and revisions
  Name of professional engineer or firm
  Professional engineer's seal
  Statement as to specifications
  Approval spaces with date spaces
  Drawing numbers

- Drainage Area Plan

  North arrow
  Contours (maximum 2-foot intervals)
  Location and elevation of U.S.G.S. bench marks
  Property lines
  Boundary lines (counties, districts, tributary area, etc.)
  Streets and street names, and approximate grades with width
  Subdivision (name and location by section)
  Existing irrigation ditches
  Existing drainage structures, including flow directions
  Drainage sub-basin boundaries
  Easements required
  Proposed curbs and gutters and gutter flow directions
  Proposed valley gutter and flow directions
  Proposed inlet locations and inlet sizes
  Proposed piping and open drainage ways

- Construction Plans

  North arrow
  Property lines and ownership or subdivision information
  Street names and easements with width dimensions
  Testhole locations and log
  Existing utility lines (buried), location and depth
    - water
    - gas
    - telephone
    - storm drain
    - irrigation ditches
    - sanitary sewers

  Vertical and horizontal grids with scales
  Ground surface existing and proposed
  Existing utility lines where crossed
  Pipes
    - Plan showing stationing
    - Profile
    - Energy Grade Line/Hydraulic Grade Line
    - Size, lengths between manholes and type
    - Grades
    - Inlet and outlet details
    - Manhole details (station number and invert elevations)
    - Typical bedding detail

  Open channels
    - Plan showing stationing
    - Profile
    - Grades
    - Typical cross section
    - Lining details water surface elevations
    - Water surface elevations

  Special Structures (Manholes, headwalls, trash racks, etc.)
    - Plan
    - Elevation
    - Details of design and appurtenances

CHAPTER 4

HYDROLOGIC/HYDRAULIC COMPUTATION METHODS

INTRODUCTION

To assist in the design and/or assessment of a storm drainage system, computational models are often used. These models generally fall into two categories, the hydrologic models and the hydraulic models.

Hydrologic models are designed to simulate mathematically the rainfall-runoff process. These models can, therefore, determine an estimate of the runoff rate from a particular area resulting from a given design storm. This runoff rate can then be used to design the storm drainage facilities or to evaluate existing facilities. In order to use a hydrologic model, rainfall data as well as the characteristics of the basins under study are needed. In this chapter the sources of rainfall data and the basin characteristics required for the hydrological computation are presented.

There are numerous hydrologic models being used ranging from mere guesses to complicated computer programs. In review of the purposes of this manual, several computational methods will be discussed. Two of these, the Rational method and the SCS TR-55 method, are for the calculation of peak flow rates. For the determination of hydrograph shapes and volumes two unit hydrograph methods will be discussed; the Denver Unit Hydrograph Approach and the SCS method of unit hydrograph. Also the ILLUDAS computer simulation model will be briefly introduced as an alternative to hand calculations. When properly applied, each of these computation methods should yield approximately the same result for any given drainage area and design storm, hence one method can be used to check another.

Hydraulic computation methods deal with the design and sizing of a structure rather than the simulation of a rainfall-runoff event. Therefore, hydraulic methods are applied to the results determined in the hydrologic simulation to provide for the design of the storm drainage facility. The methods used in the design of these hydraulic structures are presented in this chapter following the discussion on hydrologic models.

HYDROLOGIC METHODS

Before any hydrologic computations can be carried out, the design engineer must collect the required data for the chosen computation method. Generally these data requirements fall into two basic categories; rainfall data and basin characterization data.

Rainfall Data

Rainfall data for small developments is typically the same for all of the drainage area sub-basins. Fluctuations could occur between sub-basins because of several factors:

- Change in elevation
- Changes in topographic and orographic features
- Changes in climatic patterns

However, because most developments are relatively small compared to the scale of a thunderstorm the precipitation values for any hydrologic calculations are considered constant over the drainage basin.

Sources of Data. Rainfall data can be obtained from the following sources:

- NOAA ATLAS 2, National Weather Service
- Rainfall Frequency Altas of the United States, U.S. Weather Bureau Technical Paper No. 40
- State Climatologist

The rainfall data in the above sources are in the form of isohyetal lines for different rainfall frequencies and durations. In order to use the data for hydrologic calculations, depth-duration-frequency tables and curves have been developed. These are shown in Figures 4-1 to 4-4 and Tables 4-1 and 4-2.

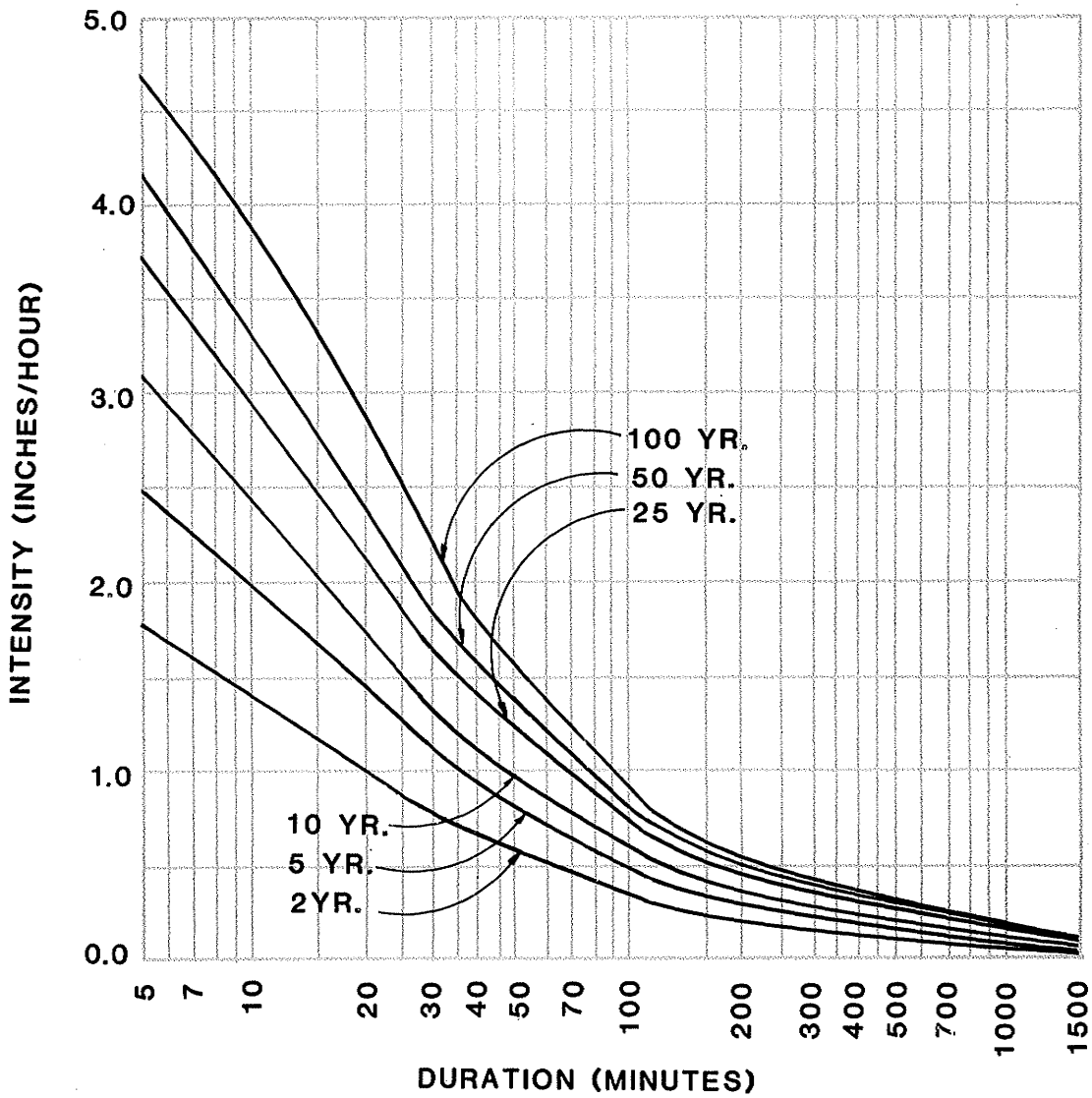
Distribution of Rainfall. The distribution of rainfall varies greatly from storm to storm, however studies on the time distribution of rainfall in mountainous areas have shown that more than 50 percent of the total storm depth occurs in 25 percent of the storm period. Also, more than half of the total depth of rain is usually delivered as burst rainfall. Along the Wasatch Front rainfall bursts occur most frequently in the first quarter of the storm period. Figure 4-5 shows typical rainfall time distribution curves.

The rainfall data and distribution have been discussed in more detail in the Provo City Master Storm Drainage Plan Volume I. The information presented here is for convenience in the use of this manual.

Basin Characterization Data

Unlike the rainfall data presented above, the physical basin characteristics can vary tremendously between sub-basins. This variation requires that each of the sub-basins have its own unique set of characteristic data.

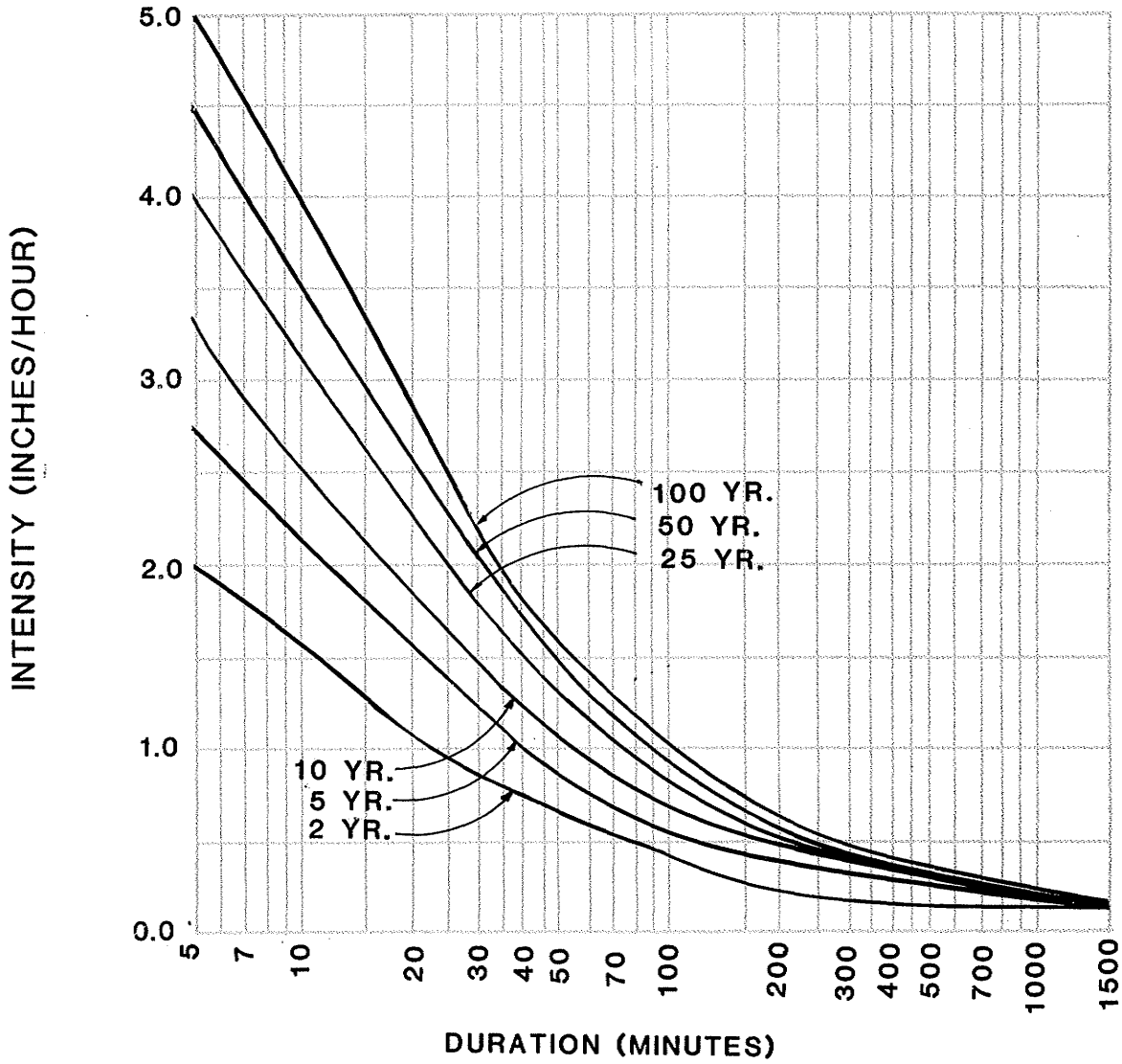
Generally there are three types of data required to fully describe a sub-basin.



PROVO CITY
STORM DRAINAGE MASTER PLAN

RAINFALL INTENSITY-DURATION-FREQUENCY CURVES
FOR AREAS LESS THAN 5000'

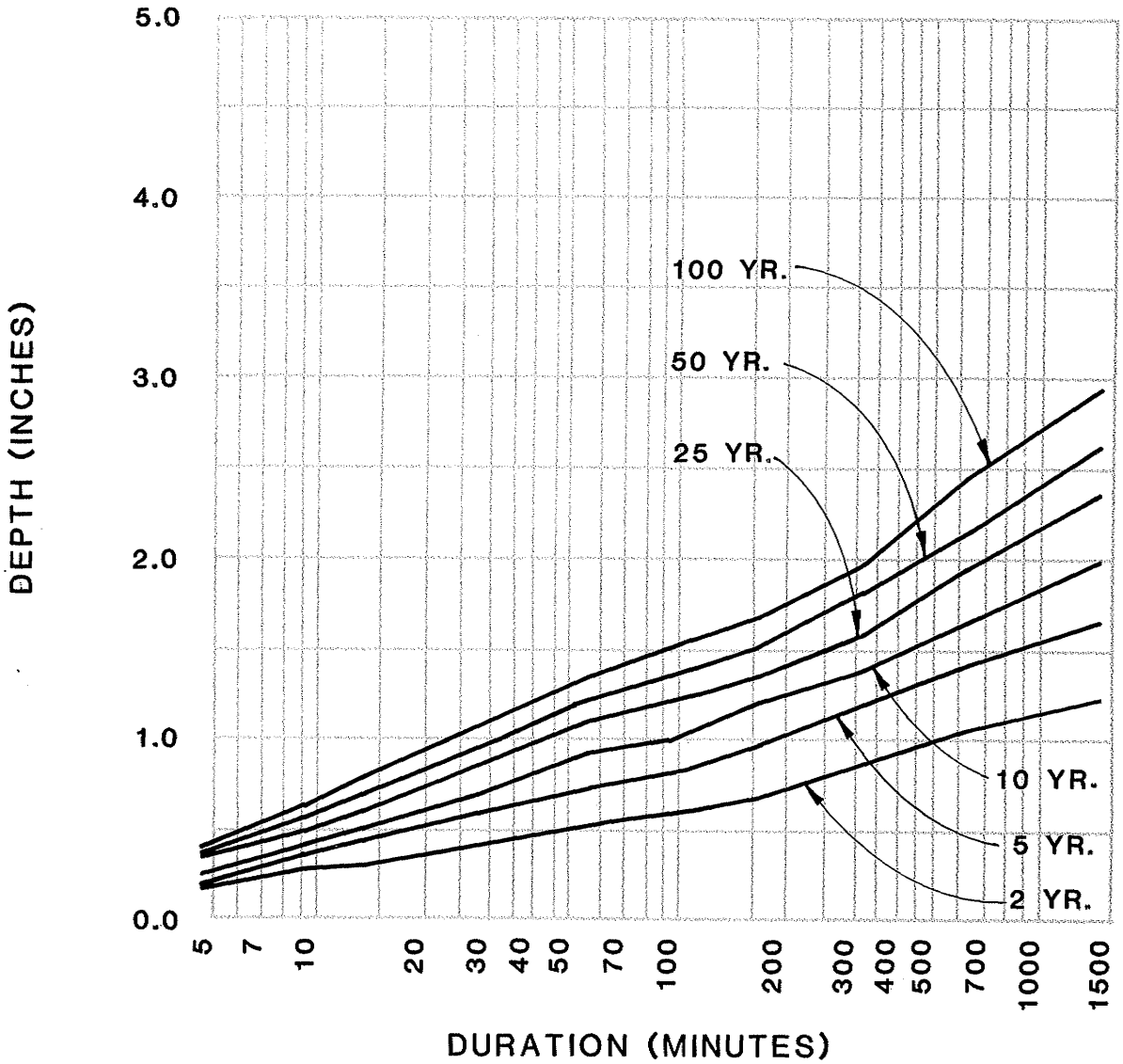
FIGURE NO. 4-1



PROVO CITY
STORM DRAINAGE MASTER PLAN

RAINFALL INTENSITY-DURATION-FREQUENCY CURVES
FOR AREAS GREATER THAN 5000'

