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Road Design Manual

Volume 2: Hydrology and Drainage Design

Part 1: Hydrological Surveys

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Foreword

This manual was developed by the Ministry pursuant to The Fourth Schedule of the Constitution which assigns to the National Government the functions and powers of setting standards for the construction and maintenance of all public roads including those under the County Governments.

It is part of a series of manuals that replace the first generation of road manuals developed in the first and second decades after independence. This second generation of the road manuals were developed to cover the entire road project cycle covering planning, appraisal, design, contracts, construction, maintenance, operations and monitoring. The series incorporates best practices, climate change considerations, and recent technologies to enable the provision of road infrastructure that is safe, secure, and efficient.

Under the Kenya Vision 2030 long term plan, infrastructure expansion and modernisation are some of the foundations for the realisation of economic, social and political transformation of Kenya into a rapidly industrialising middle-income country. The plan envisages an integrated, safe and efficient transport and communication infrastructure network consisting of roads, railways, ports, airports, waterways, and telecommunications infrastructure.

The strategies to be pursued under the Vision 2030 plan to improve infrastructure services and to maximise the economic and social impacts of infrastructure development and management include: Strengthening of the institutional framework for infrastructure development and maintenance; Raising efficiency and quality of infrastructure projects; Enhancing local content of identified infrastructure projects to minimise import content; Benchmarking infrastructure facilities and services provision with globally acceptable performance standards; and, Implementing infrastructure projects that will stimulate demand in hitherto marginalised areas.

The first three 5-year Medium Term Plans (MTP) under the Vision 2030 from 2008 to 2022 targeted construction of 1,950 km, 5,500 km and 10,000 km of new paved roads under MTP I, II and III, respectively, totalling 17,450 km. This was a massive infrastructure development program intended to double the paved road network in 10 years compared to 8,600 km developed from independence in 1963 to 2008.

Implementation of MTP I to III resulted in the construction of 14,000 km of paved roads, which extended the paved road coverage to Arid and Semi-Arid regions, that had been previously neglected. However, some key milestones of the Vision 2030 goals have not been realised. This has been due to internal and external challenges. External challenges included: climate change – prolonged droughts; the emergence of COVID-19 pandemic; global supply chain disruptions; exchange rate volatility; and rising interest rates in the leading economies.

The internal challenges included: inadequate road maintenance equipment; pavement overloading by heavy goods vehicles; huge maintenance backlog of the road network; low contracting and supervision capacity particularly in the Counties; poor quality control and assurance of works; congestion in urban areas; encroachment on road reserves; high costs and delays in payments of land acquisition; lack of harmonisation of cross-border transport regulation and operational procedures; rapid urbanisation; increased traffic volume with exponential growth of motorcycle traffic; high cost/delays in relocation of utilities and services along and across road reserves; inadequate funding of projects and programs; and, delay or default in payments for goods, services and works.

The implementation of MTP III came to an end on 30th June 2023, ushering in the implementation of the Fourth Medium Term Plan (MTP IV), which has been aligned to the aspirations of the Kenya Vision 2030 and the Kenya Kwanza Government's Bottom-Up Economic Transformation Agenda (BETA) planning approach and its key priorities.

BETA is the Government's transformation agenda geared towards economic turnaround through a value chain approach. BETA has targeted sectors with the highest impact to drive economic recovery and growth. This will be achieved through bringing down the cost of living; eradicating hunger; creating jobs; expanding the tax base; improving foreign exchange balances; and inclusive growth. BETA ensures rational resource allocation by eliminating wastage of resources occasioned by duplication, overlaps, fragmentation and ineffective coordination in the implementation of programmes and projects.

The Fourth Medium Term Plan key priorities are clustered under five key sectors, namely: Finance and Production; Infrastructure; Social; Environment and Natural Resources; and Governance and Public Administration. The infrastructure sector seeks to: enhance transport connectivity by constructing 6,000 km of new roads, maintaining rural and urban roads, rail, air and seaport facilities and services; expand communication and broadcasting systems; and promote the development of energy generation and distribution by increasing investments in green energy (geothermal, wind, solar and hydro). The infrastructure gap is expected to be bridged by promoting economic participation of the private sector through public private partnerships in the financing, construction, development, operation, and maintenance of infrastructure.

The plan entails a shift of focus to fundamentals in project planning and implementation which include: respect for technical input, regulations and standard practices; adherence to project life cycle i.e., planning, feasibility studies and design before procurement of works; public and stakeholder consultation; procurement within budgetary ceilings; shifting focus during project implementation from the finished product ‘black top’ to the construction of the foundation; building local capacity particularly MSMEs by ensuring prompt payments; and capacity building at all levels to enable internalisation of policies and processes.

The first generation of the road manuals were used for 35 to 45 years. It is my sincere hope that the second generation of the road standards which have been developed in alignment with the Government’s strategy will provide guidance in solving most of the above challenges and those expected to emerge in the next 50 years. Implementation of the manuals will enable achievement of the Government aspirations which include inclusive growth; creation of sustainable employment; building of MSMEs; climate change adaptation and realisation of the UN SDGs; enhanced efficiency in management of infrastructure and transport system; and, laying the foundation for the next national long-term plan at the end of the Vision 2030.

On behalf of the Government of Kenya, I would wish to thank the European Union for financing the development of the first drafts of the manuals in 2009 and the African Development Bank for the financial support in the review and updating of the manuals. I would also like to thank the members of the National Steering Committee and the Technical Task Force for their input. The Technical Administrators, and the Kenya National Highways Authority (KeNHA) for the procurement and able administration of the consultancy Contract. I also thank the Consultant, TRL Limited for their role in providing technical expertise that was essential for the success of the manuals updating exercise. I also wish to express my deepest appreciation to our stakeholders and all those who have contributed to this process and the staff of the Ministry for their continued input.

Hon. Davis K. Chirchir, E.G.H
Cabinet Secretary, Ministry of Roads and Transport

Preface

The current existing Kenya bridge design manual was produced in 1991 the Country has used it since then. The manual is inclusive of flood calculation and waterway computations. The details are brief, partially clear and in use to date. Most of the details in the manual were solely used and handled by the bridge section. Over time some sections are found to be brief and hence requiring more details including update. The road flood computation tended to utilise only one key single method which is limited. In order to complement the bridge design manual, other related information requires update for use.

This current manual has incorporated the vast local and regional experience in the hydrology practice. Various data sources, that are mainly government sources have been indicated. Thresholds for the use data have been set up. Specific return period for various road structures have been proposed. Emerging issues that relate like rapid changes in land use, climate changes of road infrastructure have been considered. The manual also proposes several methods on climate change adaptation measures.

The updated manual now covers various review process that are required in hydrology and design of structures with details and content necessary to support the modern and changing trends in the field of hydrology. Understanding the various methods of modelling makes easier for the practitioners in the field to easily customise data requirements, field surveys and the anticipated challenges in the design.

Eng. Joseph M. Mbugua, CBS
Principal Secretary, State Department for Roads

Document Management

Document Status

This document has the status of a Manual. Users shall apply the contents there-in to fully satisfy the requirements set out. The content of the manual is based on current practice in Kenya and latest practices in the road sector, both regionally and internationally.

Sources of the Document

Copies of the document can be obtained from:
The Principal Secretary, State Department for Roads, Ministry of Roads and Transport, Works Building, Ngong Road, P.O. Box 30260 - 00100, NAIROBI Email: ps@road.go.ke

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Notification of Errors and Requests for Amendments

While all care and consideration has been applied in the compilation of this document, the Ministry accepts no responsibility for failure in any way related to the application of this manual or any reference documents cited in it.

Requests for edits and corrections can be freely sent to the following address:
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Amendments Request Form

Request No.	Name	Organisation	Chapter	Page	Section/ Clause	Ref. to: Figure/ Table/	Type of Request	Request

Type of request: General – G; Editorial – E; Technical - T

Amendments to Date

Amendment No.	Description	Amendment Effective Date	Amended Approved by

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A National Steering Committee was set up and chaired by the Permanent Secretary, Ministry of Roads and Transport, with the following membership: Principal Secretary for Devolution, Office of the Deputy President; Chief Executive Officer, Inter-Governmental Relations Technical Committee; Chief Executive Officer, Council of Governors; Managing Director and Council Secretary, Kenya Bureau of Standards; Director, National Transport and Safety Authority; Director General, Kenya Roads Board; Director General, Kenya Wildlife Services; Chief Executive Officer, Engineers Board of Kenya; Director General, Kenya Rural Roads Authority; Director General, Kenya Urban Roads Authority; President, Institution of Engineers Kenya; Director Policy, Strategy and Compliance; Kenya National Highways Authority; Chief Engineer, Roads Division, State Department for Roads; Chief Engineer, Materials Testing and Research Division, State Department for Roads.

The technical work was undertaken under the guidance of a Technical Task Force, chaired by Eng. David Maganda, with the following gazetted members: Francis Gichaga (Prof.) (Eng.), Andrew Gitonga (Eng.), Timothy Nyomboi (Dr.) (Eng.), Rosemary Kungu (Eng.), Charles Obuon (Eng.), Sylvester Abuodha (Prof.) (Eng.), Samuel Kathindai (Eng.), Nicholas Musuni (Eng.), Charles Muriuki (Eng.), Tom Opiyo (Eng.), John Maina (Eng.), Fidelis Sakwa (Eng.), Daniel Cherono (Eng.), Maurice Ndeda (Eng.), Theo Uwamba (Eng.).

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Abbreviations

A	Catchment area
A	Area of cross section of flow
AASHTO	American Association of State Highway Transport Officials
AMC	Antecedent moisture conditions
BDF	Basin development factor
C	Runoff coefficient
Cf	Frequency factor
CN	SCS-runoff curve number
Ct, Cp	Physiographic coefficients
d	Time interval
D	Culvert diameter or barrel height
d	Depth of flow
DEM	Digital Elevation Model
DFL	Design flood level
DH	Difference in elevation
FEMs	Flow Estimation Methods
g	Acceleration due to gravity
HEC-RAS	Hydrological Engineering Centre – River Analysis System
HFL	High flood level
HSG	Hydrologic Soils Groups
IA	Percentage of impervious area
IDF	Intensity duration frequency
Ia	Initial abstraction from total rainfall
K	Frequency factor for a particular return period and skew
L	Lag
l	Length of mainstream to furthest divide
L	Length of culvert
Lca	Length along main channel to a point opposite the Catchment area centroid
LWL	Low water level
M	Rank of a flood within a long record
n	Manning roughness coefficient
N	Number of years of flood record
n	Manning's roughness coefficient
P	Accumulated rainfall
P	Wetted perimeter
Q	Rate of runoff
q	Storm runoff during a time interval
Q	Discharge (flow rate)
R	Hydraulic radius
R	Hydraulic radius (A/P)
RC	Regression constant
RQ	Equivalent rural peak runoff rate
S	Potential maximum retention storage
S	Slope of culvert
S or Y	Ground slope
SCS	Soil Conservation Service
SL	Main channel slope
SL	Standard deviation of logarithms of peak annual floods
SRTM	Shuttle Radar Topography Mission
ST	Basin storage factor
TB	Time base of unit hydrograph
tc or Tc	Time of concentration
TL	Lag time
Tr	Snyder's duration of excess rainfall
UQ`	Urban peak runoff rate
V	Velocity
V	Mean velocity of flow with barrel full
Vd	Mean velocity in downstream channel
Vo	Mean velocity of flow at culvert outlet
Vu	Mean velocity in upstream channel
X	Logarithm of the annual peak
yc	Critical depth of flow
yH	Headwater depth (subscript indicates section)
yT	Tailwater depth above invert of culvert