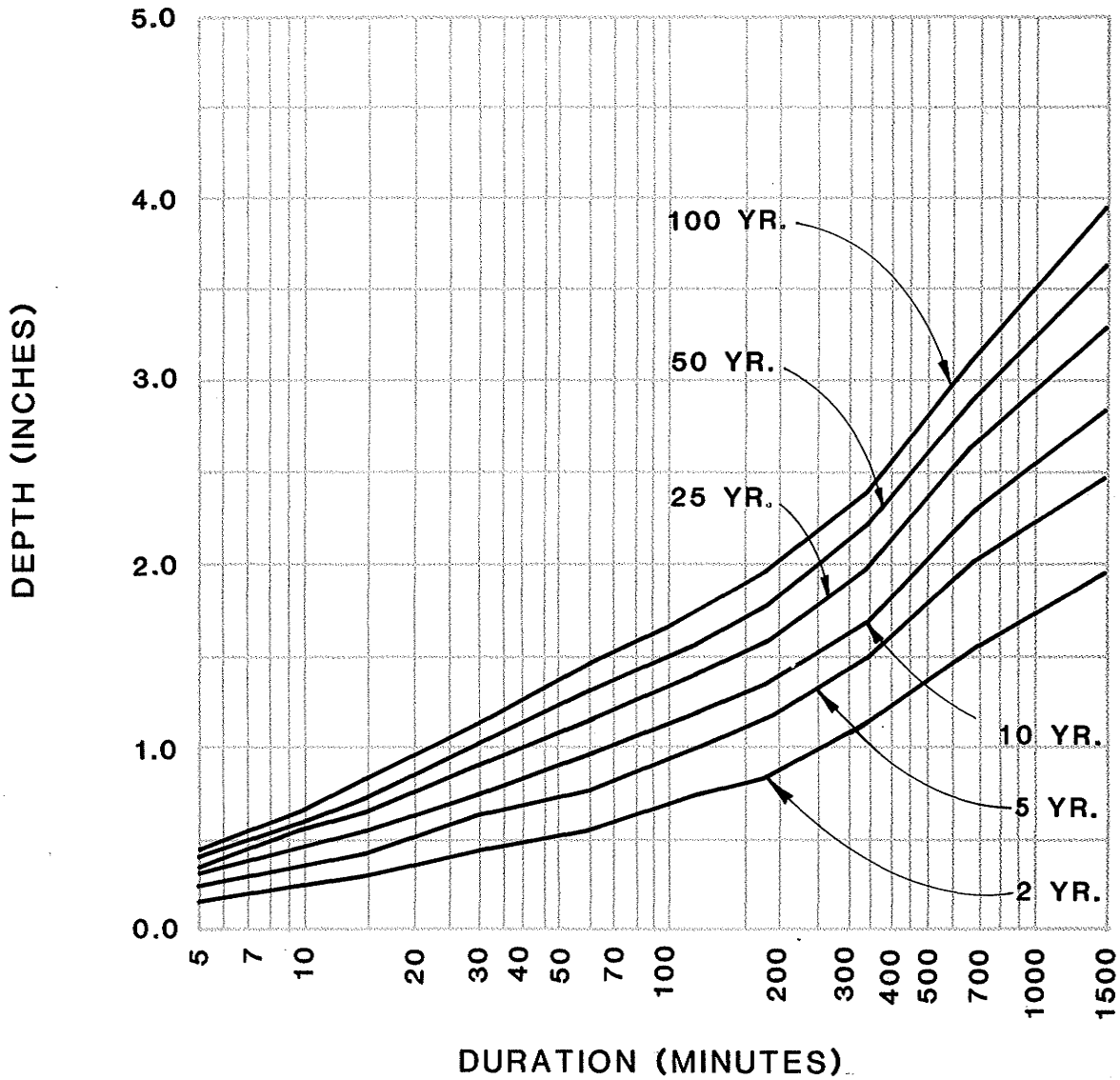
FIGURE NO. 4-2



PROVO CITY
STORM DRAINAGE MASTER PLAN

RAINFALL DEPTH -DURATION- FREQUENCY CURVES
FOR AREAS LESS THAN 5000'

FIGURE 4-3



PROVO CITY
STORM DRAINAGE MASTER PLAN

RAINFALL DEPTH - DURATION - FREQUENCY CURVES
FOR AREAS GREATER THAN 5000'

FIGURE 4-4

TABLE 4-1

RAINFALL DEPTHS FOR PROVO AREA (Inches)

AREAS ABOVE 5000 FEET ELEVATION

Time	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
5 min	0.17	0.23	0.28	0.34	0.38	0.43
10 min	0.26	0.36	0.43	0.53	0.59	0.67
15 min	0.32	0.46	0.55	0.67	0.75	0.84
30 min	0.45	0.63	0.76	0.92	1.04	1.17
60 min	0.57	0.80	0.96	1.17	1.32	1.48
2 hours	0.74	1.00	1.18	1.42	1.58	1.76
3 hours	0.86	1.17	1.35	1.60	1.78	1.96
6 hours	1.13	1.50	1.70	1.99	2.20	2.40
12 hours	1.56	2.00	2.28	2.64	2.92	3.16
24 hours	1.94	2.50	2.84	3.31	3.63	3.94

AREAS BELOW 5000 FEET ELEVATION

Time	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
5 min	0.15	0.21	0.26	0.32	0.35	0.39
10 min	0.23	0.33	0.40	0.49	0.55	0.61
15 min	0.30	0.42	0.51	0.62	0.70	0.78
30 min	0.41	0.58	0.70	0.86	0.96	1.07
60 min	0.52	0.74	0.89	1.09	1.22	1.36
2 hours	0.62	0.86	1.03	1.24	1.39	1.54
3 hours	0.69	0.96	1.20	1.35	1.51	1.67
6 hours	0.85	1.15	1.35	1.58	1.78	1.95
12 hours	1.04	1.40	1.66	1.96	2.16	2.44
24 hours	1.20	1.66	1.97	2.34	2.60	2.90

TABLE 4-2

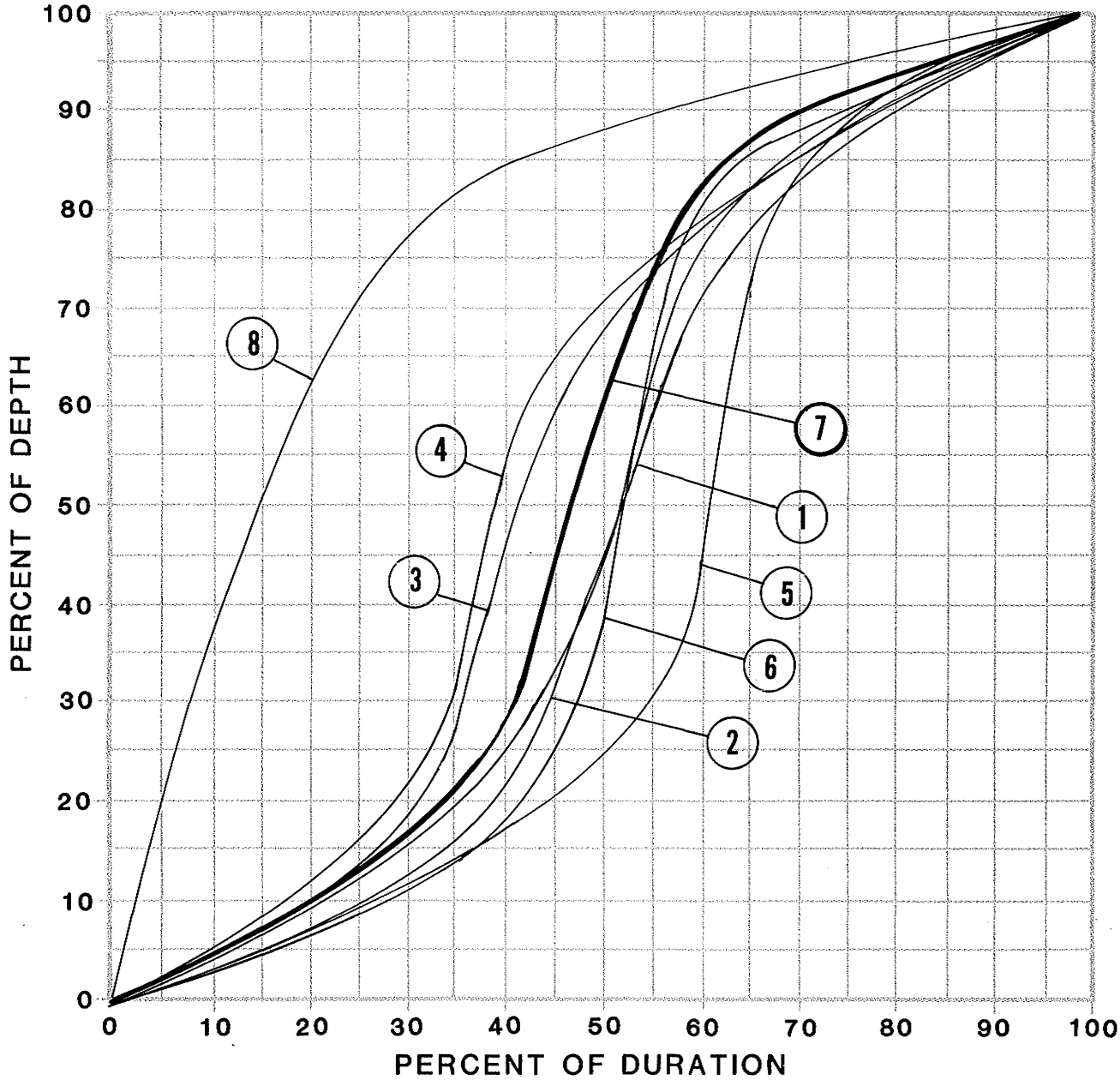
RAINFALL INTENSITIES FOR PROVO AREA (Inches/Hour)

AREAS ABOVE 5000 FEET ELEVATION

Time	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
5 min	2.04	2.76	3.36	4.08	4.56	5.16
10 min	1.56	2.16	2.58	3.18	3.54	4.02
15 min	1.28	1.84	2.20	2.68	3.00	3.36
30 min	0.90	1.26	1.52	1.84	2.08	2.34
60 min	0.57	0.80	0.96	1.17	1.32	1.48
2 hours	0.37	0.50	0.59	0.71	0.79	0.88
3 hours	0.29	0.39	0.45	0.53	0.59	0.65
6 hours	0.19	0.25	0.28	0.33	0.37	0.40
12 hours	0.13	0.17	0.19	0.22	0.24	0.26
24 hours	0.081	1.10	0.12	0.14	0.15	0.16

AREAS BELOW 5000 FEET ELEVATION

Time	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
5 min	1.80	2.52	3.12	3.84	4.20	4.68
10 min	1.38	1.98	2.40	2.94	3.30	3.66
15 min	1.20	1.68	2.04	2.48	2.80	3.12
30 min	0.82	1.16	1.40	1.72	1.92	2.14
60 min	0.52	0.74	0.89	1.09	1.22	1.36
2 hours	0.31	0.43	0.52	0.62	0.70	0.77
3 hours	0.23	0.32	0.40	0.45	0.50	0.56
6 hours	0.14	0.19	0.23	0.26	0.30	0.33
12 hours	0.09	0.12	0.14	0.16	0.18	0.20
24 hours	0.05	0.069	0.082	0.098	0.11	0.12



1. COE SPF 1-hour
2. COE SFP 6-hour
3. SCS 24-hour
4. SCS Emergency Spillway
5. Tettemer 6-hour
6. Historical Depths via COE Ranking
7. JMM 3-hour
8. Farmer/Fletcher 1 hour

PROVO CITY
STORM DRAINAGE MASTER PLAN

SELECTED CUMULATIVE
TEMPORAL RAINFALL DISTRIBUTIONS

FIGURE NO. 4-5

- Soil information
- Land uses
- Physical system

Soil Information. Soil properties influence the generation of runoff from rainfall and must be considered, even if only indirectly, in methods of runoff estimation. When runoff from individual storms is the major concern, as in flood prevention work, the soil properties can be represented by a parameter called the hydrologic soil group.

The Soil Conservation Service has grouped all soils into four main soil groups. These are described as follows:

Group A (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.

Group B Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Group C Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

Group D (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Soil types are listed in the SCS Hydrology Handbook by name and soil group. Soil mapping for the Provo area can be obtained from the SCS and the Forest Service. The soils map used for this study is presented in Figure 4-6.

Another soil parameter commonly used in the determination of runoff is the Infiltration Rate.

Infiltration Rate.

The infiltration rate is the rate at which water enters the soil at the surface and which is controlled by surface conditions. Factors affecting infiltration rates include: Soil type, soil cover, slope of the land, soil compaction and antecedent soil moisture.

The infiltration amount is given by the Horten Equation.

$$f=fc + (fo-fc)e^{-kt}$$

where;

fo= initial infiltration rate in inches per hour
fc= final infiltration rate in inches per hour
e= base of natural logs
k= a shape factor
t= time from start of rainfall in hours

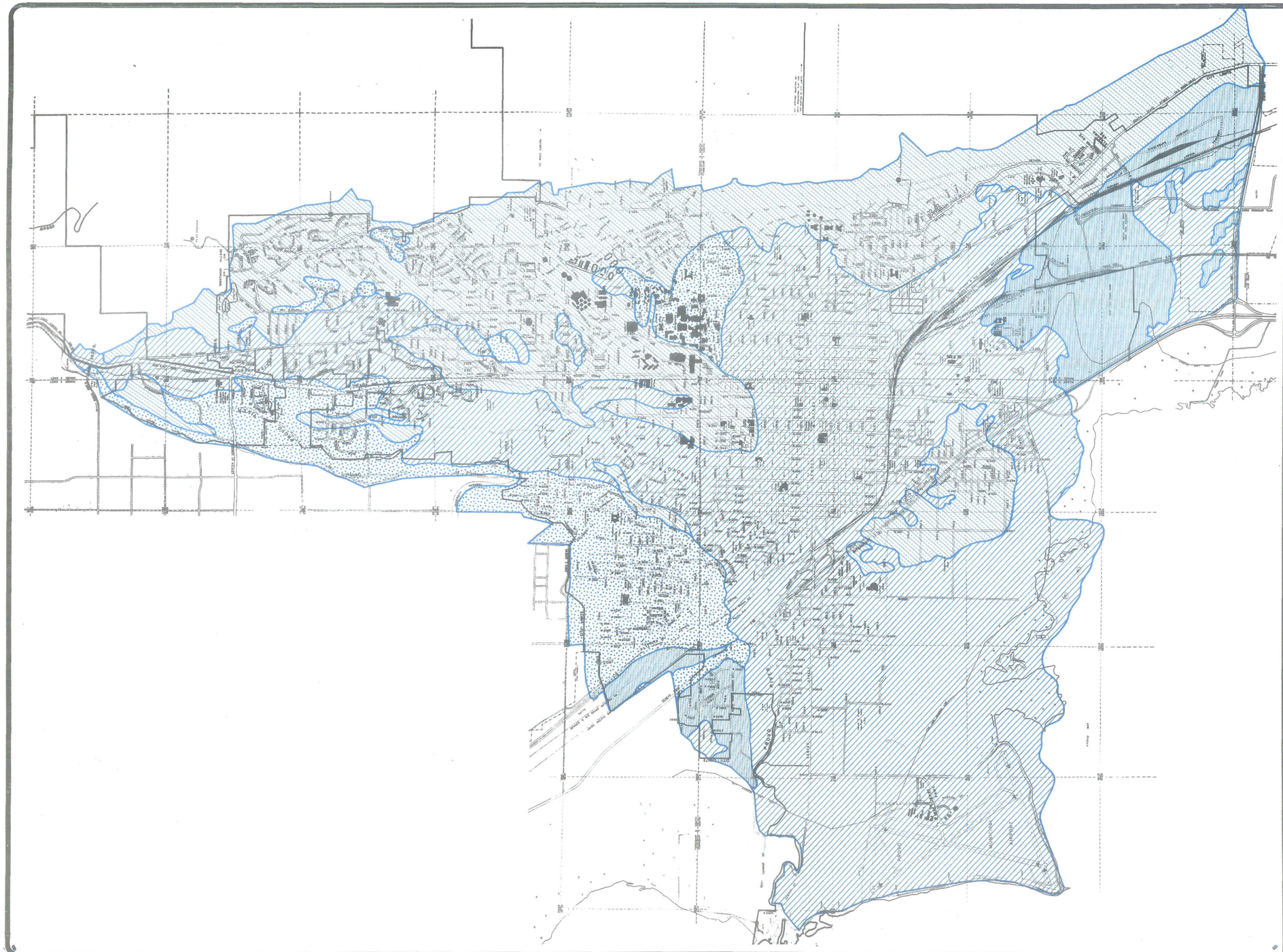
In practice many designers use a higher infiltration rate at the beginning of the storm and a lower rate as the storm progresses. These amounts vary from place to place and depend on the factors affecting the infiltration rate. Table 4-3 contains the estimated infiltration rates for the Provo City area that were generally used in the development of the Storm Drainage Master Plan.

Land Uses. In the estimation of runoff, the effects of surface conditions of a watershed are evaluated by means of land uses. Land use is defined as the watershed cover. It includes every kind of vegetation, litter, mulch, and fallow as well as nonagricultural uses such as water surfaces (lakes, swamps, etc.) and impervious surfaces (roads, roofs, etc.). Land uses are readily obtained by observation and measurement of vegetation and litter cover, housing density, and areas of impervious materials. Typically for runoff estimation, the various land use types are grouped into discrete categories. This allows each individual sub-basin to be categorized into a few land use types, thereby simplifying the effort needed to obtain the required parameters for whichever model the designer has chosen to do runoff calculations with.

Physical System. The physical system parameters are those that define the physical characteristics of how excess rainfall gets to the outlet of the sub-basin. Generally these parameters include the following:

- Area of sub-basin
- Typical length of overland flow to the conveyance systems
- Typical slope of overland flow elements
- Typical length of the conveyance system
- Typical slope of the conveyance system
- Typical cross section of the conveyance system, whether it be a channel or pipe.

The actual parameters required for runoff estimation are dependent on which methods of computation is being used, hence these are discussed in the appropriate sections below.



LEGEND

- HYDROLOGIC SOIL GROUP A
- HYDROLOGIC SOIL GROUP B
- HYDROLOGIC SOIL GROUP C
- HYDROLOGIC SOIL GROUP D

0' 2000' 4000'
SCALE

PROVO CITY
STORM DRAINAGE MASTER PLAN

HYDROLOGIC SOIL GROUPINGS

FIGURE NO. 4-6

TABLE 4-3

INFILTRATION RATES FOR DIFFERENT SOIL TYPES

Soil Type	Initial Loss (Inches)	Uniform Loss (Inches/Hour)	
A	1.75	1.00	60 min/in
B	1.25	0.50	120 min/in
C	0.75	0.25	240 min/in
D	0.50	0.10	600 min/in

Rational Method

For basins that are not complex and generally have 200 acres or less, the design storm runoff can be analyzed by the Rational Method. Even though this method has frequently come under academic criticism for its simplicity, no other practical drainage design method has been evolved to a level of general acceptance by the practicing engineer. The Rational Method properly understood and applied can produce satisfactory results for urban storm drainage design.

Rational Formula. The Rational Method is based on the Rational Formula:

$$Q = CIA$$

where;

Q = defined as the maximum rate of runoff in cubic feet per second. (Actually Q has units of inches per hour per acre; however, since this rate of in/hr/ac differs from cfs by less than one percent, the more common unit, cfs, is used).

C = a runoff coefficient which is the ratio between the maximum rate of runoff from the area and the average rate of rainfall intensity, in inches per hour, for the period of maximum rainfall of a given frequency of occurrence having a duration equal to the time of concentration. This factor takes into account the soil information and the land use type.

I = the average intensity of rainfall in inches per hour for a duration equal to the time of concentration. The time of concentration usually is the time required for water to flow from the most remote point of the area to the point being investigated. This factor represents the physical system of streets, pipe, and channels.

Limitations. The Rational Method is a wholly adequate method of approximating the peak rate of runoff from a rainstorm in a given basin. The many critics of the method usually are unsatisfied with the results, because the answers are only approximations.

The greatest drawback to the Rational Method is that it normally provides only one point on the runoff hydrograph. When the basins become complex and where sub-basins come together, the Rational Method will tend to over-estimate the actual flow, which results in oversizing drainage facilities. The Rational Method provides no direct data to route hydrographs through the drainage facilities. One reason the Rational Method is limited to small areas is that good design practice requires the routing of hydrographs for larger basins for an economical design.

Time of Concentration. One of the basic assumptions underlying the Rational Method is that runoff is a function of the average rainfall rate during the time required for water to flow from the most remote part of the drainage area to the point under consideration. In the application of the method, the time of concentration must be estimated so that the average rainfall rate for a

corresponding duration can be determined from the rainfall intensity-duration-frequency curves.

For urban storm drains, the time of concentration consists of an inlet time, or time required for runoff to flow over the surface to the nearest inlet, and time of flow in the storm drain to the point under consideration. The latter time can be closely estimated from the hydraulic properties of the storm drain. Inlet time, on the other hand, will vary with surface slope, depression storage, surface cover, antecedent rainfall, and infiltration capacity of the soil, as well as distance of surface flow. In general, the higher the rainfall intensity, the shorter the inlet time. It should be noted that the time of concentration has no relationship to the time of beginning of rainfall, being related rather to the position of the peak rainfall intensity. When dealing with pipe systems, the time of concentration may be readily calculated from the inlet time plus time of flow in each successive pipe run. The latter value is calculated from the velocity of flow as given by the Manning Formula for hydraulic conditions prevailing in the pipes.

The inlet time can be estimated by calculating the various overland distances and flow velocities taken from the most remote point.

Often the remote areas have flow that is very shallow and, in this case, the velocities cannot be calculated by "channel" equations such as Manning's but special overland flow analysis must be considered. Figure 4-7 can be used to help estimate time of surface flow.

When studying a proposed subdivision, it is not necessarily correct to take the overland flow path perpendicular to the contours since the land will be graded and swales will often intercept the natural contour and route the water to the streets thus cutting down on the time of concentration.

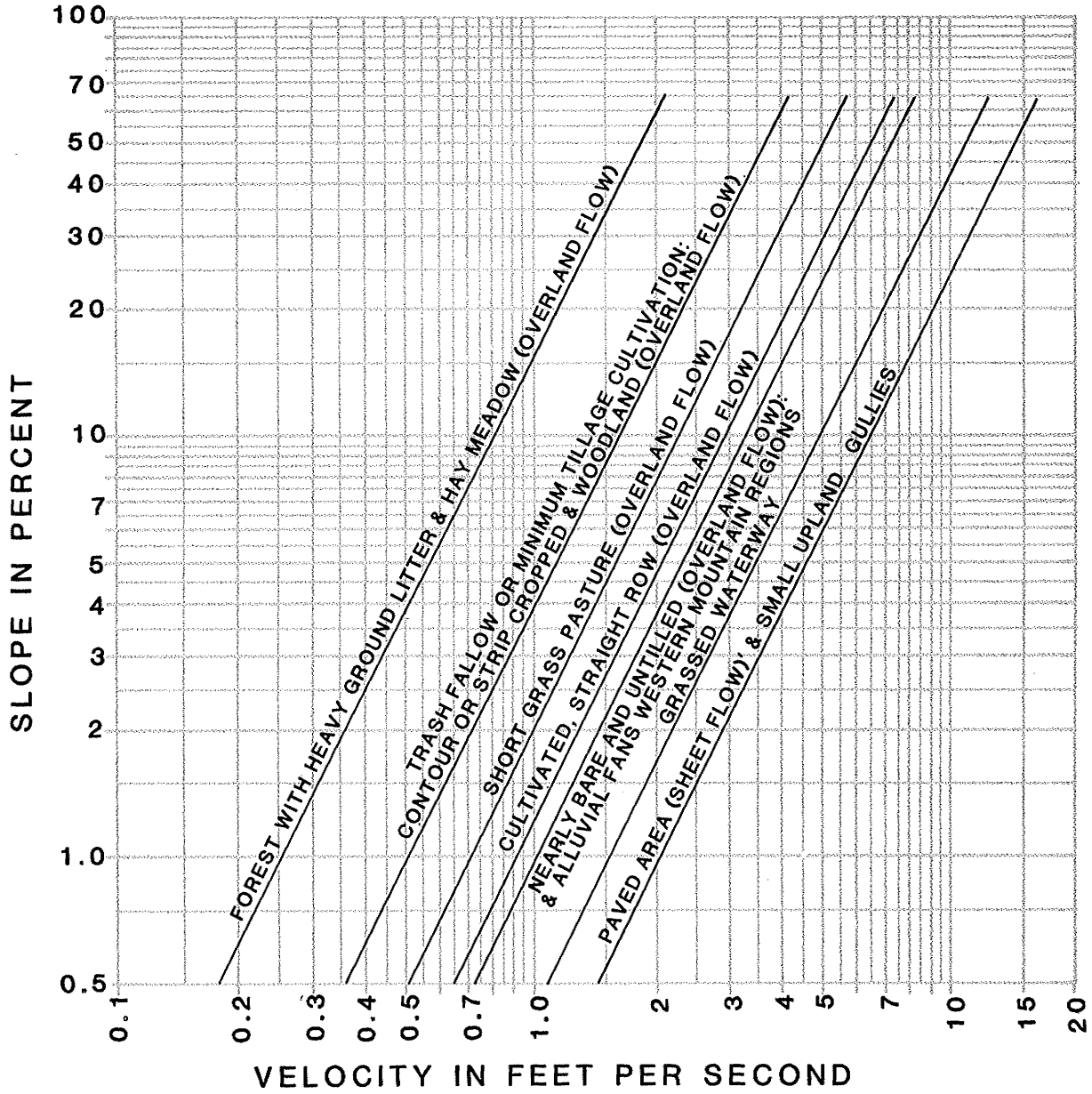
Rainfall Intensity. The intensity, I, is the average rainfall rate in inches per hour for the period of maximum rainfall of a given frequency having a duration equal to the time of concentration.

The rainfall data was discussed in more detail at the beginning of this chapter.

Runoff Coefficient. The runoff coefficient, C, is the variable of the Rational Method least susceptible to precise determination and requires judgment and understanding on the part of the engineer. Its use in the formula implies a fixed ratio for any given drainage area. In reality, this is not the case. The coefficient represents the integrated effects of infiltration, detention storage, evaporation, retention, flow routing, and interception which all affect the time distribution and peak rate of runoff. Table 4-4 presents recommended ranges for C values.

Adjustment for Infrequent Storms. The adjustment of the Rational Method for use with major storms can be made by multiplying the right side of the Rational Formula by a frequency factor C_f. This factor is used to account for antecedent precipitation conditions. The Rational Formula now becomes:

$$Q = CIAC_f$$



PROVO CITY
STORM DRAINAGE MASTER PLAN

VELOCITIES FOR ESTIMATING Tc

FIGURE NO. 4-7

TABLE 4-4

RECOMMENDED RATIONAL "C" - FACTORS

DESCRIPTION	ZONING	NORMAL VALUE "C"	RANGE OF VALUES "C"
Open Land/Agricultural	A-1	0.10	0.10-0.30
Single Family Residential	R-1	0.35	0.25-0.50
Two Family Residential	R-2	0.40	0.50-0.70
Multiple Family Residential	R-3, R-4, R-5	0.40	0.50-0.70
Planned Residential	P-C, (PD)	0.40	0.50-0.70
Professional Office	PO	0.70	0.70-0.90
Commercial	C-B-D, C-G, C-H, C-M, C-A	0.70	0.70-0.90
Light Industrial	M-1, M-D	0.60	0.50-0.80
General Industrial	M-2	0.60	0.50-0.80
Streets			
Asphaltic			0.70-0.95
Concrete			0.80-0.95
Drives and Walks			0.75-0.85
Roofs			0.75-0.95
Lawns, Sandy Soil			
Flat, 2%			0.05-0.10
Average, 2 to 7%			0.10-0.15
Steep, 7%			0.15-0.20
Lawns, Heavy Soil			
Flat, 2%			0.15-0.20
Average, 2 to 7%			0.20-0.25
Steep, 7%			0.25-0.35

The following table of C_f values can be used. The product of C times C_f should not exceed 1.0.

Frequency Factors for Rational Formula

Recurrence Interval (years)	C_f
2 to 10	1.0
25	1.1
50	1.2
100	1.25

Application of the Rational Method. The first step in applying the Rational Method is to obtain a good topographic map and define the boundaries of all of the relevant drainage basins. Basins to be defined include all basins tributary to the area of study and sub-basins in the study area. A field check and possibly field surveys should be made for each basin.

Next, the parameters required for the application of the Rational equation are estimated for each sub-basin and the equation applied to obtain a peak runoff rate.

For an example of how to apply the Rational Method, refer to the examples at the end of this chapter.

Soil Conservation Service TR-55 Method

This section presents the method used by the SCS (Soil Conservation Service) to obtain design discharge and runoff volume.

The equation for the peak flow rate is as follows:

$$q_p \text{ (cfs)} = q\ A\ Q$$

where;

q = discharge in cubic feet per second per square mile per inch of runoff
A = area in square miles
Q = runoff in inches

The input values required to use the procedure outlined above are drainage area in acres, curve number, time of concentration in hours, and 24-hour design precipitation.

Drainage Area. The drainage area is the area that contributes surface runoff to a stream at a given point. The number of acres within the drainage area can be determined using a planimeter, a grid counting technique, summation of trapezoids, or rectangular coordinate computation methods.

Runoff Curve Number. The runoff curve number, CN, indicates runoff potential and is a number assigned to various hydrologic soil-cover complexes. A hydrologic soil-cover complex is a combination of hydrologic soil group (A, B, C or D) and land use or cover. Table 4-5 is a listing of CNs for the hydrologic groups, the various land use categories, and the ground cover and vegetation conditions.

A weighted CN must be calculated when the drainage area has more than one hydrologic soil-cover complex. Figure 4-8 shows an example of this calculation.

Time of Concentration. The time of concentration, Tc, is defined as the time it takes runoff to travel from the hydraulicly most distant part of the watershed to the outlet or point of reference.

Tc in the TR55 method is found as

$$Tc\ (\text{hours}) = \frac{L^{0.8}\ (S+1)^{0.7}}{1140\ Y^{0.5}}$$

where;

$S = \frac{1000}{CN} - 10.$
L = greatest flow length in feet
Y = watershed average slope in percent
CN = curve number

The greatest flow length in feet (L) is measured from the outlet point, upstream along the channel, tributary and/or estimated flow line to the top of the divide. All possible routes should be checked to get the greatest L.

The average watershed slope in percent (Y) is the average slope of the land and not the water course. Theoretically, the average slope would be the average of land slopes computed at each corner of a grid placed over the watershed. For small areas having little relief, the average slope may be estimated with an Abney level or obtained using slopes given in soil survey reports. For large or complex areas, average slope should be computed. One method is to select a grid size that will give enough points to represent the watersheds relief and place it over the drainage area. Compute the slope at each grid point using the elevation difference and the shortest distance between the two closest contours. The average of slopes at all the grid points that fall within the watershed area would then be the average slope of the sub-basin. Another good method to determine the average slope is the "summation of contour lengths method" illustrated in Figure 4-9.

Rainfall Intensity. The 24-hour precipitation value, P, is read from the appropriate rainfall distribution curve as discussed previously in this Chapter.