Glossary of Terms

Absorption	The act or process of taking in water by inflow of atmospheric vapor, hydroscopic absorption, wetting, infiltration, influent seepage, and gravity flow of streams into sinkholes or other large openings.
Abstraction	That portion of rainfall, which does not become runoff. It includes interception, infiltration, and storage in depression. It is affected by land use, land treatment and condition, and antecedent soil moisture.
Abutment	The support at either end of a bridge, usually classified as spill-through or vertical.
Accretion	A process of accumulation by flowing water whether of silt, sand, or pebbles. May be due to any cause and includes alluviation, the gradual building up of a beach by wave action, the gradual building of the channel bottom, bank, or bar due to silting or wave action.
Aggradation	General and progressive building up of the longitudinal profile of a channel by deposit of sediment.
Allowable Headwater	The depth or elevation of impounded water at the entrance to a hydraulic structure after which flooding or some other unfavourable result could occur.
Alluvial Channel	A channel wholly in alluvium, no bedrock exposed in channel at low flow or likely to be exposed by erosion during major flow.
Alluvium	Unconsolidated clay, silt, sand, or gravel deposited by a stream in a channel, flood plain, fan, or delta.
Annual Flood	The highest peak discharge in a water year.
Annual Series	A frequency series in which only the largest value in each year is used, such as annual floods.
Antecedent Moisture Condition (AMC)	The degree of wetness of a watershed at the beginning of a storm.
Armor	Artificial surfacing of channel beds, banks, or embankment slopes to resist scour and lateral erosion.
Aquifer	A porous, water-bearing geologic formation. Generally restricted to materials capable of yielding an appreciable supply of water.
Artesian	Pertains to groundwater that is under pressure and will rise to a higher elevation if given an opportunity to do so.
B	Barrel width, distance measured in meters.
Backwater	The increase in water-surface profile, relative to the elevation occurring under natural channel and flood-plain conditions, induced upstream from a structure, bridge, or culvert that obstructs or constricts a channel. It also applies to the water surface profile in a channel or conduit.
Baffle	A structure built on the bed of a stream to deflect or disturb the flow. Also, a device used in a culvert to facilitate fish passage.
Bank	Lateral boundaries of a channel or stream, as indicated by a scarp, or on the inside of bends, by the stream ward edge of permanent vegetal growth.
Bar	An elongated deposit of alluvium, not permanently vegetated, within or along the side of a channel.

Glossary of Terms *(continued)*

Base Flood	The 100-year flood.
Base Flow	Stream discharge derived from groundwater sources. Sometimes considered to include flows from regulated lakes or reservoirs. Fluctuates much less than storm runoff.
Basin, Drainage	The area of land drained by a watercourse.
Basin Lag	That portion of rainfall, which does not become runoff. It includes interception, infiltration, and storage in depression. It is affected by land use, land treatment and condition, and antecedent soil moisture.
Bed (of a channel or stream)	The part of a channel not permanently vegetated or bounded by banks, over which water normally flows.
Bed Load	Sediment that is transported in a stream by rolling, sliding, or skipping along the bed or very close to it; considered to be within the bed layer.
Bed Material	Sediment consisting of particle sizes large enough to be found in appreciable quantities at the surface of a streambed.
Berm	A narrow shelf or ledge; also, a form of dike.
Braided Stream	A stream whose surface is divided at normal stage by small mid-channel bars or small islands. The individual width of bars and islands is less than three times the water width. A single large channel that has subordinate channels.
Breakers	The surface discontinuities of waves as they break-up. They may take different shapes (spilling, plunging, surging). Zone of break-up is called surf zone.
Bridge Waterway	The area of a bridge opening available for flow, as measured below a specified stage and normal to the principal direction of flow.
Broken-Back Culvert	A culvert comprising two or more longitudinal structure profiles. Such culverts are sometimes effective in reducing outflow velocities by the energy dissipation of a hydraulic jump.
Criterion	A standard, rule, or test on which a judgment is based.
Critical Depth	The depth at which water flows over a weir; this depth being attained automatically where no backwater forces are involved. It is the depth at which the energy content of flow is a minimum.
Cross-Section	The shape of a channel, stream, or valley viewed across its axis. In watershed investigations it is determined by a line approximately perpendicular to the main path of water flow, along which measurements of distance and elevation are taken to define the cross-sectional area.
Kerb-Opening Inlet	Drainage inlet consisting of an opening in the roadway curb.
Cumulative Conveyance	A tabulation or graphical plot of the accumulated measures of conveyance; proceeding from one stream bank to the other.
Cutoff Wall	A wall that extends from the end of a structure to below the expected scour depth or scour-resistant material.
D	Culvert diameter or barrel depth.
D50	Median size of riprap. The particle diameter at the 50th percentile point on a size weight distribution curve.
D15	The particle diameter at the 15th percentile point on a size/weight distribution curve.

Glossary of Terms *(continued)*

D85	The particle diameter at the 85th percentile point on a size weight distribution curve.
yc	Critical depth of flow in meters.
Debris	Material transported by the stream, either floating or submerged, such as logs or brush.
Degradation	General and progressive lowering of the longitudinal profile of a channel by erosion.
Deposition	The settling of material from the stream flow onto the bottom.
Depression Storage	Rainfall that is temporarily stored in depressions within a watershed.
Depth-Area Curve	A graph showing the change in average rainfall depth as size of area changes.
Design Discharge or Flow	The rate of flow for which a facility is designed and thus expected to accommodate without exceeding the adopted design constraints.
Design Flood Frequency	The recurrence interval that is expected to be accommodated without contravention of the adopted design constraints. The return interval (recurrence interval or reciprocal of probability) used as a basis for the sizing.
Design High	The maximum water level that a bridge opening is designed to accommodate without contravention of the adopted design constraints.
Design Flood	A flood that does not overtop the roadway.
Design Flow	See Design Discharge.
Design Storm	A given rainfall amount, areal distribution, and time distribution used to estimate runoff. The rainfall amount is either a given frequency (25-year, 50-year, etc.) or a specific large value.
Detention Basin	A basin or reservoir incorporated into the watershed whereby runoff is temporarily stored, thus attenuating the peak of the runoff hydrograph.
Detour	A temporary change in the roadway alignment. It may be localised at a structure or may be along an alternate route.
Dike	An impermeable linear structure for the control or confinement of overbank flow. River training structure used for bank protection.
Direct Runoff	The water that enters the stream channels during a storm or soon after forming a runoff hydrograph. May consist of rainfall on the stream surface, surface runoff, and seepage of infiltrated water (rapid subsurface flow).
Discharge	The rate of the volume of flow of a stream per unit of time, usually expressed in m^3/s.
	General and progressive lowering of the longitudinal profile of a channel by erosion.
Drainage Area	The area draining into a stream at a given point. The area may be of different sizes for surface runoff, subsurface flow, and base flow, but generally the surface flow area is used as the drainage area.
Drop Inlet	Drainage inlet with a horizontal or nearly horizontal opening.
Effective Duration	The time in a storm during which the water supply for direct runoff is produced. Also used to mean the duration of excess rainfall.

Glossary of Terms *(continued)*

Effective Particle Size	The diameter of particles, spherical in shape, equal in size and arranged in a given manner, of a hypothetical sample of granular material that would have the same transmission constant as the actual material under consideration.
End Section	A concrete or metal structure attached to the end of a culvert for purposes of retaining the embankment from spilling into the waterway, appearance, anchorage, etc.
Energy Dissipation	The phenomenon whereby energy is dissipated or used up.
Energy Grade Line	A line joining the elevation of energy heads; a line drawn above the hydraulic grade line a distance equivalent to the velocity head of the flowing water at each section along a stream, channel, or conduit.
Energy Gradient	Slope of the line joining the elevations of total energy along a conduit of flowing water
Equivalent Cross-Slope	An imaginary straight cross-slope having conveyance capacity equal to that of the given compound cross-slope.
Erosion	The wearing away or scouring of material in a channel, opening, or outlet works caused by flowing water.
Evapotranspiration	Plant transpiration plus evaporation from the soil. Difficult to determine separately, therefore used as a unit for study.
Filter	A material which allows water to pass into and through it while preventing soil particles from entering or passing through it.
Filtration	The process of passing water through a filtering medium consisting of either granular material of filter cloth for the removal of suspended or colloidal matter.
Flood	In common usage, an event that overflows the normal banks. In technical usage, it refers to a given discharge based, typically, on a statistical analysis of an annual series of events.
Flood Frequency	The average time interval, in years, in which a given storm or amount of water in a stream will be exceeded.
Groundwater	Subsurface water occupying the saturation zone, that feeds wells and springs, or a source of base flow in streams. In a strict sense, the term applies only to water below the water table. Also called phreatic water.
Guide Banks	Embankments built upstream from one or both abutments of a bridge to guide the approaching flow through the waterway opening.
Gutter	That portion of the roadway section adjacent to the curb that is used to convey storm runoff water.
Head	The height of water above any datum.
Head loss	A loss of energy in a hydraulic system.
Headwall	The structural appurtenance usually applied to the end of a culvert to control an adjacent highway embankment and protect the culvert end
Headwater, H_w	That depth of water impounded upstream of a culvert due to the influence of the culvert constriction, friction, and configuration.
H_f	The friction head loss, measured in meters.

Glossary of Terms *(continued)*

High Water Elevation	The water surface elevation that results from the passage of flow. It may be 'observed high water elevation' as a result of an event, or 'calculated high water elevation' as part of a design process.
Historical flood	A past flood event of known or estimated magnitude.
H_c	The height of the hydraulic grade line above the outlet invert, in meters.
Hydraulic Grade Line	A profile of the piezo metric level to which the water would rise in piezometer tubes along a pipe run. In open channel flow, it is the water surface.
Hydraulic Gradient	The slope of the hydraulic grade line.
Hydraulic Head	The height of the free surface of a body of water above a given point.
Hydraulic Jump	A hydraulic phenomenon, in open channel flow, where supercritical flow is converted to subcritical flow. This can result in an abrupt rise in the water surface.
Hydraulic Radius	A measure of the boundary resistance to flow, computed as the quotient of cross-sectional area of flow divided by the wetted perimeter. For wide shallow flow, the hydraulic radius can be approximated by the average depth.
Hydraulic Roughness	A composite of the physical characteristics that influence the flow of water across the earth's surface whether natural or channelised. It affects both the time response of a watershed and drainage channel, as well as the channel storage characteristics.
Hydraulics	The characteristics of fluid mechanics involved with the flow of water in or through drainage facilities.
Hydrograph	A graph showing, for a given point on a stream or for a given point in any drainage system, the discharge, stage, velocity, or other property of water with respect to time.
Hydrologic Soil Group	A group of soils having the same runoff potential under similar storm and cover conditions.
Hydrology	The study of the occurrence, circulation, distribution, and properties of the waters of the earth and its atmosphere.
Impermeable Strata	A stratum with a texture that water cannot move through perceptibly under pressure ordinarily found in subsurface water.
Impervious	Impermeable to the movement of water.
Improved Inlet	Flared, depressed, or tapered culvert inlets that decrease the amount of energy needed to pass the flow through the inlet and thus increase the capacity of culverts.
Infiltration	That part of rainfall that enters the soil. The passage of water through the soil surface into the ground. Used interchangeably herein with percolation.
Infiltration Rate	The rate at which water enters the soil under a given condition. The rate is usually expressed in centimetres per hour or day, or cubic meters per second.
Inflow	The rate of discharge arriving at a point (in a stream, structure, or reservoir).
Initial Abstraction (Ia)	When considering surface runoff, Ia is all the rainfall before runoff begins When considering direct runoff, Ia consists of interception, evaporation, and the soil-water storage that must be exhausted before direct runoff may begin. Sometimes called 'initial loss'.