TABLE 4-5

RUNOFF CURVE NUMBERS FOR SELECTED AREAS

LAND USE DESCRIPTION		CN VALUE FOR HYDROLOGIC SOIL GROUP A	B	C	D
Cultivated Land[1]:	without conservation treatment	72	81	88	91
	with conservation treatment	62	71	78	81
Pasture or Range Land:	poor condition	68	79	86	89
	good condition	39	61	74	80
Meadow:	good condition	30	58	71	78
Wood or Forest Land:	thin stand, poor cover, no mulch	45	66	77	83
	good cover[2]	25	55	70	77
Open Spaces, Lawns, Parks, Golf Courses, Cemeteries, etc.					
good condition:	grass cover on 75% or more of the area	39	61	74	80
fair condition:	grass cover on 50-75% of the area	49	69	79	84
Commercial and Business Areas (85% impervious)		89	92	94	95
Industrial/Manufacturing Districts (72% impervious)		81	88	91	93
Residential[3]					
Average lot size	Zone / Average % Impervious[4]				
1/8 acre or less	R4 / 65	77	85	90	92
1/4 acre	R2,R3,RP / 38	61	75	83	87
1/3 acre	R1 / 30	57	72	81	86
1/2 acre	RE, REL / 25	54	70	80	85
1 acre	20	51	68	79	84
Paved Parking Lots, Roofs, Driveways, etc.[5]		98	98	98	98
Streets and Roads:					
paved with curbs and storm sewers[5]		98	98	98	98
gravel		76	85	89	91
dirt		72	82	87	89

TABLE 4-5

RUNOFF CURVE NUMBERS FOR SELECTED AREAS
(continued)

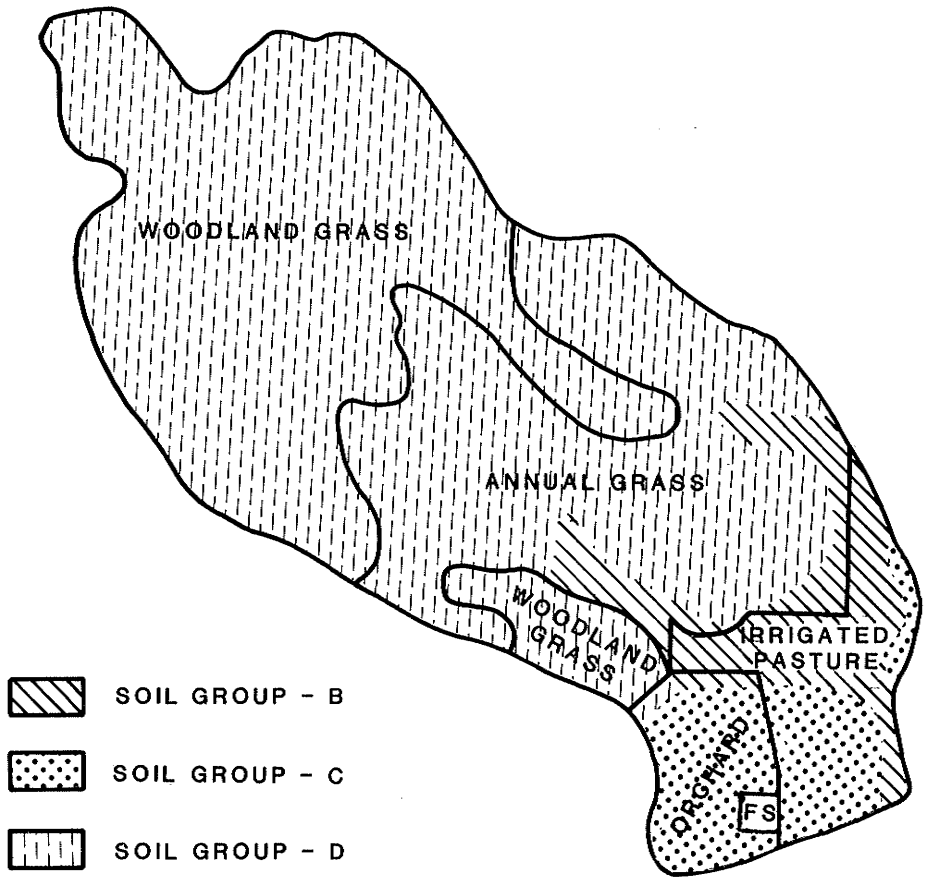
1. For a more detailed description of agricultural land use curve numbers refer to National Engineering Handbook, Section 4, Hydrology, Chapter 9, August 1972.

2. Good cover is protected from grazing and litter and brush cover soil.

3. Curve numbers are computed assuming the runoff from the house and driveway is directed towards the street with a minimum of roof water directed to lawns where additional infiltration could occur.

4. The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

5. In warmer climates a curve number of 95 may be used.



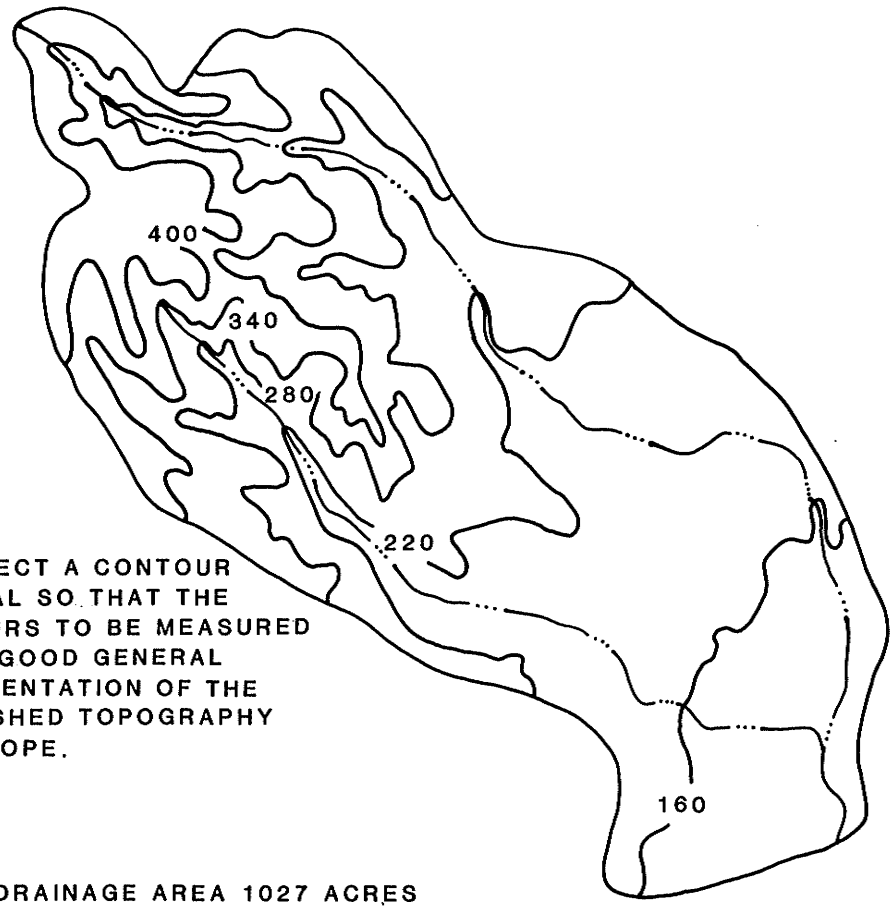
VEGETATIVE COVER	CONDITION	HYDRAULIC SOIL GROUP	AREA IN ACRES	CN	(AREA X CN)
Woodland Grass	Good	B	5.1	58	295.8
Woodland Grass	Good	D	499.0	79	39421.0
Annual Grass	Good	B	45.0	61	2745.0
Annual Grass	Good	D	326.0	81	26406.0
Irrigated Pasture	Good	B	52.0	58	3016.0
Irrigated Pasture	Good	C	38.0	72	2736.0
Orchard (Evergreen)	Good	B	1.3	58	75.4
Orchard (Evergreen)	Good	C	58.0	72	4176.0
Farmstead	(20% Imperv.)	C	2.6	79	205.4
TOTAL			1027.0		79076.6

$$CN = \frac{\text{TOTAL (AREA X CN)}}{\text{TOTAL AREA}} = \frac{79076.6}{1027} = 77.00 \qquad \underline{\text{USE CN = 77}}$$

PROVO CITY
MASTER STORM DRAINAGE PLAN

WEIGHTED CN OF WATERSHED

FIGURE 4-8



NOTE: SELECT A CONTOUR INTERVAL SO THAT THE CONTOURS TO BE MEASURED GIVE A GOOD GENERAL REPRESENTATION OF THE WATERSHED TOPOGRAPHY AND SLOPE.

EXAMPLE: DRAINAGE AREA 1027 ACRES
SELECTED CONTOUR INTERVAL - 60 FT.

CONTOUR	LENGTH (FT.)
400	12300
340	20500
280	20600
220	15100
160	5600
	74100 Σ CONTOUR LENGTHS

$$\text{AVERAGE WATERSHED SLOPE} = \frac{60 \text{ FT. X } 74100 \text{ FT.}}{1027 \text{ X } 435.6} = 9.94\% \text{ SLOPE}$$

USE AVERAGE SLOPE - (S) = 10 %

PROVO CITY
MASTER STORM DRAINAGE PLAN

AVERAGE SLOPE OF WATERSHED BY SUMMATION OF CONTOUR LENGTHS METHOD

FIGURE 4-9

Methodology. Once the above values have been obtained, an estimate of the direct surface runoff, Q, is found

$$Q \text{ (inches)} = \frac{(P - 0.2S)^2}{P + 0.8S}$$

where;

S = previously defined

This equation is also presented as a family of curves in Figures 4-10 and 4-11. The peak discharge, in CSM/inch can now be found using Figure 4-12. Once all of these values are estimated the basic runoff equation can be used to obtain a peak flow rate in cfs;

$$q_p(\text{cfs}) = q*A*Q$$

Examples of the use of this method are presented in a later section of this Chapter.

Hydrograph Methods

For the development and design of a detention basin the storm runoff volume must be known. In the Rational Method there is no total storm volume computed. Therefore a unit hydrograph method must be implemented to obtain a storm volume and its distribution. However, unit hydrograph methods generally require that the basin be relatively large. When applied to smaller areas, the peak flow rate is excessive. Therefore, for areas with a single family dwelling, a multiple family dwelling, or small industrial or commercial areas, or where the unit hydrograph approach is not used, an emperical equation can be used to obtain the storage volume:

$$V = 0.1A$$

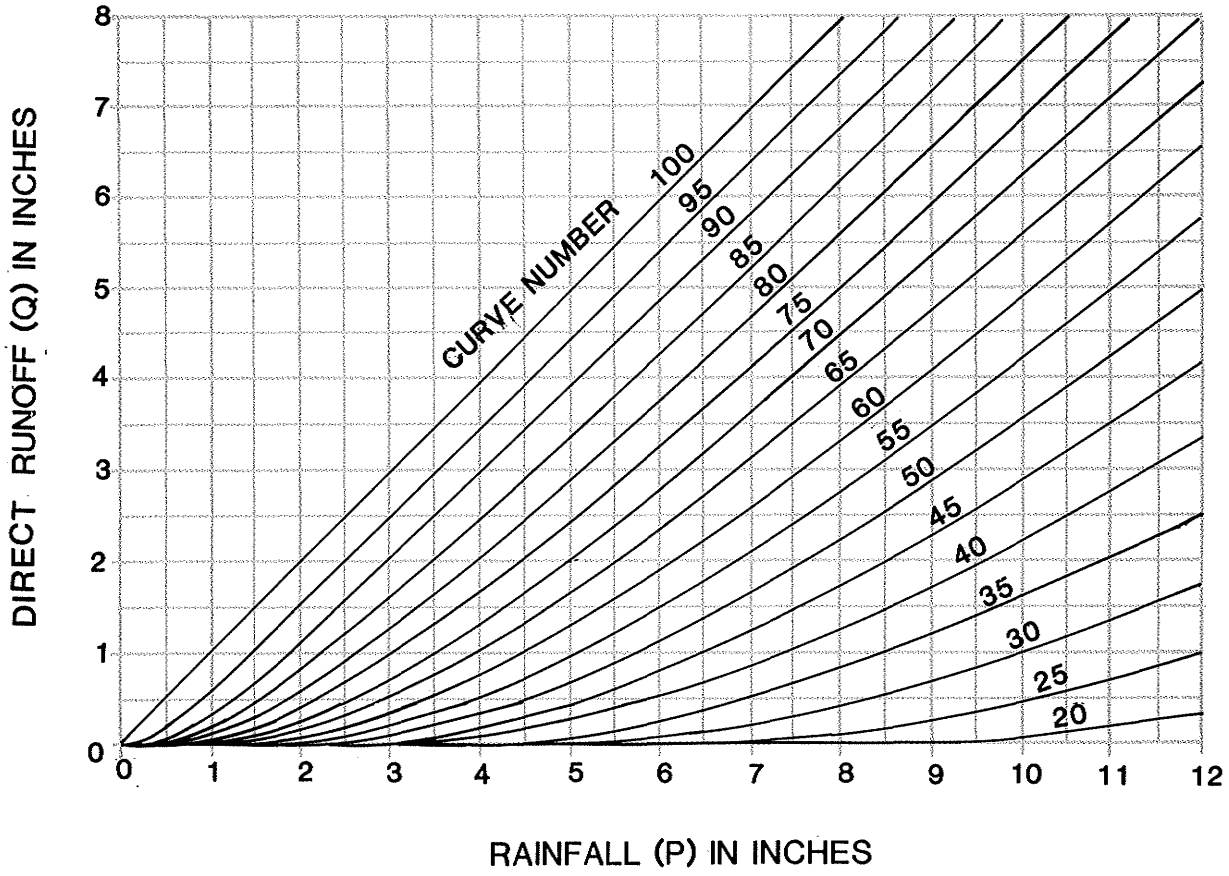
where;

V = the required storage value for the detention facility in acre feet
A = the area of the drainage basin in acres

The required storage volume is the same volume as 0.1 feet of water applied over the entire surface area of the drainage basin.

Unit Hydrograph Method. A unit hydrograph is defined as the hydrograph resulting from one inch of direct runoff from the tributary area resulting from a unit storm. A unit storm is a rainfall of such duration that the period of surface runoff is not appreciably less for any rain of shorter duration (ie., the duration is at least equal to the time of concentration). The unit hydrograph thus represents the integrated effects of factors such as tributary area, shape, street pattern, channel capacities, and street and land slopes.

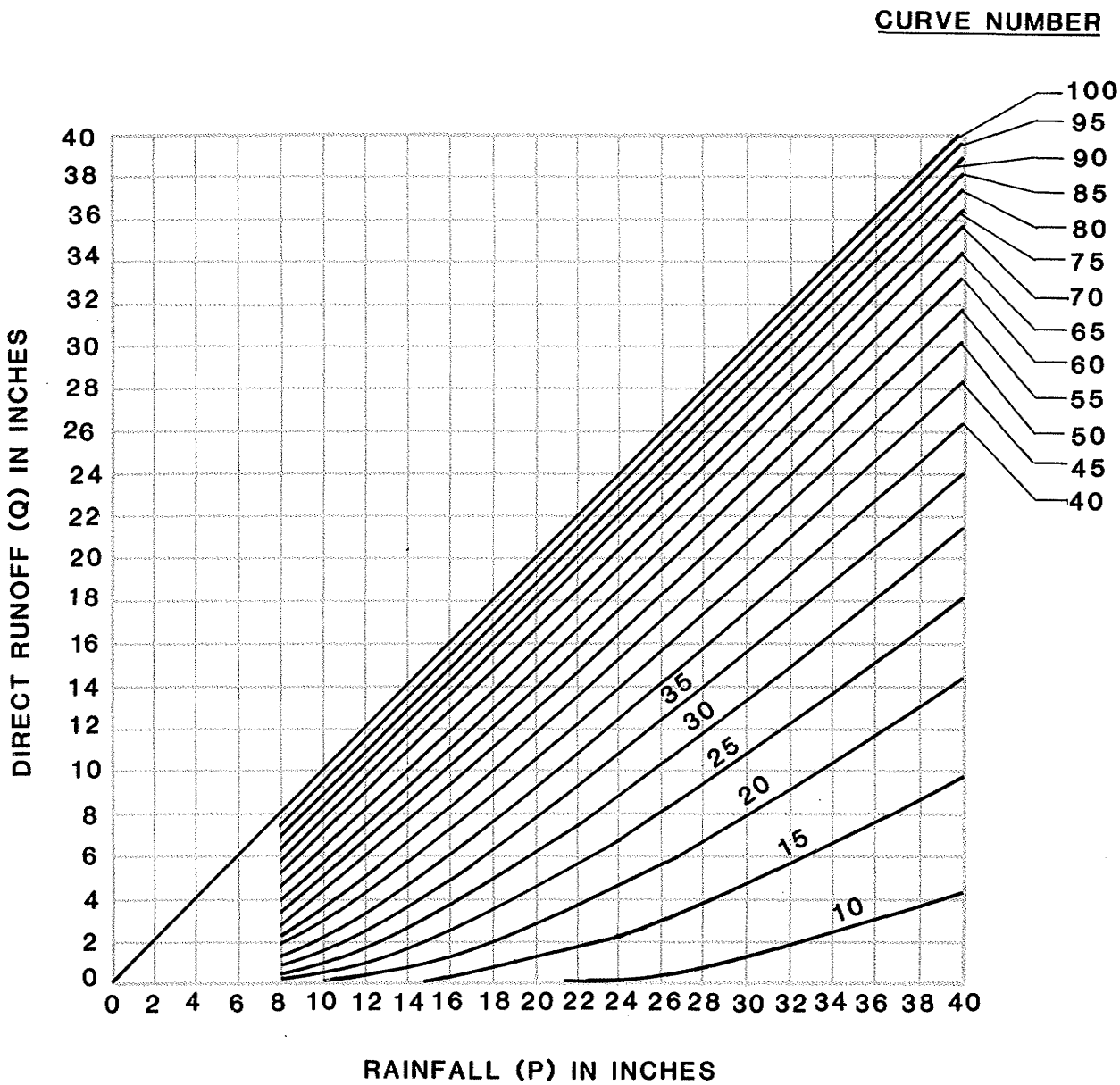
To apply the unit hydrograph, the effective precipitation depth is multiplied by the ordinates of the unit hydrograph and added to obtain a design storm runoff.



PROVO CITY
STORM DRAINAGE MASTER PLAN

SOLUTION OF RUNOFF EQUATION
FOR P=0 TO 12 INCHES

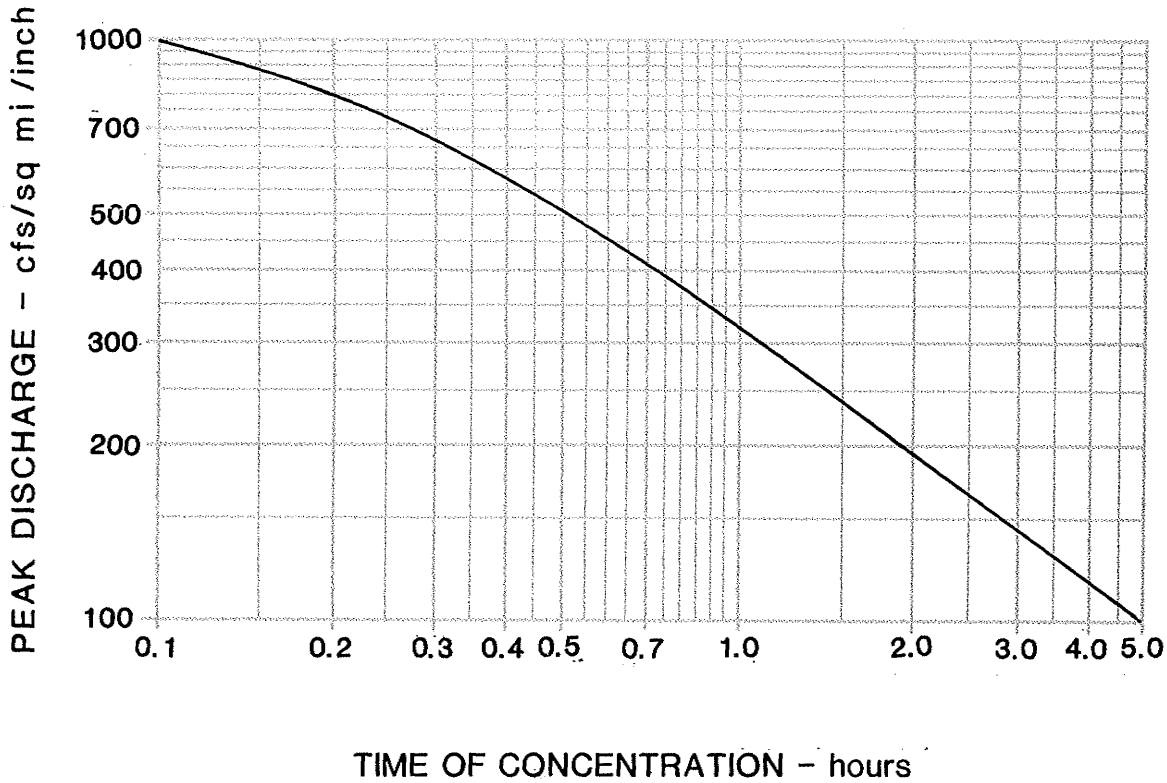
FIGURE NO. 4-10



PROVO CITY
STORM DRAINAGE MASTER PLAN

SOLUTION OF RUNOFF EQUATION
FOR P=8 TO 40 INCHES

FIGURE NO. 4-11



PROVO CITY
STORM DRAINAGE MASTER PLAN

PEAK DISCHARGE IN CFS/SQUARE MILE/INCH OF RUNOFF
VERSUS TIME OF CONCENTRATION (Tc)

FIGURE NO. 4-12

The basic premise of the unit hydrograph is that individual hydrographs resulting from the successive increments of rainfall excess that occur throughout a storm period will be proportional in discharge throughout their length; and that when properly arranged with respect to time, the ordinates of the individual unit graphs can be added to give ordinates representing the total storm discharge. The hydrograph of the total storm discharge is obtained by summing the ordinates of the individual hydrographs.

Basic Assumptions.

The derivation and application of the unit hydrograph are based on the following assumptions:

- The rainfall intensity is constant during the storm that produces the unit hydrograph.
- The rainfall is uniformly distributed throughout the whole area of the drainage basin.
- The base, or time, duration of the design runoff due to an effective rainfall of unit duration is constant.
- The ordinates of the design runoff with a common base time are directly proportional to the total amount of direct runoff represented by each hydrograph.
- The effects of all physical characteristics of a given drainage basin, including shape, slope, detention, infiltration, drainage pattern, channel storage, etc., are reflected in the shape of the unit hydrograph for that basin.

Denver Unit Hydrograph Approach. There are two basic equations used in defining the limits of this synthetic unit hydrograph method. The first equation defines the lag time of the basin in terms of time to peak, t_p, which is defined as the time from the center of the unit storm duration to the peak of the unit hydrograph. For most urban studies the unit storm duration should range between 5 to 10 minutes.

$$t_p = C_t (L L_{ca})^{.3}$$

where;

t_p	=	time to peak of hydrograph from midpoint of unit rainfall in hours
L	=	length along stream from study point to upstream limits of the basin in miles
L_{ca}	=	distance from study point along stream to the centroid of the basin in miles
C_t	=	a coefficient reflecting time to peak

The second equation defines the unit peak of the unit hydrograph.

$$q_p = \frac{640\ C_p}{t_p}$$

where;

q_p = peak rate of runoff in cfs per square mile
C_p = a coefficient related to peak rate of runoff

If the peak discharge for a unit storm has already been computed from other methods it may also be used for q_p.

The C_p and C_t values in the above equations are determined from the following equations:

$$C_t = \frac{7.81}{(l_a)^{0.78}} \quad \text{for } l_a = 30 \text{ percent}$$

where;

l_a = percent of watershed which is impervious

C_p = $0.89\ (C_t)^{0.46}$

The percent of impervious watershed can be estimated from aerial photographs of an existing urban watershed having a similar plan of development adjacent to the planned watershed.

For estimating C_t: Add 10% for sparsely stormdrained areas. Subtract 10% for fully stormdrained areas.

Correct for slope using following equations:

For S_e 0.01 ft/ft ; $C_t = 0.40\ C_{t_o} S_e^{-0.2.}$

For S_e 0.025 ft/ft ; $C_t = 0.48\ C_{t_o} S_e^{-0.2.}$

For 0.01 S_e 0.025 ft/ft ; $C_t = C_{t_o}$.

where;

S_e = Effective main water course computed using downstream 80% of channel
C_{t_o} = The initial C_t coefficient

For estimating C_p: Use the slope corrected C_t.
subtract 10% for sparsely sewered areas;
add 10% for fully sewered areas.

Unit Hydrograph Shape.

The shape of the unit hydrograph is a function of the physical characteristics of the watershed. The shape is developed from empirical relationships.

The following equations may be used to estimate the width of the unit hydrograph at 50 percent and 75 percent of the peak discharge:

$$W_{@50\%Q_P} = 500/Q_p/A$$

$$W_{@75\%Q_P} = 260/Q_p/A$$

where;

Q_p = as defined below

Drawing the Unit Hydrograph.

Once q_p is determined, Q_p, the maximum unit hydrograph peak for the basin can be computed by:

$$Q_p = q_p A$$

where;

A = the area of the basin in square miles

The time from the beginning of rainfall to the peak of the unit hydrograph is determined by:

$$T_p = 60\ t_p + 0.5\ t_u$$

where;

t_u = time of unit rainfall duration in minutes, and
T_p = time from beginning of unit rainfall to peak of hydrograph in minutes

Once Q_p is located, the unit hydrograph can be sketched with the aid of the approximate widths at $Q_{50\%}$ and $Q_{75\%}$. After the hydrograph is sketched, the area under the hydrograph should be planimetered to determine the volume of runoff in acre feet or other suitable units.

This volume should equal the volume of one inch of runoff from the entire basin. If the two volumes are within 5 percent, then the sketched unit hydrograph is acceptable. If the volume from the drawn hydrograph is more or less than the equivalent of one inch of runoff, the unit hydrograph should be adjusted to within 5 percent of one inch of runoff. The final step is to define the unit hydrograph in tabular form showing time vs. rate of flow in cfs. If Q_p does not fall on a chosen time interval so that the tabulation does not represent the graph, then the graph may be shifted so that the table will more truly represent the graph.

SCS Unit Hydrograph Method. The Soil Conservation Service has also developed a method for constructing a unit hydrograph based on a dimensionless hydrograph (Figure 4-13). The method requires only the determination of the time to peak and the peak discharge.

The equation for the time to peak is:

$$t_p = \frac{D}{2} + t_1$$

where;

t_p = the time from the beginning of rainfall to peak discharge in hours

D = the duration of rainfall in hours. $D = 0.133t_c$; where t_c is the time of concentration

t_1 = the lag time from the centroid of rainfall to peak discharge in hours

The equation for the peak discharge is:

$$Q_p = \frac{484A}{t_p}$$

where;

Q_p = Peak discharge in cfs

A = drainage area in square miles

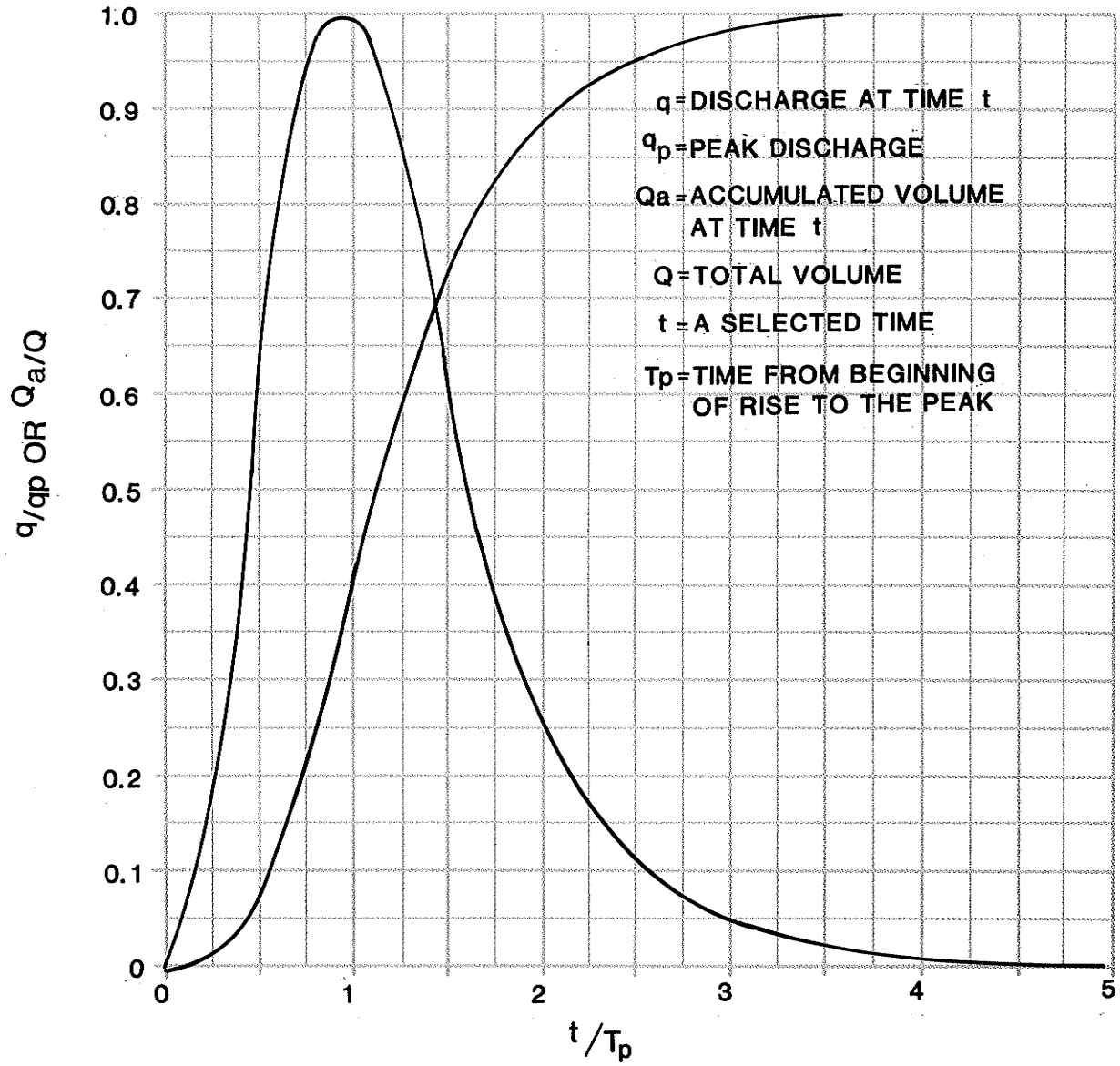
t_p = the time to peak in hours

Most of the parameters are the same as defined in the Denver Unit Hydrograph method.

An example of the use of each of these methods is presented in the examples section of this chapter.

Design Storm Runoff. Now that the unit hydrograph has been calculated and the effective precipitation from the design storm determined, the design storm hydrograph can be calculated. The time units of the unit hydrograph should be the same as the time units of the excess precipitation which, for convenience, should all be equal to the unit storm duration and can generally be taken as 10 minutes for an urban area less than 5 square miles. Unit times of 5 minutes can be used for small basins up to 0.5 square miles and unit times of 15 minutes or more for larger basins.

The determination of the total storm runoff is most easily solved using a table such as Table 4-6, putting time intervals in the first column and unit hydrograph ordinates in the second column. Place the design excess precipitation values across the top, and then multiply the excess precipitation values times all the unit hydrograph ordinates in Column 2 and put answers in the appropriate



PROVO CITY
STORM DRAINAGE MASTER PLAN

SOIL CONSERVATION SERVICE DIMENSIONLESS
UNIT HYDROGRAPH AND MASS CURVE

FIGURE NO. 4-13

TABLE 4-6

DESIGN STORM HYDROGRAPH COMPUTATION

Time Period	Unit Hydrograph	Excess Precipitation Values (Inches) 1	2	3	4	5	6	7	Total Runoff (cfs)
1			X	X	X	X	X	X	
2				X	X	X	X	X	
3					X	X	X	X	
4						X	X	X	
5							X	X	
6								X	
7									

columns. Each successive column is lagged one time unit as shown by the blocked out areas in the table. Finally, add up all the multiplied values horizontally to obtain the design storm runoff hydrograph.

An example of the calculation of a hydrograph using this table is presented at the end of this chapter.

The Illinois Urban Drainage Area Simulator (ILLUDAS).

The Illinois Urban Drainage Area Simulator (ILLUDAS) is a modification of the Road Research Laboratory Model which was developed in England. It is a computer simulation model, which computes the outflow hydrograph from connected paved areas and connected pervious areas (including those unconnected, contributing paved and pervious areas). The computed hydrographs are combined into an outflow hydrograph, which is routed through a reservoir-type storage model to account for the effects of storage within the sub-basin.

Hydrologic parameters used in the "ILLUDAS" Computer Model are:

- Design Storm Precipitation and Distribution
- Sub-basin Characteristics (Length, Slope, Paved Area, Unpaved Area)
- Soil Types (Similar to SCS TR-55 Method)
- Hydraulic Pipe Flow Parameters (Manning's "n")
- Physical Properties of Outlet Conveyance System

The model appears most sensitive to percent imperviousness and to the soil type within the pervious areas. Output from the model includes the outflow hydrographs from the paved and unpaved areas, and the combined sub-basin outflow hydrograph, along with the computed runoff volume.

ILLUDAS is applied by first dividing the basin to be studied into sub-basins. A sub-basin is normally a homogeneous portion of the basin tributary to a single inlet or set of inlets that constitute a design point in the drainage area. Within each sub-basin, certain hydrologic properties of the basin must be determined. These items are explained in the following paragraphs.

Paved Area Runoff. The paved area within the sub-basin which is directly connected to the storm drainage system (streets, driveways, roofs, etc.) needs to be determined. This can be either an actual area (acres) or a percentage of the total area. This can be accomplished by actual site measurements and observations or through the use of aerial photography of a sufficient scale to determine physical characteristics. After the directly connected paved area has been determined, calculations are made to determine the time-of-travel for the runoff from various parts of the paved area to the inlets at the downstream end of the sub-basin.