Glossary of Terms *(continued)*

Inlet	A structure for capturing concentrated surface flow. May be located along the roadway, in a gutter, in the highway median, or in a field.
Inlet Efficiency	The ratio of flow intercepted by an inlet to the total flow.
Inlet Time	The time required for storm water to flow from the most distant point in a drainage area to the point at which it enters a storm drain.
Intensity	The rate of rainfall upon a watershed, usually expressed in centimetres per hour.
Interception	Precipitation retained on plant or plant residue surfaces and finally absorbed, evaporated, or sublimated. That which flows down the plant to the ground is called 'streamflow' and not counted as true interception.
Invert	The flow line in a channel cross-section, pipe, or culvert.
Jetty	An elongated obstruction projecting into a stream to control shoaling and scour by deflection of currents and waves. They may be permeable or impermeable.
Lag Time, TL	The differences in time between the centroid of the excess rainfall (that rainfall producing runoff) and the peak of the runoff hydrograph. Often estimated as 60 % of the time of concentration ($TL = 0.6Tc$).
Land Use	A land classification. Cover, such as row crops or pasture, indicates a kind of land use; roads may also be classified as a separate land use.
Levee	A linear embankment outside a channel for containment of flow.
Local Scour	Scour in a channel or on a flood plain that is localised at a pier, abutment, or other obstruction to flow. The scour is caused by the acceleration of the flow and the development of a vortex system induced by the obstruction to the flow.
Manning's 'n'	A coefficient of roughness, used in a formula for estimating the capacity of a channel to convey water. Generally, 'n' values are determined by inspection of the channel.
Mass Inflow Curve	A graph showing the total cumulative volume of storm water runoff plotted against time for a given drainage area.
Maximum Probable Flood	The maximum probable flood is the greatest flood that may reasonably be expected, taking into collective account the most adverse flood related conditions based on geographic location, meteorology, and terrain.
Mean Daily Discharge	The average of mean discharge of a stream for one day, usually given in m^3/s.
Meanders	The changes in direction and winding of flow that are sinuous in character.
Migration, Channel	Change in position of a channel by lateral erosion of one bank and simultaneous accretion of the opposite bank.
Natural Scour	Scour that occurs along a channel reach due to an unstable stream, no exterior causes.
Normal Stage	The water stage prevailing during the greater part of the years.
One- Dimensional Water Surface Profile	An estimated water surface profile that accommodates flow only in the upstream-downstream direction.

Glossary of Terms *(continued)*

Ordinary High Water	The line on the shore established by the fluctuations of water and indicated by physical characteristics such as clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas.
Outfall	The point location or structure where drainage discharges from a channel, conduit, or drain.
Overland Flow	Runoff that makes its way to the watershed outlet without concentrating in gullies and streams (often in the form of sheet flow).
Peak Discharge	Maximum discharge rate on a runoff hydrograph.
Percolation	The movement or flow of water through the interstices or the pores of a soil or other porous medium. Used interchangeably herein with infiltration.
Permeability	The property of a material that permits appreciable movement of water through it when it is saturated, and movement is actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.
Perennial Stream	A stream or reach of a stream that flows continuously for all or most of the year.
Pervious Soil	Soil containing voids through which water will move under hydrostatic pressure.
Precipitation	The process by which water in liquid or solid-state falls from the atmosphere.
Principal Spillway	Conveys all ordinary discharges coming into a reservoir and all of an extreme discharge that does not pass through the emergency spillway.
Rainfall Excess	The water available to runoff after interception, depression storage, and infiltration have been satisfied.
Rainfall Intensity	Amount of rainfall occurring in a unit of time, converted to its equivalent in centimetres per hour at the same rate.
Rating Curve	A graphical plot relating stage to discharge.
Reach	A length of stream or valley, selected for purpose of study.
Regional Analysis	A regional study of gauged watersheds that produce regression equations relating various watershed and climatological parameters to discharge. Use for design of ungauged watershed with similar characteristics.
Reservoir Routing	Flood routing of a hydrograph through a reservoir.
Retard	A structure designed to decrease velocity and induce silting or accretion. Retard type structures are permeable structures customarily constructed at and parallel to the toe of slope.
Revetment	A rigid or flexible armour placed on a bank or embankment as protection against scour and lateral erosion.
Riprap	Stones placed in a loose assemblage along the banks and bed of a channel to inhibit erosion and scour.
Roadway Cross- Slopes	Transverse slopes and/or super elevation described by the roadway section geometry. Usually provided to facilitate drainage and/or resist centrifugal force.

Glossary of Terms *(continued)*

Roughness	The estimated measure of texture at the perimeters of channels and conduits. Usually represented by the '*n-value*' coefficient used in Manning's channel flow equation.
Runoff	That part of the precipitation that runs off the surface of a drainage area after all abstractions are accounted for.
Runoff Coefficient	A factor representing the portion of runoff resulting from a unit rainfall. Dependent on terrain and topography.
Saturated Soil	Soil that has its interstices or void spaces filled with water to the point at which runoff occurs.
Scour	The result of the erosive action of running water, excavating and carrying away material from the bed and banks of streams.
Sedimentation	The deposition of soil particles that have been carried by floodwaters.
Sedimentation Basin	A basin or tank in which stormwater containing settleable solids is retained for removal by gravity or filtration of a part of the suspended matter.
Skew	A measure of the angle of intersection between a line normal to the roadway centreline and the direction of the streamflow at flood stage on the lineal direction of the main channel.
Skewness	When data are plotted in a curve on log-normal paper, the curvature is skewness.
Soffit	The inside top of the culvert or storm drainpipe.
Soil Porosity	The percentage of the soil (or rock) volume that is not occupied by solid particles, including all pore space filled with air and water.
Soil-Water- Storage	The amount of water the soils (including geologic formations) of a watershed will store at a given time. Amounts vary from watershed to watershed. The amount for a given watershed is continually varying as rainfall or evapotranspiration takes place.
Spur	A structure, permeable or impermeable, projecting into a channel from the bank for the purpose of altering flow direction, inducing deposition or reducing flow velocity along the bank.
Spur Dike	A dike placed at an angle to the roadway for the purpose of shifting the erosion characteristics of stream flow away from a drainage structure. Often used at bridge abutments.
Stage	Height of water surface above a specified datum.
Stage- Discharge Relationship	A correlation between stream flow rates and corresponding water surface elevations. Sometimes referred to as the Rating Curve of a stream cross-section.
Stilling Basin	An energy dissipater placed at the outlet of a structure.
Storm Drain	The water conveyance elements (laterals, trunks, pipes) of a storm drainage system, that extend from inlets to outlets.
Storm Duration	The period or length of storm.
Stream Contraction/ Constriction	A narrowing of the natural stream waterway. Usually in reference to a drainage facility installed in the roadway embankment.

Glossary of Terms *(continued)*

Stream Reach A length of stream channel selected for use in hydraulic or other computations.

Submerged Inlets Inlets of culverts having a headwater greater than about 1.2* D.

Submerged Outlets Submerged outlets are those culvert outlets having a tailwater elevation greater than the soffit of the culvert.

Superflood Flood used to evaluate the effects of a rare flow event; a flow exceeding the 100-year flood. It is recommended that the superflood be on the order of the 500-year event or a flood 1.7 times the magnitude of the 100-year flood if the magnitude of the 500-year flood is not known.

Surface Runoff Total rainfall minus interception, evaporation, infiltration, and surface storage, and that moves across the ground surface to a stream or depression.

Surface Storage Stormwater that is contained in surface depressions or basins.

Surface Water Water appearing on the surface in a diffused state, with no permanent source of supply or regular course for a considerable time; as distinguished from water appearing in water courses, lakes, or ponds.

Synthetic Hydrograph A graph developed for an ungauged drainage area, based on known physical characteristics of the watershed basin. A hydrograph determined from empirical rules.

Tailwater, TW The depth of flow in the stream directly downstream of a drainage facility. Often calculated for the discharge flowing in the natural stream without the highway constriction. Term is usually used in culvert design and is the depth measured from the downstream flow line of the culvert to the water surface.

Thalweg The line connecting the lowest flow points along the bed of a channel. The line does not include local depressions.

Time of Concentration, Tc The time it takes water from the most distant point (hydraulically) to reach a watershed outlet. Tc varies, but is often used as constant.

Tractive Force The drag on a stream bank caused by passing water, which tends to pull soil particles along with the streamflow, expressed as force per unit area.

Travel Time The average time for water to flow through a reach or other stream or valley length.

Tributaries Branches of the watershed stream system.

Ungauged Stream Sites Locations where no systematic records are available regarding actual stream flows.

Uniform Flow Flow of constant cross-section and average velocity through a reach of channel during an interval of time.

Unit Hydrograph A hydrograph of a direct runoff resulting from 1 centimetre of effective rainfall generated uniformly over the watershed area during a specified period of time or duration.

Unsteady Flow Flow of variable cross-section and average velocity through a reach of channel during an interval of time.

Watercourse A channel where a flow of water occurs, either continuously or intermittently, with some degree of regularity.

Water Elevation The usual term used to describe the estimated water surface elevation in the stream at the project site for the design discharge.

Glossary of Terms *(continued)*

Watershed	The divide between catchment areas.
Water Table	The upper surface of the zone of saturation, except where that surface is formed by an impermeable body (perched water table).
Weir Flow	Free surface flow over a control surface that has a defined discharge vs. depth relationship.
Wells	Shallow to deep vertical excavations, generally with perforated or slotted pipe backfilled with selected aggregate. The bottom of the excavation terminates in pervious strata above the water table.
Wetted Perimeter	The boundary over which water flows in a channel or culvert taken normal to flow.

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1 Introduction

1.1 General

This Manual was prepared by the Ministry as part of a series of manuals that cover the entire project cycle. The series incorporate best practices, climate change considerations, and recent technologies thereby enabling the provision of road infrastructure that is safe, secure, and efficient.

The roads manual series is as follows:

Project Cycle Stage	Manual: Volume or Part/Chapter	Code
A. General	**Procedures and Standards Manual**	**PSM**
	1. General	
	2. Policies	
	3. Procedures Guidance	
	4. Codes of Practice	
	5. Guidelines	
	6. Product/Testing Standards	
B. Planning	**Network and Project Planning Manual**	**NPM**
	1. Road Classification	
	2. Route/Corridor Planning	
	3. Route/Corridor Planning	
	4. Highway Capacity	
	5. Project Planning	
C. Appraisal	**Project Appraisal Manual**	**PAM**
	1. Environmental Impact Assessment and Audit	
	2. Social Impact Assessment	
	3. Traffic Impact Assessment	
	4. Road Safety Audits	
	5. Project Appraisal	
	6. Feasibility Studies	
D. Design	**Road Design Manual**	**RDM**
	1. Geometric Design	
	2. Hydrology and Drainage Design	
	3. Materials and Pavement Design for New Roads	
	4. Bridges and Retaining Structures Design	
	5. Pavement Maintenance, Rehabilitation and Overlay Design	
	6. Traffic Control Facilities and Communication Systems Design	
	7. Road Lighting Design	
E. Contracts	**Works and Services Contracts Manual**	**WSCM**
	1. Forms of contracts	
	2. Standard Specification for Road and Bridge Construction	
	3. Bills of Quantities	
	4. Standard/Typical Drawings	
F. Construction	**Road Construction Manual**	**RCM**
	1. Construction Management	
	2. Project Management	
	3. Site Supervision	
	4. Quality Assurance	
	5. Quality Control	
G. Maintenance	**Road Asset Management Manual**	**RAAM**
	1. Maintenance Management	
	2. General Maintenance	
	3. Pavement Maintenance	
	4. Bridges and Structures Maintenance	

This table continues onto the next page...