In the present program, travel times on the paved area are computed in two steps. As the first step, flow of 0.5 to 1.0 cfs per acre of contributing paved area is assumed to exist in the street gutters. The second step is to apply Manning's equation to compute the velocity of flow in the gutters. With these velocities, travel times are computed at various points on the paved area in each sub-basin. These travel times are plotted on the paved area, and by connecting points of equal travel time a series of isochrones are drawn on the paved area, as shown in Figure 4-14. The directly connected paved area between these isochrones is measured and designated areas PA1, PA2, PA3, PA4 and PA5, etc. These various areas are accumulated and plotted against travel time to the inlet as shown in Figure 4-14. This time-area curve shows the amount of paved area within the sub-basin that is contributing water at the storm drain inlet at any time after the beginning of runoff.

By applying the various initial losses, such as initial wetting and depression storage, along with the incremental rainfall pattern on the contributing paved area, a paved hydrograph is generated, again see Figure 4-14. By combining this paved area hydrograph with a similar hydrograph for the connected grassed areas, a complete outflow hydrograph is generated for each sub-basin within the system.

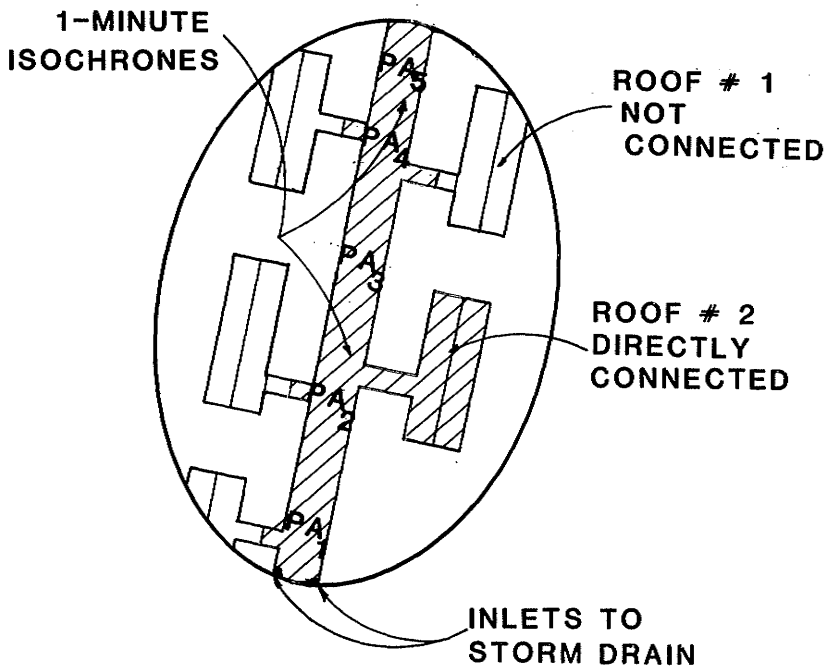
Grassed-Area Runoff. Computation of a grassed-area hydrograph for each sub-basin closely parallels that of the paved-area hydrograph. Figure 4-15 represents the same sub-basin used to illustrate paved-area runoff. The shaded area represents the contributing grassed area which in this case includes only the front yards of a residential neighborhood. More grassed area could contribute to runoff, but front yards are typically graded to drain quickly to the street. Runoff from back and side yards often drains gradually to a common back lot line and then laterally to the nearest street. The travel time required for this long flow path virtually removes such grassed areas from consideration during relatively short, intense storms normally used for drainage design.

After the contributing grassed area has been determined, the time vs. grassed-area curve in Figure 4-15 can be constructed. The location on the street of the 1-minute isochrones in Figure 4-15 was determined earlier for the paved-area runoff. Travel times on the grass strip itself are equivalent to the time of equilibrium in the following equations by Izzard (1946).

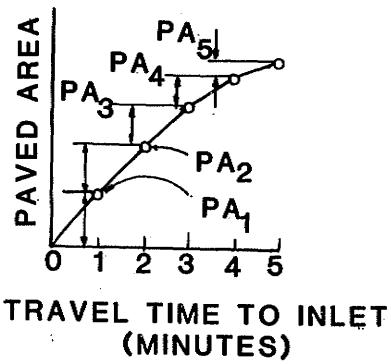
$$q_e = 0.0000231IL$$

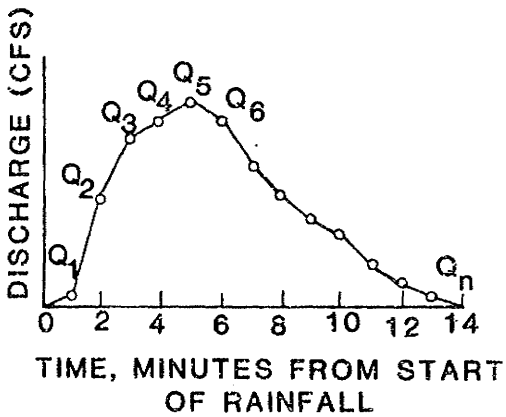
where;

q_e = discharge of overland flow, in cfs per foot of width, at equilibrium
I = supply rate in inches per hour assumed to be 1.0 in this study
L = length of overland flow in feet



SUB-BASIN MAP
(DIRECTLY CONNECTED
PAVED AREA SHADED)

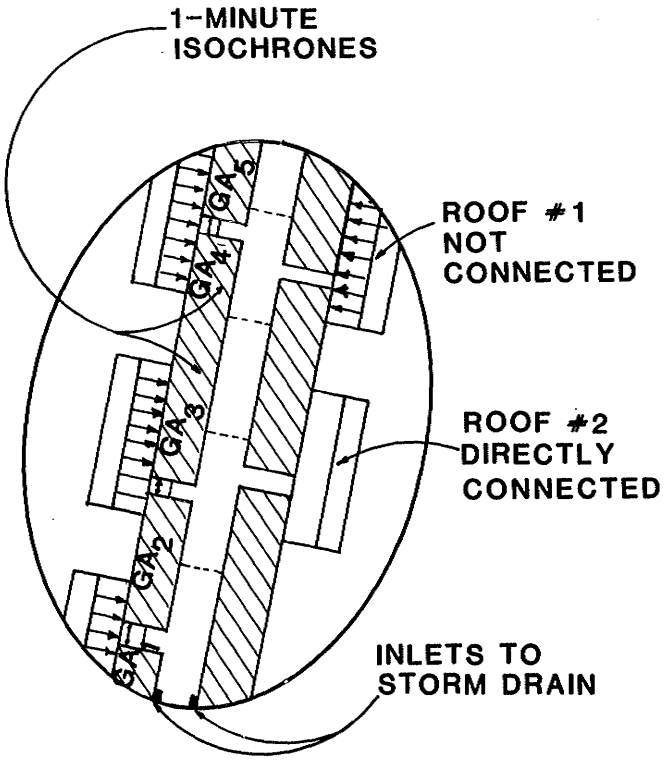




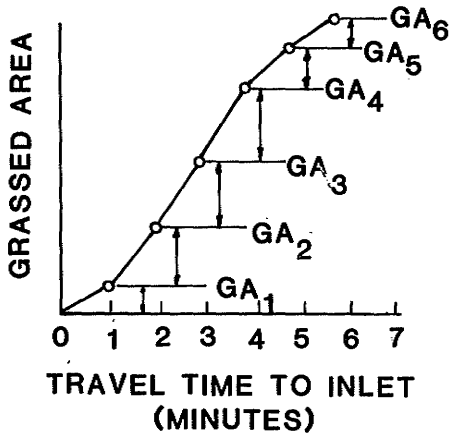
PROVO CITY
STORM DRAINAGE MASTER PLAN

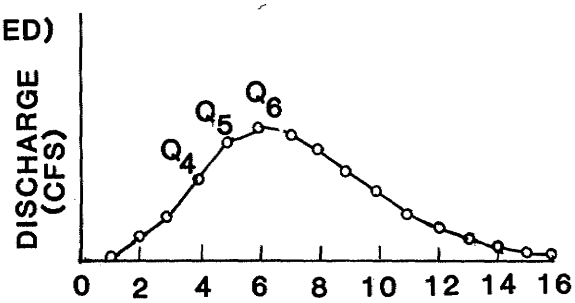
PAVED AREA RUNOFF

FIGURE NO. 4-14



SUB-BASIN MAP
(CONTRIBUTING GRASSED AREA SHADED)





PROVO CITY
STORM DRAINAGE MASTERPLAN

GRASSED AREA RUNOFF

FIGURE NO. 4-15

and

$$t_e = 0.033\ K\ q_e^{-0.67}$$

where;

t_e = time of equilibrium in minutes
K = $(0.0007I+c)S^{-0.33}$
S = surface slope in feet per foot
c = coefficient having a value of 0.046 for bluegrass turf

After the travel times at various points on the contributing grassed area have been computed and plotted, the 1-minute isochrones in Figure 4-15 are drawn. The contributing grassed areas within time zones GA_1 through GA_6 are then measured and plotted cumulatively against time-of-travel from the inlet as shown in Figure 4-15. This time-area curve shows the amount of grassed area within the sub-basin that is contributing water at the storm drain inlet at any time after the beginning of runoff. Rainfall on the supplemental paved areas, sidewalks, etc., are considered to add to the grassed areas.

By applying the same abstraction parameters, as given for the paved area as well as infiltration, along with the incremental rainfall pattern, the grassed area runoff hydrograph can be developed. As explained, this hydrograph combined with the paved area hydrograph provides the outflow hydrograph from each sub-basin.

Computation Modes. The ILLUDAS computer model has two modes of computation.

- Evaluation Mode
- Design Mode

When the model is in the evaluation mode, the computer routes the hydrograph through the given existing outflow conveyance system. If the flow from the hydrograph exceeds the capacity of the conveyance system then water is stored as it waits to travel through the system. This storage value as well as the capacity of the conveyance system is printed as part of the computer printout. The storage given in cubic feet, is very valuable in sizing needed detention storage facilities.

The design mode can be used for either new undrained areas or existing developed areas. In the design mode the ILLUDAS program calculates the minimum circular conveyance system (pipe) needed to handle the peak runoff from a given sub-basin.

A given amount of storage at the outlet can also be specified and the ILLUDAS program will use this storage to reduce the peak flow and then size a pipe system to convey the reduced peak flow value.

Typical "ILLUDAS" Input Parameters. As explained previously the "ILLUDAS" model computes paved area and grassed area hydrographs within the urban watershed.

The following parameters are needed as the input data for the "ILLUDAS" model.

Basin parameters.

- Basin area
- Paved area abstraction
- Grassed area abstraction
- Predominant soil group
- Minimum diameter to be considered in the system
- Manning's "n"

The recommended amounts for paved area abstraction and grassed area abstraction are 0.1 and 0.2 respectively.

Rainfall parameters.

- Number of rainfall increments
- Time increment
- Total rainfall
- Antecedent moisture condition

Sub-basin Data.

- Sub-basin area
- Directly connected paved area
- Supplemental paved area
- Paved area entry time
- Paved area flow path
- Contributing grassed area
- Grassed area entry time
- Grassed area flow path

- Grassed flow path slope
- Hydrologic soil group

An example run of the ILLUDAS model is presented in the section on examples at the end of this Chapter.

HYDRAULIC METHODS

Pipeline Sizing

Pipelines, culverts, and other closed sections shall be designed as flowing full. They may be allowed to go under pressure if by doing so the number and size of grade changes can be reduced. If designed under pressure, the hydraulic, or pressure gradient, shall not rise above the ground surface or prohibit surface flow collection.

Equations. The general sizing of these structures is based on the Manning formula,

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$$

where;

Q	=	flow rate in cfs
n	=	Mannings roughness coefficient
A	=	cross sectional area of the structure in ft^2
R	=	wetted perimeter of the structure in ft
S	=	slope

Design values for "n" are, 0.013 for concrete structures and 0.022 for corrugated metal structures.

Application. The application of the Manning formula to size a pipeline depends on whether the pipe is flowing full or partially full. In the case of a pipe flowing full the Manning formula can be explicitly solved for the diameter of the pipe.

$$D = \left(\frac{nQ}{0.147\ S^{1/2}} \right)^{3/8}$$

where;

D	=	diameter of the pipe in feet
Q	=	flow rate in cfs
S	=	slope of the pipe
n	=	Mannings' 'n'

In the case of a pipe flowing partially full, Manning formula can not be explicitly solved for the diameter of the pipe. An analytical solution is possible by

applying the Newton-Raphson Method. In order to simplify the computation, dimensionless curves showing the relation between the depth and section factor

$$D = \frac{nQ}{1.49\ S1/2}$$

have been prepared for rectangular, trapezoidal, and circular channel sections (Figure 4-16). These self-explanatory curves will help to determine the depth for a given section factor and vice versa. Examples of determining the pipe diameter and normal depth of flow in the pipe are presented at the end of this chapter.

Open Channel Sizing

Open channel sizing is similar to the pipeline sizing methodology except there is not any explicit solution of Manning formula for normal depth in a channel. Newton-Raphson Method or dimensionless curves such as Figure 4-16 may be used to calculate the normal depth. The Manning roughness coefficient, n, can be estimated from Table 4-7. An example of the computation of normal depth by using the dimensionless curves is presented at the end of this chapter.

Detention Basin Sizing

The Modified Puls method is frequently used for modeling the flow through a detention basin. The routing method is based on the conservation formula:

$$I - O = dS/dT$$

where;

I	=	detention basin inflow rate in cfs
O	=	detention basin outflow rate in cfs
dS	=	change in basin storage in cubic feet
dT	=	time step in seconds

The above equation can be approximated by replacing the variables I and O with time averaged values of

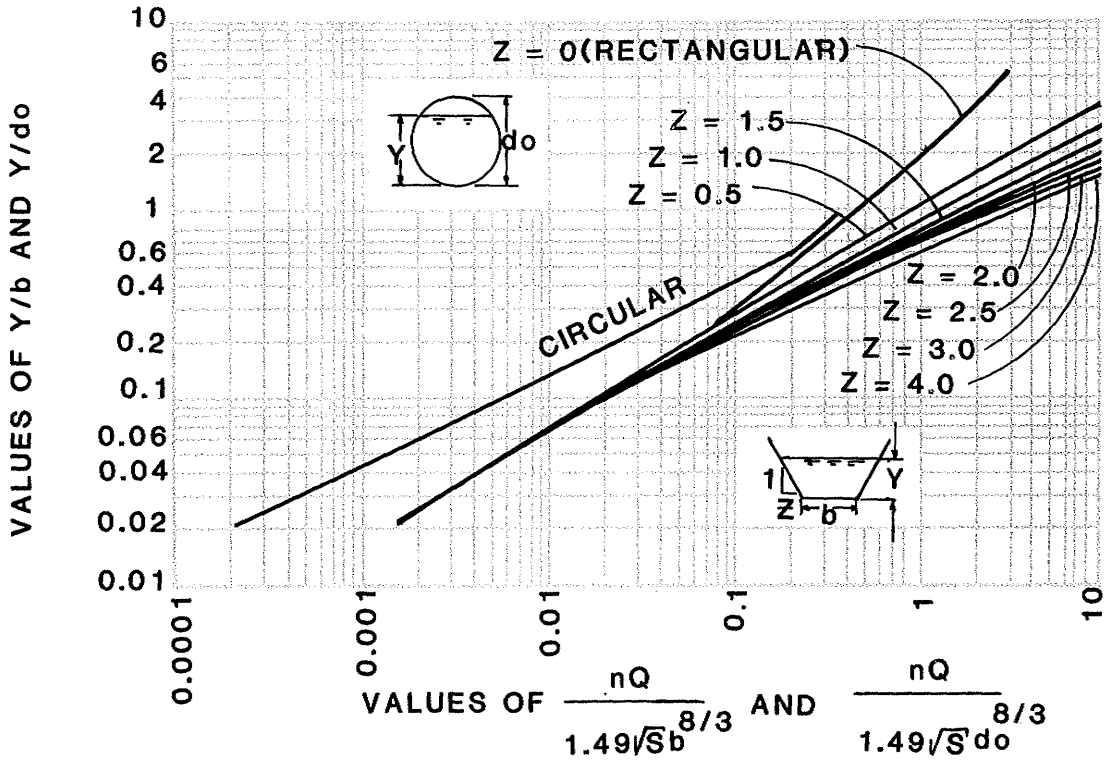
$$I = (I_1 + I_2)/2$$

$$O = (O_1 + O_2)/2$$

where;

the subscript 1 indicates the beginning of a time step, and the subscript 2 indicates the end of the timestep. Substituting the time averaged approximations for basin inflow and outflow into the conservation formula gives

$$(S_2 + O_2 dT/2) = (S_1 - O_1 dT/2) + (I_1 + I_2)dT/2$$



PROVO CITY
STORM DRAINAGE MASTERPLAN

CURVES FOR DETERMINING NORMAL DEPTH

FIGURE NO. 4-16

TABLE 4-7

VALUES FOR ROUGHNESS COEFFICIENT "n"