Project Cycle Stage	Manual: Volume or Part/Chapter	Code
H. Operations	**Road Operation Manual**	ROM
	1. Traffic Management	
	2. Vehicle Load Control	
	3. Emergency Services	
	4. Tolling	
I. Monitoring and Evaluation	**Road Design Manual**	MEM
	1. Performance Monitoring Manual	
	2. Technical Audits	
	3. Poverty, Gender Equality and Social Inclusion Monitoring	

This Road Design Manual, Volume 2, Part 1 – Hydrology and Drainage Design, Hydrological Survey is part of the Roads Design Manual made up of a series of volumes as shown below:

Table 1.1 Road Design Manual (RDM) Coding Structure

Vol.	Manual Title	Part Name	Code
1	**Road Design Manual: Vol. 1** Geometric Design	**Part 1** - Topographic Survey	RDM 1.1
		Part 2 – Traffic Surveys	RDM 1.2
		Part 3 – Geometric Design of Highways, Rural and Urban Roads	RDM 1.3
2	**Road Design Manual: Vol. 2** Hydrology & Drainage Design	**Part 1** – Hydrological Surveys	RDM 2.1
		Part 2 – Drainage Design	RDM 2.2
3	**Road Design Manual: Vol. 3** Materials & Pavement Design for New Roads	**Part 1** – Ground Investigations and Material Prospecting	RDM 3.1
		Part 2 – Materials Field and Laboratory Testing	RDM 3.2
		Part 3 – Pavement Foundation and Materials Design	RDM 3.3
		Part 4 – Flexible Pavement Design	RDM 3.4
		Part 5 – Rigid Pavement Design	RDM 3.5
4	**Road Design Manual: Vol. 4** Bridges & Retaining Structures Design	**Part 1** – Geotechnical Investigation and Design	RDM 4.1
		Part 2 – Bridge and Culvert Design	RDM 4.2
		Part 3 – Retaining Structures Design	RDM 4.3
		Part 4 – Reinforced Fill Structures Design	RDM 4.4
		Part 5 – Bridges and Structures Condition Survey	RDM 4.5
		Part 6 – Bridge Maintenance Design	RDM 4.6
5	**Road Design Manual: Vol. 5** Pavement Maintenance, Rehabilitation & Overlay Design	**Part 1** – Pavement Condition Survey	RDM 5.1
		Part 2 – Pavement Maintenance, Rehabilitation and Overlay Design	RDM 5.2
6	**Road Design Manual: Vol. 6** Traffic Control Facilities & Communication Systems Design	**Part 1** – Road Marking	RDM 6.1
		Part 2 – Traffic Signs	RDM 6.2
		Part 3 – Traffic Signals and Communication System	RDM 6.3
		Part 4 – Other Traffic Control Devices	RDM 6.4
7	**Road Design Manual: Vol. 7** Road Lighting Design	**Part 1** – Grid-connected Road Lighting	RDM 7.1
		Part 2 – Solar Road Lighting	RDM 7.2

This manual must be applied sensibly and flexibly in conjunction with the skill and judgement of the designer. Compliance with the guidance given in the manual does not relieve designers of the responsibility for establishing that their design is suitable, appropriate, safe and adequate for the purpose stated in the project requirements.

1.2 Objectives of the Manual

The main objective of the Manual is to give guidance on hydrological investigation assessments for the purpose of design for road drainage to the current road agencies in the country.

The hydrological manual outlines methods of investigation, assessment design and recommended drainage provisions for road and related infrastructure. It is intended to be a comprehensive hydrological investigation, assessment design manual for drainage design for new roads and recommendations to the criteria for sizing drainage structures on roads. In addition to providing international best practice on design methods, approaches, and standards, this manual provides references to other documents and software for more rigorous drainage analysis. The roads, bridge and drainage designers need guidance on the effect of runoff, floods, and the emerging climate change challenges on the drainage related structures.

This manual provides guidance on hydrological investigations, survey, data collection method, analysis and optimal flow return period for various drainage structures. Further detailed on drainage hydraulic design are provided in the drainage design manual part II. Structural design of drainage structures other than bridges structural design details are given in the Standard Details for Roads and Bridges and Specifications for Roads and Bridges Manual.

1.3 Scope of this Part

The Hydrology and Drainage Manual provides guidance and information for the hydrological investigation and analysis for design for road drainage and related infrastructure for the new and existing roads in Kenya.

In the past context of Road Design in Kenya the aspects of Hydrology, Hydraulics and Drainage Design – and the issue of water in general - were treated as cross cutting issues. While the design and the hydraulic dimensioning of side drains was considered part of the Geometric Road Design (**Part I** Rural Road Design Manual), the aspects of Pavement Drainage and Erosion Control were dealt with in the Materials and Pavement Design Manual (**Part III** Road Design Manual). Classic hydrological and hydraulic calculations concerning catchment runoff and culvert and bridge hydraulics were discussed in the Bridge Design Manual (**Part IV** Road Design Manual, Draft Version).

The Hydrology and Drainage Manual is divided in 2 parts:

- Part 1 deals with Hydrology Surveys and
- Part 2 deals with Drainage Design for culverts and bridges

This new **Hydrology and Drainage Design Manual** – as integral part of the updated Kenyan Road Design Manual – aims at integrating all Hydrology and Drainage – related aspects of road and drainage design into one comprehensive volume.

For a better clarification, a glossary of items is provided for concepts and definitions presented in the text. The Road designer should refer to the Standards Details for Roads and Bridges for structural design details. Good roads requires a drainage system to drain off the runoff that mainly affects the road reducing its lifespan; therefore, the drainage system becomes an important and integral consideration in the planning and design of road infrastructure.

When new road projects are identified, detailed hydrology and drainage designs should be carried out after selecting the road alignment. Preliminary design for hydrology and drainage is carried out at route selection stage and feasibility study stage. While carrying out the detailed design for hydrology and drainage, reference should be made to the detailed geometric design of the road, where the locations and positioning of the drainage structures and systems have already been identified and specified.

In cases where we have already existing roads, an inventory of existing drainage structures and their drainage hydraulic capacities should be determined before designing the new ones.

1.4 Organisation of the Manual

The Manual sets out the functional requirements for both rural and urban roads in Kenya. In order to carry out the hydrological survey, there is need to collect the basic topographical, hydrological, meteorological, soil among others depending on the nature of hydrological investigations to be done. Detailed data requirements are set out in the various sections of the manual. Worked out examples are included in the Appendices of this manual.

The hydrological investigations for roads design consists of three distinct components. They are:

1. Data collection; design of the individual components of all the sections of the road namely horizontal and vertical alignment and cross sections.
2. Hydrological analysis for gauged catchments, these are flow analysis that we have known flow records within or a nearby catchment.
3. Hydrological analysis for ungauged catchments, these are flow analysis that are carried out using rainfall runoff models.

All these aspects are covered in Chapters 3, 4, 5 and 6. Chapter 7 of the manual and deals with the cross-cutting issues of climate change.

1.5 Basic Design Process

This section introduces the basic design process that are followed in the road flood hydrology for the key purpose of estimating flows that are used in sizing of the road structures.

1.5.1 Compliance with National Policies

Hydrological Survey and Investigations are subject to existing law set under the Water Acts and subsidiary legislations as read together with other relevant rules like EMCA Act and should always refer to the most up to date policies and legislations. It is important that hydrology and drainage design comply with national policies.

1.5.2 Data Requirements

To carry out the road design, data on hydrological parameters such as rainfall, river flow, river gauge levels known highest flood marks, key hydrological year data and river cross sectional profiles are required. The sources and guidance on the data sources, collection and processing are detailed in Chapter 3.

1.5.3 Hydrological Data Analysis

This involves the estimation and forecasting of flood discharges through the analysis of data collected in relation to the hydrometric parameters. The hydrological analysis is carried out using different methods such as the frequency analysis of flow data, rational method, East Africa Flood (EAF) model, the Soil Conservation Service (SCS) method based on standard return periods assigned for various drainage structures. The outputs of these analyses are the peak design flood discharge and flow characteristics. Selection of appropriate design systems and structure depends on the outputs of the hydrological analyses. These are explained in Chapter 4.

1.5.4 Drainage Designs

The peak design flood discharge values are used for the design of drainage structures. These include and not limited to the following:

i. Design of open channels.
ii. Design of culverts.
iii. Bridge hydraulic design.
iv. River training and erosion protection.
v. Design of storm drainage.

1.5.5 Climate Change Resilience

In areas that are prone to extreme high flood risk, it is recommended to include the effects of climate change into the design. Chapter 7 provides guidance to design climate resilient infrastructure.

2 Hydrology and Planning

2.1 General Overview

This chapter gives guidance on the assessment and management of the impact that road construction projects may have on the existing water environment. Roads are constructed on land that forms part of an ecosystem and could have impacts on the quality of water bodies on the existing hydrology of the catchments through which roads pass. Where new road passes through built up areas and private lands, there could be challenges on draining the water from the road.

Local knowledge and experience in the project area is the best indicator of maintenance problems, and interviews with maintenance personnel can be extremely helpful in identifying potential drainage problems. Past records on road maintenance, flood reports, damage surveys, and interviews with local community goes a long way to giving indicators of potential areas of risks of floods.

Road and related infrastructure flooding can often be prevented, and its impacts can be avoided or reduced through good planning and management. Flooding and their impact on the natural and built environment are all planning considerations. The road agencies should attach great importance to the management of flood risk in the planning process and taking account of recent emerging challenges on climate change.

2.2 Hydrological Basins in Kenya

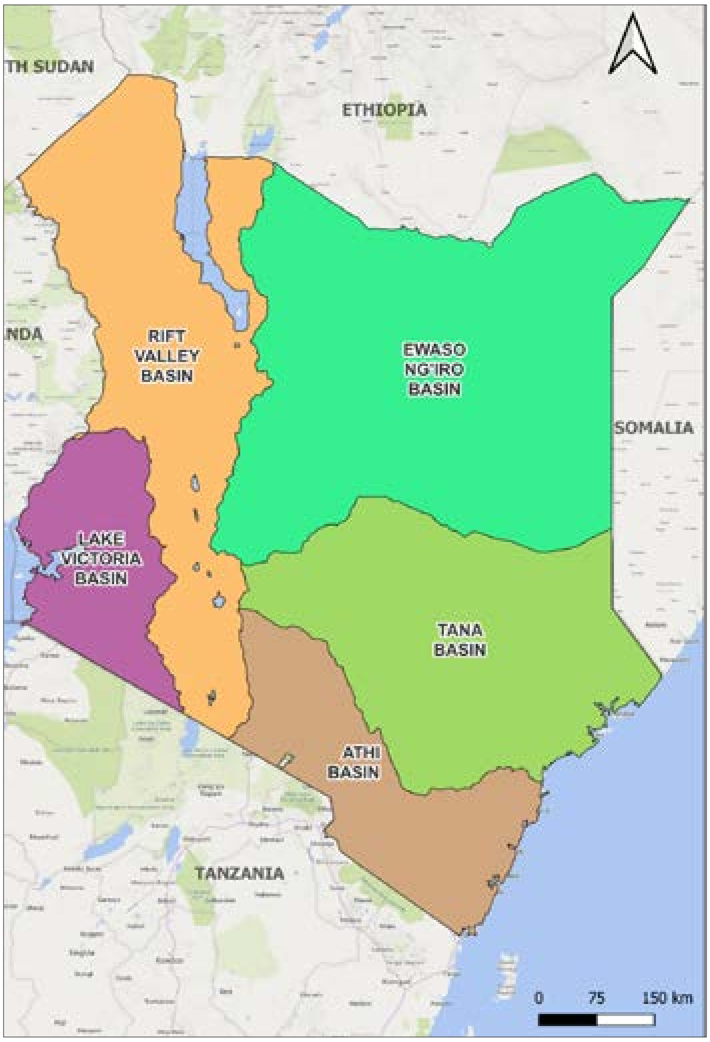
Kenya has 5 hydrological basins. The basins are classified according to the way the natural surface water drains and flows. The roads are built across the basins with some roads traversing several basins. The basins ease in terms of direction of flows is applied in the catchments. The basins ease in terms of direction of flows as applied in the catchments. The five drainage basins in Kenya are:

i. Rift Valley basin.
ii. Lake Victoria basin.
iii. Ewaso Ngiro basin.
iv. Tana basin.
v. Athi basin.

Each of the basin catchments have different hydrological regimes.

The Figure 2.1 shows the 5 drainage basins in Kenya.

Figure 2.1 The 5 Drainage Basin in Kenya



2.2.1 Road Flood Hydrology and Drainage

Structures on the roads are designed to drain freely to prevent build-up of stagnant water and runoff on the carriageway whilst avoiding flooding. Pollutants that could be deposited on the road surface are quickly washed off during rainfall. Where traffic levels are high, the level of contamination increases and therefore, the potential for unacceptable harm being caused to the receiving water also increases. The road should be designed such that the risks on the contaminants are reduced.

Considerations should be made while planning and handling drainage on the road, due to the high costs associated with the road construction.

2.3 Planning and Location of Road and Highways

The planning and locating of road facilities are the first steps in a challenging process of providing a safe and efficient transportation system. Hydrologic and hydraulic requirements are among the features, which must be considered during the early phases of the design process.

Runoff and storm water management are key considerations in the planning and locating of structures on the road highway. Apparently, only major drainage features, such as large rivers and environmentally sensitive areas, have been considered during early stages of project feasibility study. The overall drainage solution must be visualised and studied, so that substantial drainage design and construction are adequately addressed.

The possible effects that road construction may have on existing drainage patterns, river characteristics, potential flood hazards, and the environment in general, as well as the effects the river and other water features may have on the highway, should be considered at the early stages of the design.

Hydrologist must be actively involved during the initial project phases to ensure that proper consideration is being given to drainage aspects. This involvement should include participation during the highway location selection phase.

Early input from these specialists will result in a better design, both hydraulically and economically. It must be emphasised that early studies are not comprehensive, detailed and technical designs should be considered at every stage. Rather, most are cursory studies to consider obvious drainage related problems that may be encountered or created, and what type of data needs to be collected for evaluation of possible impacts. The degree and extent of preliminary hydrological studies should be commensurate with the cost and scope of the project and the perceived flood hazards that may be encountered.

The subsequent sections present a comprehensive overview of possible considerations in the planning and locating of a road.

2.4 Location and Alignment Considerations

2.4.1 Horizontal Alignment on Major River Crossings

The horizontal alignment of a road determines where stream crossings will occur and where there will be transverse or longitudinal encroachments. From this, two key issues of the proposed alignment must be considered.

First, the design engineer must consider how the streams or storm drain systems may affect the roadway, and second, how the roadway may affect the flow characteristics of such streams or systems.

Slight changes in alignment can sometimes alter the flooding characteristics significantly.

Whether or not changes to the horizontal alignment can be made often depends on whether the project is an improvement to an existing highway or the construction of a highway in a new location.

There is often little opportunity to change horizontal alignments when the project is an improvement to an existing highway.

Minor alignment improvements or roadway widening may cause slopes to encroach water ways or streams. If unavoidable, the road design engineer and hydrologist must be prepared to offer actions to accommodate these encroachments. Changes to the horizontal alignment of the road at stream crossings can also result in hydraulic consequences.

Observations show that a number of older structures were constructed to cross the stream at a right angle to the flow. This sometimes resulted in sharp curves in the roadway approaches to the bridges. Replacement structures are often planned to correct this poor alignment by crossing the stream at a skew. Proper abutment and pier alignment of the replacement structure must be ensured. If the existing substructures are to be used as part of the replacement, their alignment with the channel must be considered.

The construction of a road on a new alignment affords the greatest opportunity for the hydrologist to influence the alignment during the location phase. During this phase, changes can be recommended to locate the road away from a stream or situate a bridge at a more stable channel location. These recommendations should be made early in the development of a project to avoid delays during the design or right-of way acquisition phase when the horizontal alignment is difficult to change. During relocation there may also be constraints, which control the alignment. Topographic and cultural features may have to be avoided, resulting in the use alternative route.

Anticipated changes in land use have a key impact on the horizontal road alignment.

2.4.2 Vertical Alignment

The effect of the vertical alignment, commonly called the profile, on highway drainage facilities is significant and must be assessed in comparing alternate locations. Although the profile usually is of greater interest to the hydraulic engineer than the horizontal alignment, it is normally easier to alter and is not firmly set as early in the project development.

The profile is the feature, along with the hydraulic opening, that determines when, as well as where, the highway will be overtopped. By raising or lowering the profile, the frequency of overtopping can be either decreased or increased.

Not only does the profile affect the frequency of overtopping, but it also determines the level of upstream flooding. Depressed roadways act as drainage interceptors and may require that upstream surface runoff be accommodated in storm drains or diversion channels. Fills on wide flat areas may intercept surface flows and require special drainage treatments with relief in place. These problems will be of special concern with large urban expressways and deserve careful evaluation at the location phase. On streams where navigation exists, clearances required for waterway vessels may become the factor controlling vertical alignment. The profile not only affects the flow from streams either over the roadway or through the structure opening, but it also affects the flow of the roadway runoff water.

Vertical profile finally affects the finished road level.

2.4.3 Physical Considerations

A highway crossing at, or near, to the confluence of two or more streams represents a complex hydrologic and hydraulic location and should be avoided at all costs. The hydrology is complicated because several combinations of events should be considered especially during the peak flows.

Large peaks could occur simultaneously on both streams, though this probability is usually small if one watershed is much larger or hydrologically different from the other. Large peaks on one watershed should also be evaluated in combination with lesser events on the other stream, because although headwaters may not be as high as with large runoff events on both, velocities could be higher when only one stream is experiencing a flood due to increased energy gradients caused by a low tailwater.

Such locations require an analysis involving the hydraulics of confluences. This includes an analysis of the various combinations of flood events and how they may change flow distributions, hydraulic gradients, headwaters, and velocities. Stream stability can also be more critical at confluences due to middle and point bar formation, which can cause abrupt changes in flow directions. Pier location and alignment and culvert alignment near confluences will have to be carefully analysed for these effects.

While these complexities do not have to be studied in detail during the early planning and location stages, their effects on the location should be recognised and documented. The future potential problems with such sites must be emphasised as well as the positive factors of avoiding these locations. Minor alignment changes may eliminate the problems of a crossing close to stream or river confluence.

2.4.4 Tidal Areas and Other Large Water Mass Areas

Where we have large water mass or tidal waters this present the hydrologist and design engineer with special considerations such as regular changes in water level from astronomically induced tides, storm surges from wind and high waves, or even seismic waves or tsunamis.

Tidal inlets and their related marshes may also be highly sensitive environmental areas because of the different and often rare wildlife and fauna systems they support.

Crossings should be planned, which do not significantly alter or restrict the flow, either into or out of these marshes. The altering of flows can affect the ecological nature of the area, as well as the area wide hydraulics.

A possible reduction in interior tide heights because of the isolation of an inlet may cause increased velocities, scour, or increased wave heights somewhere else, often along the road itself. Salinity may be changed, with stratified freshwaters and salt waters flowing in different directions. This could change the type and extent of vegetation, which in turn could affect the terrestrial ecosystems.

However, the availability of daily water levels in the ocean and lake remains a key challenge.

2.4.5 Land Use Changes

This is becoming one of the major challenges in the catchments in the recent times. The use of land adjacent to the stream must be considered while carrying hydrological investigations. In rural areas, the most significant consideration is how the crossing may affect property, both upstream and downstream. Upstream, the concern is usually with increased flood levels. The degree and duration of an increased flood stage could affect the present and future land use. In Kenya agricultural land should be evaluated for increased risks due to flooding.

Downstream, the hydraulic effects, which are of usual concern are related to increased velocity through the structure. This higher velocity may increase scour immediately below the crossing or increase aggradation downstream. Potential downstream effects are usually more difficult to quantify than upstream effects. In urban areas, the effects of increased flood stages or increased velocities become important considerations. In addition to the impact on future land use, the existing property may suffer extensive physical damage from an increased flood stage.

The impact on traffic safety and operation may extend well beyond the stream crossing, as increased flooding may occur on the adjacent street network, inhibiting or obstructing vehicular movement. This may result in extensive delays, more frequent accidents. Many urban areas will have stream or watershed management regulations. These may dictate the limits on the changes, which can be made to the flow characteristics in the catchments.

2.4.6 The Location of Utilities

At the planning phase of new and existing road infrastructure, it is important for the hydrologist and design hydraulic engineer to be aware of utility locations and types as well as their relationship to the proposed road project. Locations of overhead power lines, and underwater water and sewer lines and utility facilities such as dam or river abstractions affects the project.

The hydraulic engineer must then evaluate if and how these features may affect the various hydraulic structures or, conversely, be affected by them. If power lines have to be relocated on or buried within an encroachment, their relationship to the projected flood levels must be considered.

The reconstruction of a pumping station that could either be flooded or an obstacle to flood flows if not placed at a proper level is another example of what may need to be considered. Even the maintenance of utility facilities may entail hydraulic considerations. Excavating a utility for repairs buried within an encroachment could affect the stability of the embankment or stream and thus expose, even temporarily, the highway to increased erosion potential.

The construction of a storm drainage system or the improvement to an existing one can interfere with utilities. Often, in older urban areas, types of utilities and their locations are not accurately documented, if at all. In these cases, the design engineer should coordinate early with all appropriate utility personnel to locate as many of the lines as possible to facilitate the later design process as well as provide input to the location process if needed.

2.4.7 Location of Storm Drainage Facilities

The location of storm drainage facilities should be considered during the early phases of a road project. This is because it may be required to combine the collection of storm water from several watersheds or for connecting to an existing system. The capacity of existing systems to accept the incoming flows from these collection points is critical for sizing purpose.

New road projects that are an improvement to an existing road, collection points will have been in existence for several years. The possibility of altering, adding, or deleting points should not be overlooked however, as a more cost-effective and hydraulically efficient system should be put in place. Storm drain collection pipes are commonly located parallel to the roads . However, consideration should be given to the terrain, and the possibility of construction problems with this generally accepted solution. Routes with less excavation or other advantages may be available. The location of outfall alternatives is the most important consideration for storm drainage systems made during the planning and location phases. Drainage must be discharged into natural or constructed drainage features capable of conveying this flow in a safe and efficient manner. Sinkholes or other low-lying areas without a natural outlet must be avoided. With constructed facilities, such as irrigation canals, it is advisable to obtain written agreements for the discharge and assurance the facility will remain in perpetuity. Existing outfalls must be checked for present as well as future adequacy and whether or not downstream problems such as erosion or flooding could occur.

Proposed outlet locations should be checked for the same considerations, as well as ensuring the legality of creating a flow where none, or very little, has previously existed. Coordination with the local community will often be necessary when tying into existing outfalls. New outfalls may also need to be coordinated as the community may have plans in progress utilising the outfall area for other purposes.

Roads on new locations in urban areas may significantly affect existing surface runoff patterns and storm drainage systems. Depressed roads will most likely cut through existing storm drains while highways on fills will isolate drainage areas. Early and careful attention to these types of projects is needed or alternates suggested to ensure a feasible system for accommodating disrupted drainage patterns can be designed.

2.4.8 Existing Structures Along the Alignment

Existence of a river crossing and or a river may influence and limit the type of structure that can be placed at a particular location. Decisions made during the preliminary phases of project development should not constrain the final recommendations of the Design Engineer. Detailed surveys and comprehensive hydrologic and hydraulic studies are needed to make conclusive recommendations. Even then, the Design Engineer may recommend alternate types and shapes, depending on the site conditions. Some locations are critical crossing sites, such as those within a designated flood area, roads crossing dam embankments, dam chutes etc. may require detailed studies early in the project development.