Type of Channel and Description	Minimum	Normal	Maximum
A. Close Conduits Flowing Partly Full			
A-1 Metal - Corrugated Metal			
a. Subdrain	0.017	0.019	0.021
b. Storm drain	0.021	0.024	0.030
A-2 Nonmetal			
a. Concrete			
1. Culvert, straight and free of debris	0.010	0.011	0.013
2. Culvert with bends, connections, and some debris	0.011	0.013	0.014
3. Finished	0.011	0.012	0.014
4. Sewer with manholes, inlet, etc., straight	0.013	0.015	0.017
5. Unfinished, steel form	0.012	0.013	0.014
6. Unfinished, smooth wood form	0.012	0.014	0.016
7. Unfiinished, rough wood form	0.015	0.017	0.020
b. Clay			
1. Common drainage tile	0.011	0.013	0.017
2. Vitrified sewer	0.011	0.014	0.017
3. Vitrified sewer with manholes, etc.	0.013	0.015	0.017
4. Vitrified subdrain with open joint	0.014	0.016	0.018
c. Sanitary sewers coated with sewage slimes, with bends and connections	0.012	0.013	0.016
d. Paved invert, sewer, smooth bottom	0.016	0.019	0.020
B. Lined or Built-up Channels			
B-1 Cement			
a. Neat, surface	0.010	0.011	0.013
b. Mortar	0.011	0.013	0.015
B-2 Concrete			
a. Trowel finish	0.011	0.013	0.015
b. Float finish	0.013	0.015	0.016
c. Finished, with gravel on bottom	0.015	0.017	0.020
d. Unfinished	0.014	0.017	0.020
e. Gunite, good section	0.016	0.019	0.023
f. Gunite, wavy section	0.018	0.022	0.025
g. On good excavated rock	0.017	0.020	
h. On irregular excavated rock	0.022	0.027	

TABLE 4-7 (CONTINUED)

Type of Channel and Description	Minimum	Normal	Maximum
B-3 Concrete bottom float finished with sides of			
a. Dressed stone in mortar	0.015	0.017	0.020
b. Random stone in mortar	0.017	0.020	0.024
c. Cement rubble masonry, plastered	0.016	0.020	0.024
d. Cement rubble masonry	0.020	0.025	0.030
e. Dry rubble or riprap	0.020	0.030	0.035
B-4 Gravel bottom with sides of			
a. Formed concrete	0.017	0.020	0.025
b. Random stone in mortar	0.020	0.023	0.026
c. Dry rubble or riprap	0.023	0.033	0.036
B-5 Masonry			
a. Cemented rubble	0.017	0.025	0.030
b. Dry rubble	0.023	0.032	0.035
B-6 Vegetal lining	0.030	----	0.500
C. Excavated or Dredged			
C-1 Earth, straight and uniform			
a. Clean, recently completed	0.016	0.018	0.020
b. Clean, after weathering	0.018	0.022	0.025
c. Gravel, uniform section, clean	0.022	0.025	0.030
d. With short grass, few weeds	0.022	0.027	0.033
C-2 Earth, winding and sluggish			
a. No vegetation	0.023	0.025	0.030
b. Grass, some weeds	0.025	0.030	0.033
c. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
d. Earth bottom and rubble sides	0.028	0.030	0.035
e. Stony bottom and weedy banks	0.025	0.035	0.040
f. Cobble bottom and clean sides	0.030	0.040	0.050
C-3 Dragline-excavated or dredged			
a. No vegetation	0.025	0.028	0.033
b. Light brush on banks	0.035	0.050	0.060
C-4 Rock cuts			
a. Smooth and uniform	0.025	0.035	0.040
b. Jagged and irregular	0.035	0.040	0.050
C-5 Channels not maintained, weeds and brush uncut			
a. Dense weeds, high as flow depth	0.050	0.080	0.120
b. Clean bottom, brush on sides	0.040	0.050	0.080
c. Same, highest stage of flow	0.045	0.070	0.110
d. Dense brush, high stage	0.080	0.100	0.140

TABLE 4-7 (CONTINUED)

Type of Channel and Description	Minimum	Normal	Maximum
D. Natural Streams			
D-1 Streams			
a. Streams on valley floor			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
D-2 Flood plains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160

TABLE 4-7 (CONTINUED)

Type of Channel and Description	Minimum	Normal	Maximum
D-2 Flood plains (Continued)			
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160

The right hand side of the above equation is known from previously computed values of storage S_1, outflow O_1, and average basin inflow of the timestep $(I_1 + I_2)/2$ during the timestep dT.

The solution to the above equation requires the following information:

- Initial conditions of basin storage and outflow
- A time interval, dT, typically the same as the hydrograph
- An inflow hydrograph (or unit runoff increments of duration dT)
- A functional relationship between basin storage, outflow, and basin depth

To aid in the calculation procedure, a storage indication curve may be developed from the storage-discharge relationships by selecting various values of outflow and computing (S + OdT/2). The solution procedure then consists of the following steps:

- Determine the average inflow volume from the inflow hydrograph and the selected unit period of dT by calculating the quantity $(I_1 + I_2)dT/2$.
- Determine $(S_1 - O_1dT/2)$ from the initial condition of the basin, or from the last computed values of S and O.
- Use Puls equation to compute $(S_2 + O_2dT/2)$.
- Using the quantity determined in step 3, compute O_2 from the storage indication curve. The value O_2 is used to estimate the outflow volume during the timestep dT.
- Use O_2 to estimate S_2 from the basin storage versus outflow relationship.

These five steps are repeated for successive time steps using I_2, O_2, and S_2 as the new values of I_1, O_1, and S_1, respectively. The process is repeated until all the inflow values are used and the basin outflow becomes negligible. The above procedure is illustrated in an example at the end of this chapter.

EXAMPLE PROBLEMS

This section includes examples of all of the above discussed computational methods. Following the examples are blank copies of the forms used in the calculations.

PROVO CITY

Sub-basin: TEST01 **Date:** 4-85

Project: Example

Computed By: KGS **Checked By:** KGS **Sheet:** E1

RATIONAL METHOD

Area, A (acres): 36.9 Land Use Type: Grass Pasture

Average Slope (%): 1.4 Design Frequency (yrs): 10

Maximum Flow Length (feet): 2300

Velocity = 0.83 fps (use Figure 4-7)

Time of Concentration, T_C = Flow Length/Velocity = 46 minutes

Rainfall Intensity, i = 1.13 inches/hour
(Lookup i using T_C and Design Frequency in Figures 4-3,4-4)

Coefficient, C = 0.15 (using Table 4-4)

Q = C i A

Q = 0.15 x 1.13 x 36.9

Q = 6.25 **cfs**

PROVO CITY

Sub-basin: TEST01 **Date:** 4-85

Project: Example

Computed By: KGS **Checked By:** KGS **Sheet:** E2

SCS TR-55 METHOD

Area, A (acres): 36.9 Land Use Type: Grass Pasture

Average Slope, Y (%): 1.4 Design Frequency (yrs): 10

Maximum Flow Length, L (feet): 2300

Hydrologic Soil Group: C

Curve Number, CN = 75 (using Table 4-5)

$S = \frac{1000}{CN} - 10 =$ 3.33 $T_c = \frac{L^{0.8}(S+1)^{0.7}}{1140\,Y^{0.5}} =$ 1.012 hours

q = 322 (using Figure 4-12)

P = 1.97 (24-hour precipitation using Figure 4-1,4-2)

$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} =$ 0.366

$q_p = \frac{q\,A\,Q}{640}$

$q_p =$ 322 x 36.9 x 0.366 / 640 = 6.79 cfs

PROVO CITY

Sub-basin: TEST01 **Date:** 4-85

Project: Example

Computed By: KGS **Checked By:** KGS **Sheet:** E3

DENVER UNIT HYDROGRAPH

Area, A (acres): 36.9 Land Use Type: Grass Pasture

Percent Impervious, I_a (%): 10

Maximum Flow Length, L (feet): 2300

Lenght of Channel, L_{ca} (feet): 1000 Design Freq. (yrs.): 10

$$C_t = \frac{7.81}{(Ia)^{0.78}} = 1.296 \qquad C_p = 0.89(C_t)^{0.46} = 1.003$$

$$T_p = C_t\left(\frac{L \times L_{ca}}{5280^2}\right)^{0.3} = 0.613 \text{ hours}$$

$$q_p = \frac{C_p}{T_p} = 1.636 \qquad Q_p = q_p A = 60.4 \text{ cfs}$$

$$W_{50} = \frac{500\ A}{Q_p} = 0.478 \text{ hours} \equiv 28.6 \text{ minutes}$$

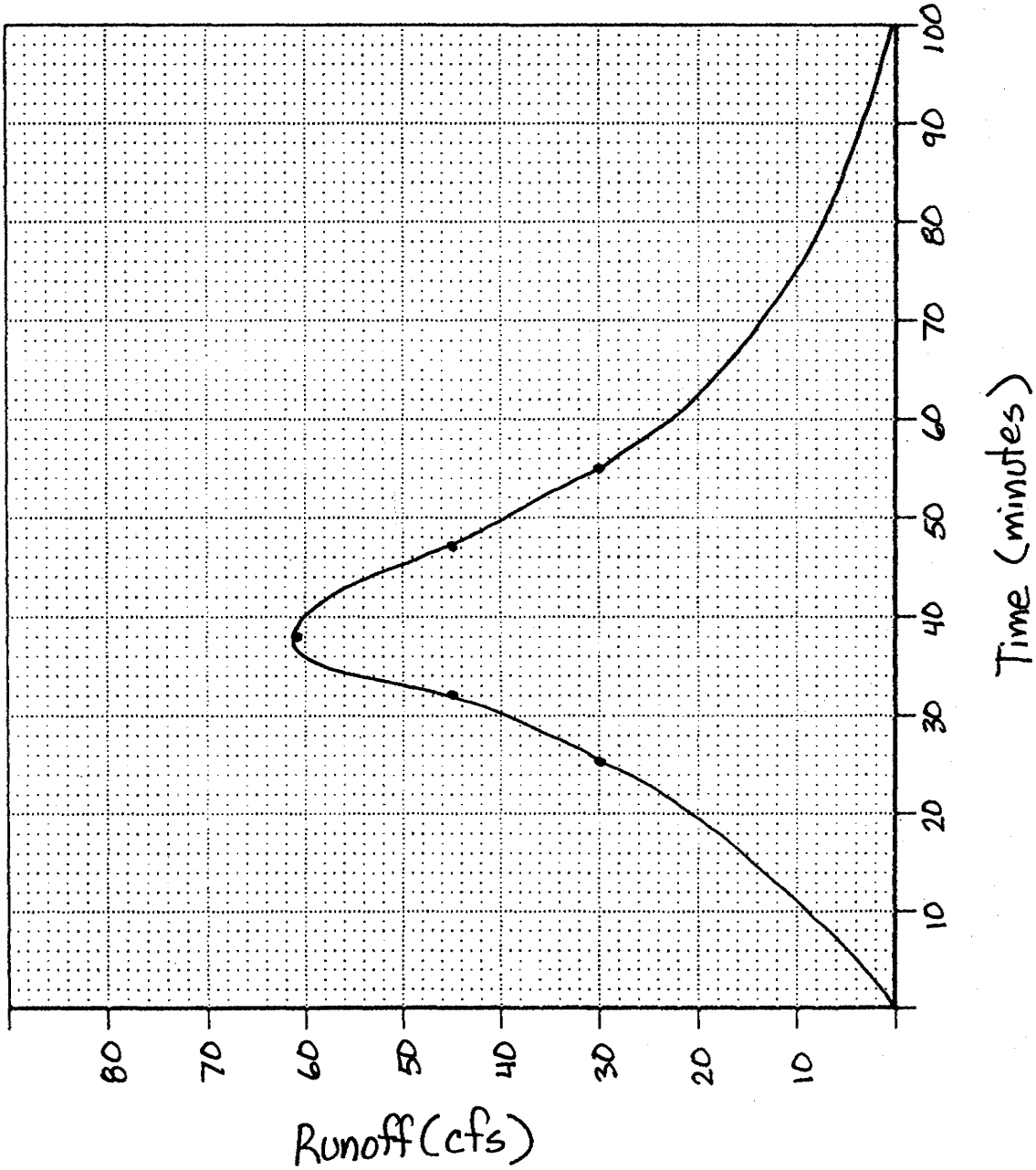
$$W_{75} = \frac{260\ A}{Q_p} = 0.248 \text{ hours} \equiv 14.9 \text{ minutes}$$

PROVO CITY

Sub-basin: TEST01 Date: 4-85

Project: Example

Computed By: KGS Checked By: KGS Sheet: E4



PROVO CITY

Sub-basin: TEST 01 **Date:** 4-85

Project: Example

Computed By: KGS **Checked By:** KGS **Sheet:** E5

SCS UNIT HYDROGRAPH

Area, A (acres): 36.9 Land Use Type: Grass Pasture

Average Slope, Y (%): 1.4 Design Frequency (yrs): 10

Maximum Flow Length, L (feet): 2300

Curve Number, CN = 75 (using Table 4-5)

$S = \frac{1000}{CN} - 10 = 3.333$ $T_L = \frac{L^{0.8}(S+1)^{0.7}}{1900\,Y^{0.5}} = 0.607$ hrs.

$Tc = \frac{T_L}{0.6} = 1.012$ hours $D = 0.133\,T_c = 0.135$ hrs.

$Tp = \frac{D}{2} + T_L = 0.674$ hours

$qp = \frac{484\,A}{640\,T_p} = \frac{484 \times 36.9}{640 \times 0.674}$

$= 41.4$ cfs

PROVO CITY

Sub-basin: TEST01 **Date:** 4-85

Project: Example

Computed By: KGS **Checked By:** KGS **Sheet:** E6

SCS UNIT HYDROGRAPH

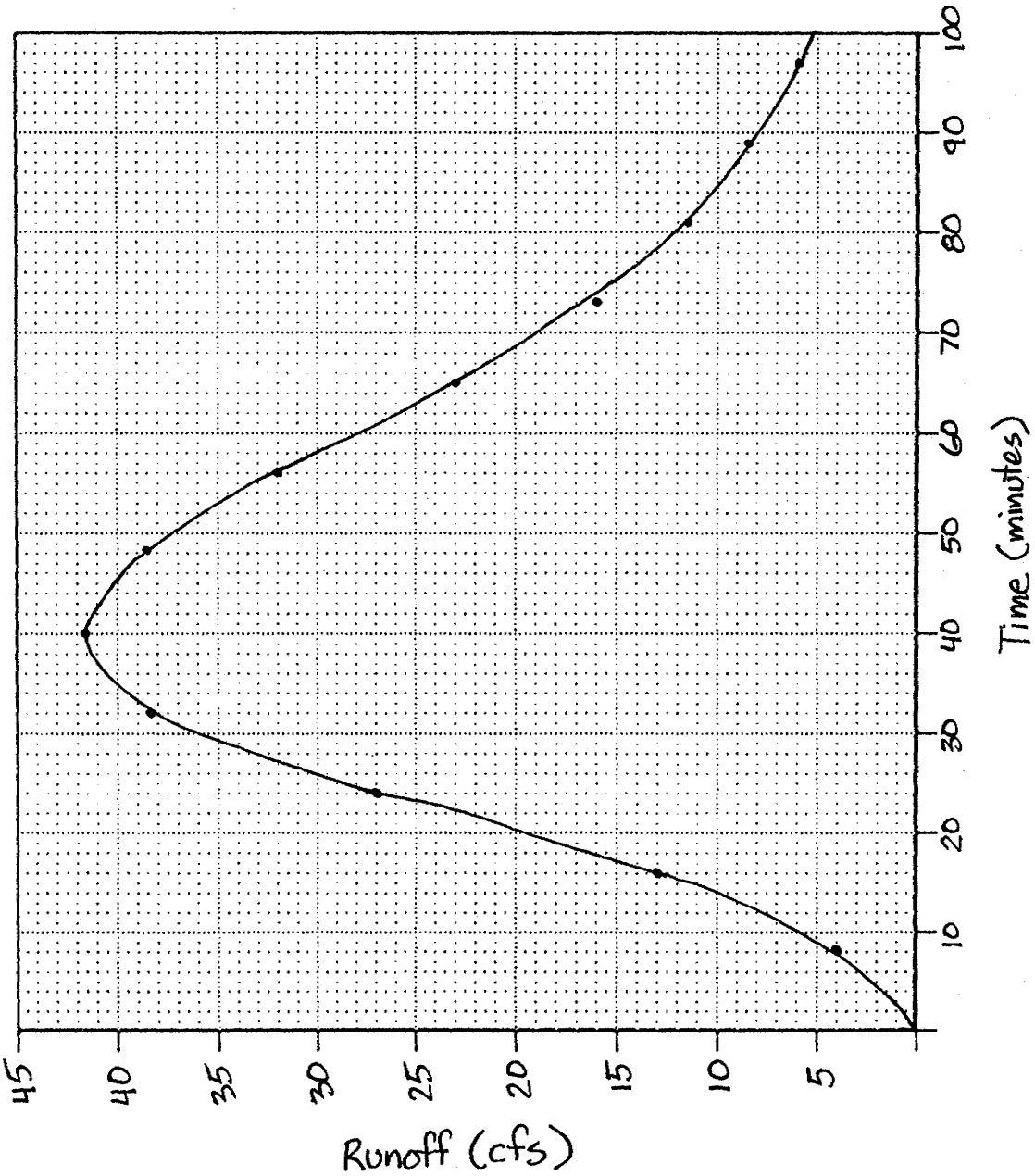
Time Ratio (t/t_p)	Time (hours)	Peak Ratio (q/q_p)	Discharge (cfs)
0.0	0	0.000	0
0.2	0.135	0.100	4.14
0.4	0.270	0.310	12.8
0.6	0.404	0.660	27.3
0.8	0.539	0.930	38.5
1.0	0.674	1.000	41.4
1.2	0.809	0.930	38.5
1.4	0.944	0.780	32.3
1.6	1.078	0.560	23.2
1.8	1.213	0.390	16.1
2.0	1.348	0.280	11.6
2.2	1.483	0.207	8.57
2.4	1.618	0.147	6.09
2.6	1.752	0.107	4.43
2.8	1.887	0.077	3.19
3.0	2.020	0.055	2.28
3.2	2.157	0.040	1.66
3.4	2.292	0.029	1.20
3.6	2.426	0.021	0.87
3.8	2.561	0.015	0.62
4.0	2.696	0.011	0.46
4.5	3.033	0.005	0.21
5.0	3.370	0.000	0