Such areas may be requiring access permits issued by the various government agencies at the initial stage or project inception. When this is the case, a final structure type can be provided. There are many considerations to be made before selecting a final design alternative. Such factors could include hydrologic, hydraulic, environmental, economic, construction, and maintenance factors.

2.4.9 Construction Related Challenges

Problems arising during construction can be eradicated and/or minimised once drainage or other water related factors are considered during the location and planning phases of the project. The occurrence of erosion and sediment, and how to control it, must be considered, at least in broad terms, during the early phases of location. The Hydrologist, the design Engineer, together with other specialists, may be involved in the identification of groundwater flows and potential unstable slopes because of underground water so that proper measures can be taken to prevent problems before they occur.

The time of the year and the total construction time should be taken into consideration in considering impacts. Certain elements, such as embankments along a stream, should be completed before the anticipated flood season. In some sections of the country, work cannot be performed as the stream may serve as an irrigation supply requiring that flows not be interrupted and that pumping and distribution systems not be contaminated with sediment.

The use of temporary structures must also be planned. Often a temporary crossing can be smaller than normal if it is only going to be utilised during the months. In case where the structure is to be used for more than one year, the structure needs to be sized for a flood of greater magnitude.

3 Hydrological Data Collection

3.1 General

Various types of hydro-meteorological data is required for the hydrological investigations and hydraulic design for different kinds of roads related infrastructure that include open channels, culverts, bridges, and other drainage structures along and across the road. This part presents the guidance on the types of data required for each design, data sources the specific data collection procedures, evaluating and processing the data for the design in the hydrological analysis and investigations.

Each of the road project has its own unique data sets in addition to the basic hydro - met data. Thus, each project has its own uniqueness and the data required could be tailored to the specific project need and thus not all of the data discussed in this Chapter will be needed for every road project. It is good to note that a well-planned data collection exercise leads to a more orderly and effective hydrological and hydraulic analysis. This avoids duplication and has direct impact on the type of drainage design that corresponds to the key components in a project that is;

i. Overall project scope;

ii. Project costing; and

iii. Adherence to the design requirements.

The need for quality data cannot be over emphasised.

Depending on the type of structure, the following are stages that are involved in gathering and processing the data.

3.2 Choice of the Drainage Structures

The various road drainage structures infrastructure that are commonly used are listed below:

i. Open channels for the natural channels that include streams, rivers and artificial channels that are roadside drainage.

ii. Culverts.

iii. Bridges.

iv. River and channel training.

v. Energy dissipaters.

When design for new road projects, information on the applicable drainage structures and their location should be determined from the geometric design.

Where we have upgrading of existing road, the improvements required on the drainage structures and systems should be determined from the previous project designs and from the observed site conditions.

3.3 Specific Data Requirements for Hydrological Investigations

Specific data requirements for hydrological and drainage investigation normally vary from one drainage structure type to another. For ease of identification Table 3.1 presents specific data needs for hydrological analysis and design. The detailed procedures to gather the data from various sources and for conducting surveys are provided in the subsequent sections.

Table 3.1 Data Requirements for Hydrological and Drainage Investigation

No.	Type of data	Open Channel	Culverts	Bridges	Storm Drainage	Stream or Channel Training	Energy Dissipaters	Subsurface Drainage
1	Desk studies	✓	✓	✓	✓	✓	✓	✓
2	Aerial photogrammetry			✓				
3	Field survey	✓	✓	✓	✓	✓		
4	Topographical survey	✓	✓	✓	✓	✓		✓
5	Geotechnical survey	✓		✓		✓		
6	Aerial survey			✓		✓		
7	Catchment area delineation	✓	✓	✓	✓	✓		
8	Vegetation cover		✓	✓	✓			
9	Land use	✓	✓	✓				
10	Stream cross sections		✓	✓	✓	✓		
11	Stream bed slope	✓	✓	✓	✓	✓		
12	Stream reach	✓	✓	✓	✓			
13	Riverbank slope	✓	✓	✓	✓			
14	Flood history	✓	✓	✓	✓	✓		
15	High flood levels	✓	✓	✓	✓	✓		
16	High water marks	✓	✓	✓	✓	✓	✓	✓
16	Manning's 'n' values	✓	✓	✓	✓	✓		
17	Debris characteristics	✓	✓	✓	✓	✓	✓	
18	Scour presence	✓	✓	✓	✓	✓	✓	
19	Observed ecological information	✓	✓	✓	✓	✓		
20	Natural constraining features	✓	✓	✓	✓			
21	Material types	✓	✓	✓	✓	✓	✓	✓

3.4 Information and Data Collection Process

The relevant information and data required for hydrological and drainage should be collected in a structured manner in order to meet the desired objectives. This process is explained in the subsequent Sections. 3.4.1.

3.4.1 Desk Studies

The desk studies involved the process of collection and obtaining all the relevant documents and information that are required for hydrological analysis and design. Some of these information, document and sources are presented in Table 3.2.

Table 3.2 Desk Study Information - Documents and Sources

S/No	Drainage Type or System	Data Requirements	Sources of Information / Data	Method of Data Collection
1	Hydromet data	Stream gauge and flow data	The parent Ministry of Water and Irrigation,	By procuring the data
			Water Resources Authority and or any other water body established by law	By procuring the data
			Historical published data	Referring to published / past flood study reports
		Rainfall	Kenya Meteorological Department (KMD)	By procuring the data
			Water Resources Authority and or any other water body established by law	By procuring the data
			Past rainfall studies report	Referring to published / past rainfall study reports
2	Mapping	Topographical data for catchment areas etc.	National Survey of Kenya	Procurement of various map sizes 1:50,000 and 1: 250,000 topographic maps
			Digital Elevation Model Maps (DEM)	Down from maps and available platforms
3	Storm drainage	Rainfall data and IDF curves	Kenya Meteorological Department (KMD)	By procuring the data
			Past rainfall studies report	Referring to published / past rainfall study reports
4	Culverts, bridges and river training	Geological maps	Ministry /Department Mines and Geology	Procure the geological maps
		Soil and land use maps	Survey of Kenya, Ministry of Agriculture	Procure the relevant maps
		Regional flood and local flood studies	Ministry of Water, Regional Water Resources Authority	Past study reports
		River basin management plans	Ministry of Water, Regional Water Resources Authority	Past study reports
		Topographical maps and areas photos	Survey of Kenya	Procurement of the required maps and images

3.4.2 Hydrological Data for Design

Data that is required for hydrological analysis and design is critical for the purpose of giving the optimal flood estimations for subsequent use in structure sizing. As such the data should be comprehensively collected, collated and analysed before use. In addition to the desk study, field investigations are very important in the hydrological design process. Some of the data types collected during the field investigation are presented in the subsequent sections.

3.4.2.1 Introduction to Topographical Data and Information

Existing terrain information and data is determined from the topography along the channel alignment. These will include conventional longitudinal and transverse level surveys along the stream reach at appropriate intervals – usually done at 20 m in the longitudinal direction of the proposed centreline and at 2 m interval offsets on each side of the centreline up to the edge of the banks especially for the bridges sites. The survey should use a GPS-based total-station with readings taken automatically and transferable to a computer. The data should preferably be reported in a format that can be imported into relevant hydrological design software and other Engineering software such as AutoCad.

3.4.2.2 Aerial Photography

This method is suitable when we require design for large structures and especially where we have large stream crossing that have no well-defined channels. Rivers that have shifting river course are critical in getting their flood extents and thus detailed mapping is required.

This method uses topographic mapping that is developed using pictures of the ground taken from an aircraft or satellite. While using this method ground controls are established using field survey methods and contours. These pictures taken can also be used as data for hydraulic investigations and studies.

In more recent times modern technologies such as drones equipped with advanced cameras and GPS technology are used. The use of drones is a cheaper option though they cannot entirely substitute the use of airplanes. High-resolution satellite and multi-spectral imagery could be utilised as well. The biggest advantage of satellite data is that it can be stored for a period of time and could be used to investigate flood potential risks zones before and after the flood events. Other comparative emerging method of aerial topographic generation is the use of laser or radar beams from GPS mounted on the aircrafts. This is laser-based method is called Light Detection and Ranging (LiDAR). LiDAR or radar generated data that has an added advantage of being inexpensive when compared to traditional photogrammetry methods. It is worthy to note that the accuracy is highly dependent on the technology available to the vendor in aerial equipment and available software that are able to filter existing features like trees and other covered land areas.

3.4.2.3 Geotechnical Surveys

The site geotechnical survey is required for the design of bridge foundations and riverbanks slope stability and mitigation such as river training. The survey should be carried out by a geotechnical expert. Such kind of survey includes and are not limited for the following:

i. Ground profiling.

ii. Slope stability.

iii. Material properties.

iv. Hydrogeology.

3.4.2.4 Geomorphological Survey Data Sets

The geo-morphological data are important in the analysis of channel stability and scour. Types of data needed are:

i. Sediment transport and related data.
ii. Stability of form over time (braided, meandering, etc.).
iii. Scour history/evidence of scour.
iv. Bed and bank material identification.

The above data sets are described in detail in the geotechnical manuals.

3.4.2.5 Catchment Area Characteristics

The key catchments characteristics are basically the carried out and established are catchment areas, length of stream, catchment slope and stream slopes.

The size of the contributing catchment area expressed in hectares or square kilometres, and can be determined from some or all of the following:

i. Use of direct field surveys with conventional surveying instruments.
ii. Observed changes in the contributing catchment area that may be caused by terraces, sinks, etc.
iii. Debris or mud flow barriers.
iv. Land area reclaimed /flood control structures and irrigation diversion.
v. Topographic maps that are available for many areas of Kenya from the Survey of Kenya especially the 1:50,000 and 1: 250,000 scale maps.
vi. Aerial maps or aerial photographs.

From the above mapping sources, various data such as the slope of the stream, the average slope of the catchment, and other important terrain characteristics are determined.

Catchment areas have traditionally been determined using a planimeter, counting squares method. In recent times the geographic information system (GIS) based software can be used to delineate catchment areas and calculate catchment physiography.

3.4.2.6 Catchment Land Use

The present and the future expected future land use, especially in catchments that are either urbanised or planned for urbanisation should be well identified and data source shall be defined and documented. Information on existing use and future trends may be obtained from:

i. Aerial photographs.
ii. Land use maps.
iii. Topographic and other maps.
iv. County Government plans.
v. Landsat (satellite) images.

Existing land use data for small catchments can be determined or verified best from a field survey. Field surveys should also be used to update information on maps and aerial photographs, especially in catchment basins that have experienced changes in development since the maps or photos were prepared. Infrared aerial photographs may be particularly useful in identifying types of urbanisation at a point in time.

This is because land use has a huge impact on the rates of infiltration when determining the surface runoff.

3.4.2.7 Stream Reach

There is a need to establish the upstream and downstream study boundaries for water profile calculations, as these define the limits of data collection and subsequent analysis. Calculations must be initiated sufficiently far enough downstream to ensure accurate results at the structure and continued sufficiently upstream to accurately determine the impact of the structure on upstream water surface profile, especially when investigating bridges. Underestimation of the upstream and downstream study lengths may produce less than desired accuracy of results, and may eventually require additional survey data at higher costs than applied to initial surveys. On the other hand, significant overestimation of the required study length can result in greater survey, data processing, and analysis costs than necessary. For example, for bridges, survey measurements should be done at least 300 m on either side of the structure.

3.4.2.8 Stream Slope and Bed Profile

Stream bed profile data is critical when bridge crossings are encountered. The profile data must be obtained, and these data should extend upstream and downstream sufficiently far enough to determine the average slope especial when large crossing are encountered. Profile data on live streams may be obtained from the water surface. Where there is a river or stream gauge relatively close the project site, the discharge, date, and hour of the reading should be obtained. The streambed profile should extend upstream and downstream for a distance of at least 300 metres.