PROVO CITY

Sub-basin: TEST01 Date: 4-85

Project: Example

Computed By: KGS Checked By: KGS Sheet: E7



PROVO CITY

Sub-basin: TEST01 **Date:** 4-85

Project: Example

Computed By: KGS **Checked By:** KGS **Sheet:** E9

PIPE DIAMETER (PARTIAL FLOW)

Flow Rate, Q (cfs): 22.6 Pipe Diameter: 27 inches

Slope, S (ft/ft): 0.01

Manning's "n": 0.013

$$d_0 = \frac{\text{Pipe Diameter}}{12} = 2.25 \qquad \frac{n\,Q}{1.486\,(S)^{0.5}\,d_0^{8/3}} = 0.227$$

y/d_0 = 0.64 (using Figure 4-16)

$y = y/d_0 * d_0$ = 1.44 **feet**

PROVO CITY

Sub-basin: TEST01 **Date:** 4-85

Project: Example

Computed By: KGS **Checked By:** KGS **Sheet:** E10

CHANNEL NORMAL DEPTH

Flow Rate, Q (cfs): 100 Bottom Width, b (ft): 5

Slope, S (ft/ft): 0.01 Side Slopes, z (ft/ft): 1

Manning's "n": 0.015

$$\frac{n\,Q}{1.486\,(S)^{0.5}\,b^{8/3}} = 0.12$$

y/b = 0.28 (using Figure 4-16)

y = y/b * b = 1.4 **feet**

PROVO CITY

Sub-basin: TEST 01 **Date:** 4-85

Project: Example

Computed By: KGS **Checked By:** KGS **Sheet:** E11

RESERVOIR ROUTING

Time Interval, Δt (seconds): 3600

Initial Outflow (cfs): 0

Initial Storage (cubic feet): 0

Depth (feet)	Outflow, O (cfs)	Storage, S (cubic feet)	$\frac{2S_n}{\Delta t} + O_n$ (cfs)
0	0.0	0.0	0.0
1.0	4.2	627,000	352.5
2.0	12.0	1,255,000	709.2
3.0	51.7	1,882,000	1097
4.0	114.7	2,509,000	1509
5.0	186.8	3,136,000	1929
6.0	263.2	3,764,000	2354

Sub-basin: TEST01 PROVO CITY Date: 4-85

Project: Example

Computed By: KGS Checked By: KGS Sheet: E12

RESERVOIR ROUTING

n	I_n (cfs)	$I_n + I_{n+1}$ (cfs)	$\frac{2S_n}{\Delta t} - O_n$ (cfs)	$\frac{2S_{n+1}}{\Delta t} + O_{n+1}$ (cfs)	Outflow, O (cfs)
0	0	60	0		0
1	60	180	58.6	60	0.7
2	120	400	233.0	238.6	2.8
3	280	530	612.4	633.0	10.3
4	250	470	1025	1142	58.6
5	220	340	1270	1495	112.7
6	120	220	1345	1610	132.7
7	100	160	1316	1565	124.5
8	60	60	1256	1476	109.8
9	0	0	1145	1316	85.4
		0	1026	1145	59.2
		0			

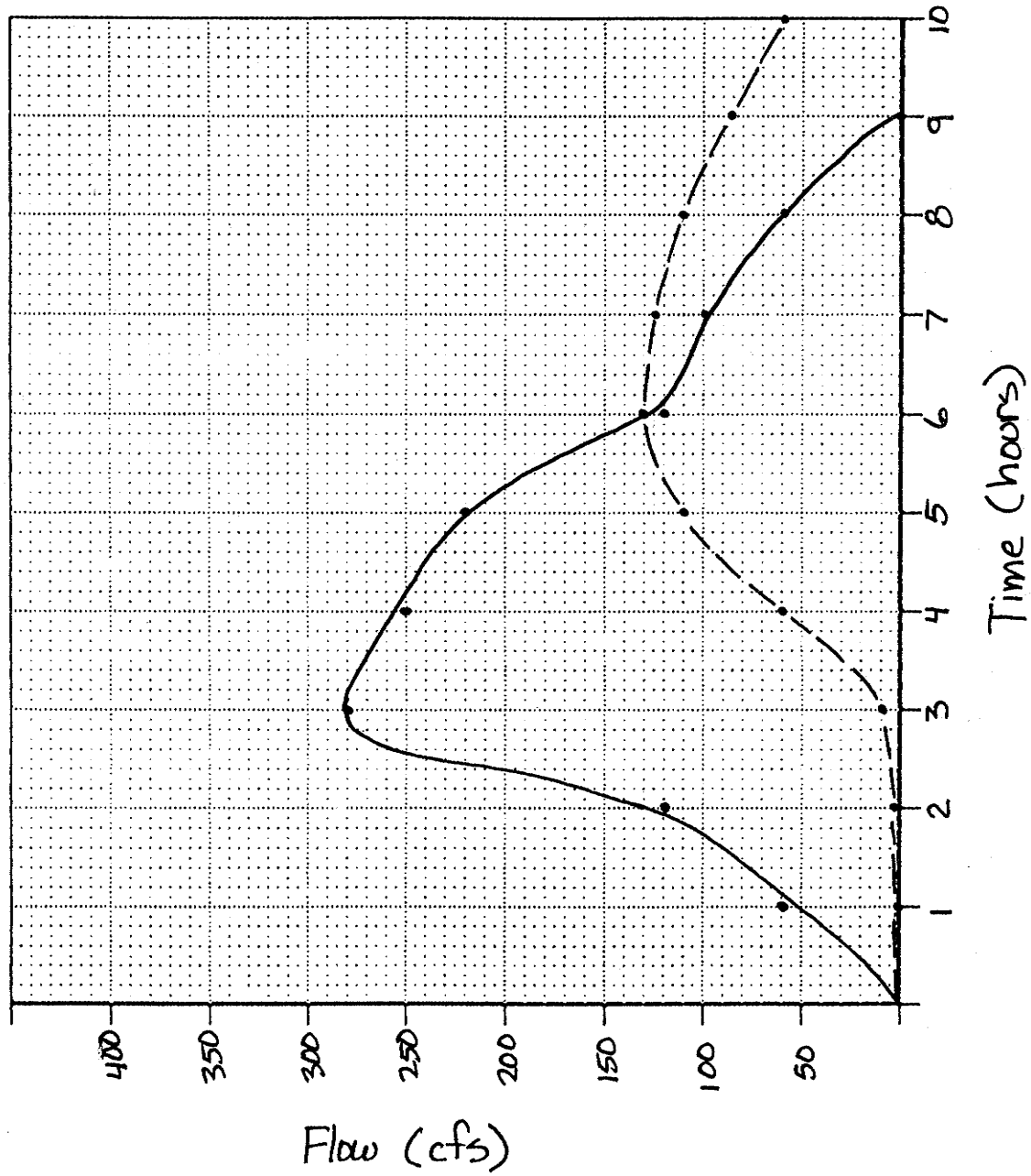
+ = TABLE

PROVO CITY

Sub-basin: TEST01 Date: 4-85

Project: Example

Computed By: KGS Checked By: KGS Sheet: E13



PROVO CITY

Sub-basin: _____ **Date:** _____

Project: _____

Computed By: _____ **Checked By:** _____ **Sheet:** _____

RATIONAL METHOD

Area, A (acres): _____ Land Use Type: _____

Average Slope (%): _____ Design Frequency (yrs): _____

Maximum Flow Length (feet): _____

Velocity = _____ fps (use Figure 4-7)

Time of Concentration, T_C = Flow Length/Velocity = _____ minutes

Rainfall Intensity, i = _____ inches/hour
(Lookup i using T_C and Design Frequency in Figures 4-3,4-4)

Coefficient, C = _____ (using Table 4-4)

Q = C i A

Q = _____ x _____ x _____

Q =_____ cfs

PROVO CITY

Sub-basin: _____ **Date:** _____

Project: _____

Computed By: _____ **Checked By:** _____ **Sheet:** _____

SCS TR-55 METHOD

Area, A (acres): _____ Land Use Type: _____

Average Slope, Y (%): _____ Design Frequency (yrs): _____

Maximum Flow Length, L (feet): _____

Hydrologic Soil Group: _____

Curve Number, CN = _____ (using Table 4-5)

$$S = \frac{1000}{CN} - 10 = _____ \qquad T_c = \frac{L^{0.8}(S+1)^{0.7}}{1140\,Y^{0.5}} = _____ \text{hours}$$

q = _____ (using Figure 4-12)

P = _____ (24-hour precipitation using Figure 4-1,4-2)

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} = _____$$

$$q_p = \frac{q\,A\,Q}{640}$$

q_p = _____ x _____ x _____ / 640 = _____ **cfs**

PROVO CITY

Sub-basin: _____ **Date:** _____

Project: _____

Computed By: _____ **Checked By:** _____ **Sheet:** _____

DENVER UNIT HYDROGRAPH

Area, A (acres): _____ Land Use Type: _____

Percent Impervious, I_a (%): _____

Maximum Flow Length, L (feet): _____

Lenght of Channel, L_{ca} (feet): _____ Design Freq. (yrs.): _____

$$C_t = \frac{7.81}{(Ia)^{0.78}} = _____ \qquad C_p = 0.89(C_t)^{0.46} = _____$$

$$T_p = C_t \left(\frac{L \times L_{ca}}{5280^2} \right)^{0.3} = _____ \text{ hours}$$

$$q_p = \frac{C_p}{T_p} = _____ \qquad Q_p = q_p A = _____ \textbf{ cfs}$$

$$W_{50} = \frac{500\ A}{Q_p} = _____ \textbf{ hours} \equiv _____ \textbf{ minutes}$$

$$W_{75} = \frac{260\ A}{Q_p} = _____ \textbf{ hours} \equiv _____ \textbf{ minutes}$$

PROVO CITY

Sub-basin: _____ **Date:** _____

Project: _____

Computed By: _____ **Checked By:** _____ **Sheet:** _____

SCS UNIT HYDROGRAPH

Area, A (acres): _____ Land Use Type: _____

Average Slope, Y (%): _____ Design Frequency (yrs): _____

Maximum Flow Length, L (feet): _____

Curve Number, CN = _____ (using Table 4-5)

$S = \frac{1000}{CN} - 10 =$ _____ $T_L = \frac{L^{0.8}(S+1)^{0.7}}{1900\,Y^{0.5}} =$ _____ hrs.

$Tc = \frac{T_L}{0.6} =$ _____ hours $D = 0.133\,T_c =$ _____ hrs.

$Tp = \frac{D}{2} + T_L =$ _____ hours

$qp = \frac{484\,A}{640\,T_p} = \frac{484 \times ____}{640 \times ____}$

= _____ **cfs**

PROVO CITY

Sub-basin: _____ **Date:** _____

Project: _____

Computed By: _____ **Checked By:** _____ **Sheet:** _____

SCS UNIT HYDROGRAPH

Time Ratio (t/t_p)	Time (hours)	Peak Ratio (q/q_p)	Discharge (cfs)
0.0	.....	0.000	.....
0.2	.....	0.100	.....
0.4	.....	0.310	.....
0.6	.....	0.660	.....
0.8	.....	0.930	.....
1.0	.....	1.000	.....
1.2	.....	0.930	.....
1.4	.....	0.780	.....
1.6	.....	0.560	.....
1.8	.....	0.390	.....
2.0	.....	0.280	.....
2.2	.....	0.207	.....
2.4	.....	0.147	.....
2.6	.....	0.107	.....
2.8	.....	0.077	.....
3.0	.....	0.055	.....
3.2	.....	0.040	.....
3.4	.....	0.029	.....
3.6	.....	0.021	.....
3.8	.....	0.015	.....
4.0	.....	0.011	.....
4.5	.....	0.005	.....
5.0	.....	0.000	.....

PROVO CITY

Sub-basin: _____ **Date:** _____

Project: _____

Computed By: _____ **Checked By:** _____ **Sheet:** _____

PIPE DIAMETER (FULL FLOW)

Flow Rate, Q (cfs): _____

Slope, S (feet/feet): _____

Manning's "n": _____

$$\text{Diameter, } d_0 = \left(\frac{n\,Q}{0.147\,\pi\,S^{0.5}} \right)^{0.375}$$

= _____ **feet**

= _____ **inches**

PROVO CITY

Sub-basin: _____ **Date:** _____

Project: _____

Computed By: _____ **Checked By:** _____ **Sheet:** _____

PIPE DIAMETER (PARTIAL FLOW)

Flow Rate, Q (cfs): _____ Pipe Diameter: _____ inches

Slope, S (ft/ft): _____

Manning's "n": _____

$$d_0 = \frac{\text{Pipe Diameter}}{12} = _____ \qquad \frac{n\,Q}{1.486\,(S)^{0.5}\,d_0^{8/3}} = _____$$

y/d_0 = _____ (using Figure 4-16)

$y = y/d_0 * d_0$ = _____ **feet**

PROVO CITY

Sub-basin: _____ **Date:** _____

Project: _____

Computed By: _____ **Checked By:** _____ **Sheet:** _____

CHANNEL NORMAL DEPTH

Flow Rate, Q (cfs): _____ Bottom Width, b (ft): _____

Slope, S (ft/ft): _____ Side Slopes, z (ft/ft): _____

Manning's "n": _____

$$\frac{n\,Q}{1.486\,(S)^{0.5}\,b^{8/3}} = _____$$

y/b = _____ (using Figure 4-16)

y = y/b * b = _____ **feet**

PROVO CITY

Sub-basin: _____ **Date:** _____

Project: _____

Computed By: _____ **Checked By:** _____ **Sheet:** _____

RESERVOIR ROUTING

Time Interval, Δt (seconds): _____

Initial Outflow (cfs): _____

Initial Storage (cubic feet): _____

$\frac{2S_n}{\Delta t} + O_n$ (cfs)																
Storage, S (cubic feet)																
Outflow, O (cfs)																
Depth (feet)																

PROVO CITY

Sub-basin: _____ Date: _____

Project: _____

Computed By: _____ Checked By: _____ Sheet: _____

RESERVOIR ROUTING

n	I_n (cfs)	$I_n + I_{n+1}$ (cfs)	$\frac{2S_n}{\Delta t} - O_n$ (cfs)	$\frac{2S_{n+1}}{\Delta t} + O_{n+1}$ (cfs)	Outflow, O (cfs)

PROVO CITY

Sub-basin: _____ Date: _____

Project: _____

Computed By: _____ Checked By: _____ Sheet: _____