3.4.2.9 Stream Cross Section Surveys

The typical stream or river cross-section data that represents the typical conditions at the structure crossings site need to be obtained. This is normally at the crossing where we have stage-discharge calculations required. This is mainly at the bridge sites. For better results typical experience has shown that the surveys should be done at least 300 m upstream and 300 m downstream of the channel. Below is the guidance on how such survey could be carried out.

i. Stream cross sections shall be taken at 10 metre intervals upstream and downstream for at least one-half the distance usually indicated as 'L', and the intervals should be shown on the plan (cross section locations should be marked on the plan).

ii. Additional cross-sections should be surveyed where the channel significantly changes width or elevation (e.g., waterfalls). Where it is not practical to survey a section at the prescribed position or interval, the position of the section may be moved. However, the interval between two adjacent sections shall not exceed the prescribed interval.

iii. Cross-sections should be surveyed viewed downstream and the origin or zero chainage of the channel cross-section must be established on the left bank (LB) of the channel viewed downstream. However, where a section is only required through the right bank (RB), the origin or zero chainage shall be located on the waterside of the bank, i.e. in the channel.

iv. All existing structures should be identified and marked on the location plan and surveyed.

v. Sufficient levels must be taken across the cross-section for the channel shape and geometry to be easily identifiable (a plan should be prepared for an indication of points where levels should be taken). A description of the material, lining the channel (e.g. silt, grass, pebbles, concrete etc.) should be provided at regular intervals with photographs being provided in support. Location of photographs should be identified by the label attached to the closest cross-section.

vi. Points along the cross-section should be surveyed at an interval that accurately depicts the shape of the channel. For open channel sections, the drawn line of the cross-section shall be correct to better than +/- 0.1m in height allowing for up to 0.2m movement along the section line. For structure details, the drawn line of the cross section shall be correct to better than +/- 0.02m in height allowing for up to 0.02m movement along the section line.

vii. If upstream views are required, e.g., downstream elevation of bridges and weirs, this will be noted in the survey brief notes. The origin or zero chainage of the upstream view shall be established on the left bank (LB) of the channel. The section shall be plotted as viewed upstream i.e. the 'range' values below the section plot will be negative.

viii. Each individual structure cross-section will be given a relevant title included in the section header. Where a cross-section is of an upstream view, this must be clearly noted in the title. Open channel sections should may not have a title.

ix. In addition to cross-sections through the channel, cross-sections should be extended from the channel to the true land level on each side and at least 20m beyond the bank crest (where possible) unless mentioned otherwise in the Survey Brief. Where trees or bushes/shrubs line the channel, the section shall extend to 5 m beyond the vegetation, but no more than 50 m from the channel. Beyond the extent of the cross-section, a general indication of the ground form should be given as a label e.g., 'flat', 'rises steeply'. The point used for the longitudinal section bank line shall be indicated on the plotted cross-section.

x. Where a riverbank is raised above the surrounding ground (floodplain), the crest is defined as the point on the top of the bank over which water will spill from the river onto the surrounding ground. Where there is no raised bank, the crest is the point marking the change of gradient from surrounding ground to the channel.

xi. Bushes, trees, fences and buildings adjacent to the channel cross-section should be shown as symbols – not true to scale.

xii. If there are buildings along the proposed road route, their floors or damp-proof course level should be indicated. Where they cannot be determined, the threshold level shall be recorded. Buildings will be labelled with name and/or number, type and whether a damp-proof course exists.

xiii. Any water body including lakes or ponds should be surveyed. This includes maximum water levels at the time of the survey and top of bank levels. Fences will be labelled with their type and height. Road crossings will be labelled with name and/or number for ease of identifications.

3.4.2.10 Roughness Coefficients

The Roughness coefficients, ordinarily in the form of Manning's 'n' values, shall be estimated for the entire flood limits of the stream. A tabulation of Manning's 'n' values with descriptions of their applications can be found in Table 6.9 and Table 6.10

3.4.2.11 Flood History, High Flood Marks and Debris Characteristics

The site history of past floods and the impacts of the flood on the existing structures is of significant value while undertaking flood studies. It gives good indicator for sizing new structures.

In Kenya it is of great significance to utilise the known hydrological years while carrying flood analysis for huge structures. Such information on key hydrological years can be obtained from the Water Resources Authorities. Known local information may be obtained from newspaper accounts, local residents, flood marks, or other positive evidence of the height of historical floods. Changes in channel and catchment conditions since the occurrence of the flood shall be evaluated in relating historical floods to present conditions. Extreme recorded flood data may be available from agencies such as the Ministry of Water Resources and Water Authorities offices. Past historical data on overtopping of structures is important as the designer sizes new drainage structures. Flood extends and magnitude gives and indicator of how higher the new structures should be.

The quantity and size of debris carried or available for transport by a stream during flood events must be investigated and such data used in the design of new structures and or during repair works.

In addition, the times of occurrence of debris in relation to the occurrence of flood peaks shall be determined; and the effect of backwater from debris on recorded flood heights shall be considered in using stream flow records. The sizes of the debris may be used to give indicators of the free board to be allowed for bridges.

3.4.2.12 Scour Potential

The scour potential is an important consideration relative to the stability of the structure over time. Scour potential is determined by a combination of the stability of the natural materials at the facility site, tractive shear force exerted by the stream and sediment transport characteristics of the stream.

Data on natural materials can be obtained from in-situ testing and materials sampling. Bed and bank material samples sufficient for classifying channel type, stability, and gradations, as well as a geotechnical study to determine the substrata if scour studies needed, will be required. The various alluvial river computer model data needs will help clarify what data are needed. In addition, these data are needed to determine the presence of bed forms so a reliable Manning's 'n' as well as bed form scour can be estimated from the site.

3.4.2.13 Natural Constraining Features

Existing natural features such as rock formations, that may cause gradient changes or affect water levels, should be treated as weirs. Changes in water level gradient over shoals and aprons, and sudden changes in bed level should be measured and added to the longitudinal section. Such any other obstructions should be noted.

3.4.2.14 Utilisation of Local Knowledge in Hydrological Design

Local knowledge in flow regimes is very useful part of the field data collection exercise. The locals who have lived longer in the catchments are a good source of stream flow characteristics in terms of:

i. River flow regimes especially when we have the streams changing their flow paths;

ii. River flow volumes during extreme flood periods; and

iii. River recession where we have drift in case of high flows.

Such information can only be obtained by the practitioner visiting the project route with a clear objective to obtain the local behaviour of streams for they have lived with the rivers for a long time and understand its behaviour. Use of the local administrative leaders and the elders is highly recommended.

3.4.2.15 Identification of Water Outfall

Water natural flows to the lowest point that are typically referred to us natural outfalls. The key purpose of draining the road is direct the water flows to the natural outfall. During the field surveys, all natural outfall should be identified, and flows directed to such, and/or the riparian areas set by the various government authorities.

Where no natural outfall is identified or have been occupied the following action should be taken:

i. Identify the blocked outfall for remedial actions.

ii. Where outfall is occupied, they should identified and referred to authority for action.

iii. Where natural outfall does not exist and are required, land survey is recommended and such land required from time to time acquired by the authority for use us outfalls.

The water outfall should be protected from any erosion and or external invasions.

3.4.2.16 Use of Data from Nearby Existing Structures

Data from the existing structures nearby the proposed project site should be looked at. Such critical data includes and not limited to location, size, description, condition, observed flood stages, and channel section on the stream reach and near the site must be collected in order to determine their capacity and effect on the stream flow.

The presence of structures either, downstream or upstream, that may cause backwater or retard stream flow should be investigated. The behaviour in which existing structures have been functioning with regard to, overtopping, debris passage, among others, shall well identified.

For bridges, the data sets should include span lengths, type of piers, and substructure orientation, which can usually be obtained from existing structure plans. The necessary culvert data includes parameters such as size, inlet and outlet geometry, slope, culvert material, and flow line profile. Where possible photographs and high-water profiles or marks of flood events at the structure and past flood scour data would be useful in assessing the hydraulic performance of the existing facility. The history of past floods and their effect on existing structures and specifically on the close nearby catchment or basin structures are of significant value to the designer.

3.4.2.17 Weather and Climate Changes

Weather and climate change have got significant changes in the transport industry. These considerations are critical transport infrastructure has a long design life. Any anticipated changes in design parameters for flood estimates during the design life should be incorporated into the planning and design process. We have two critical aspects for hydrological investigations that require great considerations in the evaluation of climate change effects; changes in rainfall intensity (including the catchment conditions like anticipated land use that affects increase infiltration and thus impacts on runoff volumes and possible sea and tidal level changes.

3.5 Determination of Stream Reach

It is worthy to note that downstream study length is governed by the effect of errors in the starting water surface elevation on the computed water surface elevations at the structure (See Figure 3.1). When possible, the analysis should start at a location where there is either a known (historically recorded) water surface elevation or a downstream control where the profile passes through critical depth.

Observed downstream high-water marks are relatively common for calibration of models to historical events, but are unlikely to be available for evaluations of hypothetical events such as the 1% chance event. Alternative starting elevations are needed for stream conditions where high water marks and control locations are non-existence or are too far downstream to be applicable. Two commonly applied starting criteria are critical depth and normal depth. The starting location should be far enough downstream so that the computer water surface profile converges to the base (existing condition) water surface profile prior to the bridge/ culvert location.

The upstream study length is the distance to where the profile resulting from a structure-created head loss converges with the profile for the undisturbed condition. The magnitude of the water surface profile change and the upstream extent of the structure- induced disturbance are two of the primary criteria used to evaluate the impacts of modified or new structures.

Determine the stream boundaries equations or using HEC-2 model, which uses regression equations given:

$$L_{dc} = 6600\ \frac{yHD}{S} \qquad \text{Equation 3.1}$$

$$L_{dn} = 800\ \frac{yHD0.8}{S} \qquad \text{Equation 3.2}$$

Where,

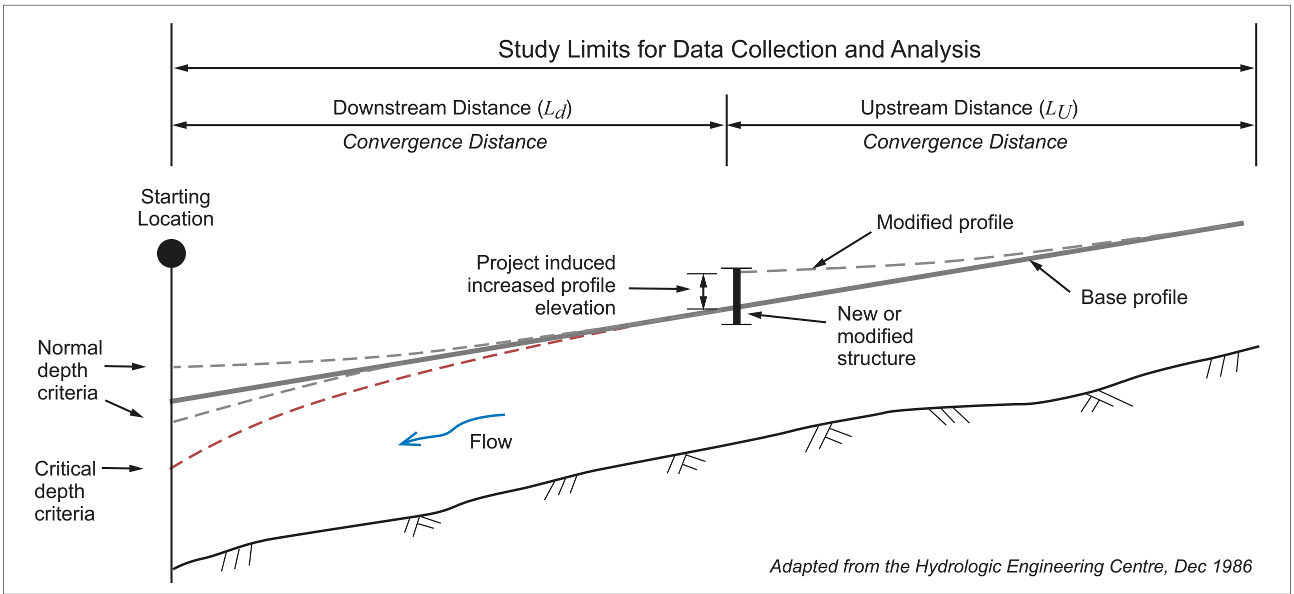
L_dc = Downstream study length (along the main channel) in metres for critical depth starting conditions.

L_{dn} = Downstream study length (along the main channel) in metres for normal depth starting conditions.

yHD = Average reach hydraulic depth 1% chance flow area divided by cross- section top width) in metres.

S = Average reach slope in m/km.

Figure 3.1 Profile Study Limits



3.5.1 Standard Procedure for Surveys

For the purpose of undertaking channel and floodplain topographical survey work the standard procedure could be used:

i. The location of the watercourses where the road crossings are proposed should be shown on the location plan.

ii. Channel cross-sections should be surveyed normal to the centre line of the channel as in Figure 3-2.

iii. The data to be supplied by the Surveyor should be in a specific format for loading into the hydraulic modelling suite of programs (e.g., HEC-RAS format). Data will also be supplied in x, y, z co-ordinates as an excel spreadsheet. This will allow channel survey data to be merged with topographic and photogrammetric surveys that could be done.

iv. Left bank and right bank shall be defined as viewed downstream.

v. For all GPS observations using the static / rapid-static technique, dual frequency survey quality GPS receivers can be used to measure altitudes.

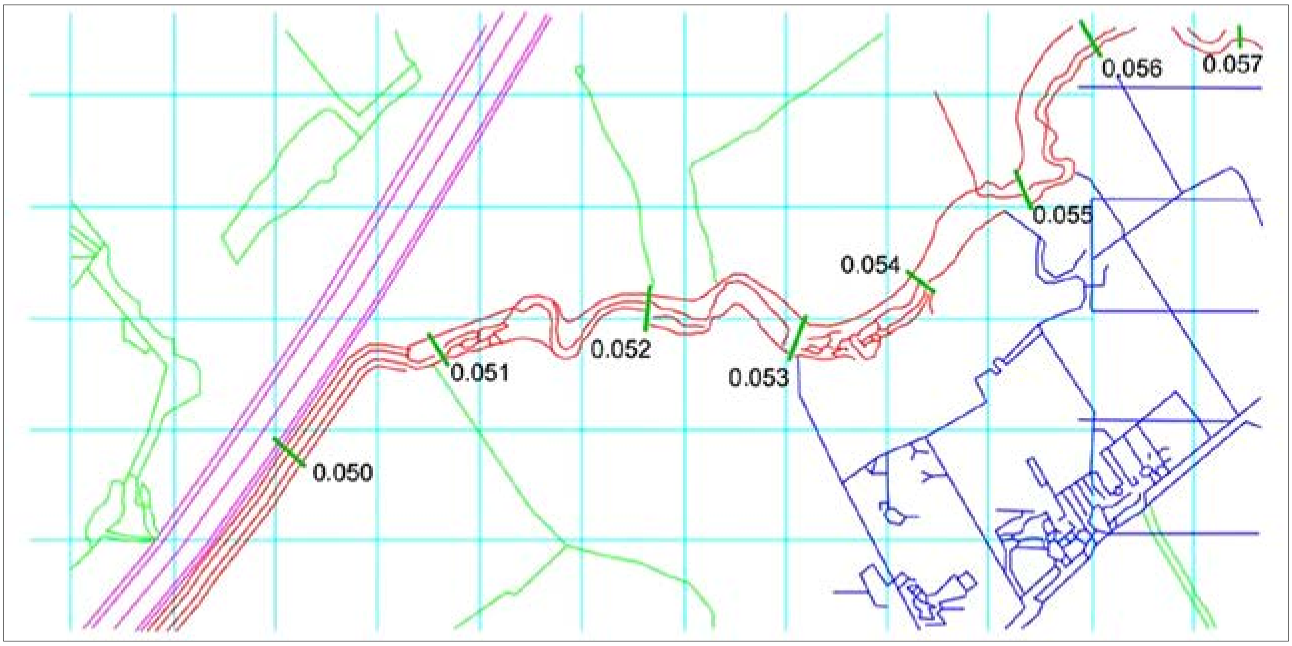
vi. Bed levels should be measured directly whenever and wherever possible. Where direct measurement is impossible, where, for instance, the water depth is too great or other causes make it impractical, then it will be sufficient to read the depth of water against a staff or to use echo sounding and to relate these readings to a measured water level.

vii. Where silt occurs, both the hard bed and the silt top will be measured at the same point. The hard bed should be shown as a solid line. The silt top should be shown as a dashed line and shall be labelled '*S*' in the digital data listing.

viii. The nature of the bed material should be recorded and plotted on the section in simplified form, e.g., 'Gravel'. Surfaces outside the water area should also be labelled.

ix. Channel surveys may be merged with photogrammetric or LiDAR surveys of the floodplain and therefore positional accuracy must be of the same order. The Kenya known National Grid Co-ordinates should be used as references.

Figure 3.2 Sample Cross Section Spacing



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x. A floodplain section should be taken normal to the centre line of the valley and not necessarily at right angles to the centre line of the channel. Because of this, flood plain sections may appear 'dog-legged' on the key plan. These sections may be defined on the contract mapping where possible.

xi. Unless otherwise stated in the survey brief, sections shall be surveyed at the upstream and downstream side of each existing structure, which significantly affects the river flow at bank-full flow condition.

xii. Where the structures are below roads and/or footpaths spot levels should be taken along the high point of the road (i.e. kerb height or road crest) every 10m for a distance of 100m either side of the structure. Where a parapet forms part of the structure a level should be taken on top of the parapet and the width of the parapet should be identified on the cross-section.

xiii. Natural features, which act as structures, such as rock outcrops, shall also be included. Structures that are not to be surveyed shall be photographed. The photographs and co-ordinates of the position of the structure shall be included as an appendix to the Survey Brief. If there is any doubt, the Surveyor should consult the Engineer to confirm whether a section is required.

xiv. A key plan based upon a 1:2,500 or 1:1,250 map data will be produced for each longitudinal section to show the cross-section positions and watercourse centreline. Whenever possible, this plan should be incorporated into the same sheet as the longitudinal section.

xv. A longitudinal section of the survey area should show all key features including the deepest bed level at each section, both hard bed (solid) and silt line (dashed), the water level at each section, the bank crest levels derived from crest point levels shown on the cross sections. Also, to be shown are the left bank as a dashed line and the right bank as a bold line, and the extent and level of any concrete sill or apron together with appropriate label. Critical levels (soffit, invert, deck, crest etc.) should be indicated.

xvi. Side weirs, etc., which are not part of the main channel shall be shown with critical levels as variations to the bank crest.

xvii. To aid clarity insets shall be used at locations where detail is dense.

xviii. Where beneficial, merge survey data collected for hydrological design with other existing data e.g., data collected for, topographical, geometric design.

xix. Most field surveys of channel and floodplain cross sections are recorded to an accuracy of 0.05 m. If the survey truly represents the cross-sections of the reach of the stream being studied to 0.05 m accuracy, the greatest accuracy that would result from a step-backwater computation could be no more than 0.5 m. Any results expressed more precisely than 0.05 m are simply due to the mathematics.

3.6 Field Survey Works

Field and site surveys for the catchments and areas contributing to the surface runoff and or flows should always be done as part of the hydrological analysis and drainage designs. The survey differs from project specifics and therefore should be site customised.

Field visits should be done by experienced hydrologist before or during the design in order for him/her to become familiar with the site. The most complete survey data cannot adequately depict all site conditions or be substituted for personal inspection by someone experienced in hydrology and drainage design. Factors that most often need to be confirmed by field inspection are:

- **i.** Selection of roughness coefficients.
- **ii.** Evaluation of apparent flow direction and diversions.
- **iii.** Flow concentration.
- **iv.** Observation of land use and related flood hazards.
- **v.** Geomorphic relationships.
- **vi.** High water marks or profiles and related frequencies.
- **vii.** Existing structure size and type.
- **viii.** Bank erosion.
- **ix.** Debris problems.
- **x.** Scour.
- **xi.** Sedimentation.

Data sheets for survey should be well prepared and reviewed before the actual survey is carried out. A sample for such form is presented in Appendix A4.

3.7 Data Quality Checks and Control

Quality checks on the data obtained is critical before the data has been utilised for any hydrological analysis and design. Past experience, knowledge, and judgment are important parts of data quality checks and evaluation. The quality, control and evaluation would involve the following:

- **i.** Reliable data should be separated from less reliable data.
- **ii.** Historical data shall be compared with data obtained from measurements and any inconsistencies shall be investigated.
- **iii.** Identify any changes from established patterns.
- **iv.** Reviews shall be made of previous studies, old plans, etc., for types and sources of data, how the data were used and indications of accuracy and reliability. Historical data must be reviewed to determine whether significant changes have occurred in the catchment and whether these data can be used.
- **v.** Basic data, such as stream flow data derived from non-published sources, shall be evaluated and summarised before use. Maps, aerial photographs, landsat images, and land use studies shall be compared with one another, and with the results of a field survey, plus any inconsistencies identified.

All the inconsistencies, errors and omissions are to be reviewed and addressed at this stage. This would include consultations, field checks and/or repeat surveys as appropriate. For possible inconsistencies and errors in historical data with major deviations then a sensitivity analysis is recommended.

For cases of hydrometric data, double mass curve analysis would be most ideal to check any suspected data inconsistencies. This is useful in determining what specific data items have major effects on the final design and are eliminated.

4 Design Standards and Flow Return Periods

4.1 General

The design standards for road flood hydrology and drainage are well spelt out in terms of the design return periods for various structures and the design frequency. This allows for the selection of the sizes once design floods have been established.

4.2 The Concept of Return Period and Design Frequency

A design frequency shall be selected to match the designed road infrastructure considering the magnitude and risk associated with damages from larger flood events. Other factors like traffic potential and budgetary allocations are secondary. With long road highway routes having no practical detour, where many sites are subject to independent flood events, it may be necessary to increase the design frequency at each site to avoid frequent route interruptions from floods. In selecting a design frequency, potential upstream land use that could reasonably occur over the anticipated life of the drainage facility shall be considered.

Hydrologic analysis should include the determination of several design flood frequencies for use in the hydraulic design. These frequencies are used to size different drainage structures to allow for an optimum design, that considers both risk of damage and construction cost. Consideration shall be given to what frequency flood was used to design other structures along major highway corridor.

Since it is not economically feasible to design a structure for the maximum runoff a catchment area is capable of producing, a design frequency must be established. The frequency with which a given flood can be expected to occur is the reciprocal of the probability or chance that the flood will be equalled or exceeded in a given year. If a flood has a 20 % chance of being equalled or exceeded each year, over a long period of time, the flood will be equalled or exceeded on an average of once every five years. This is called the return period or recurrence interval (RI).

The designer should note that the 5-year flood is not one that will necessarily be equalled or exceeded every five years. There is a 20 % chance that the flood will be equalled or exceeded in any year; therefore, the 5-year flood could conceivably occur in several consecutive years. The same reasoning applies to floods with other return periods.

Table 4.1 Applicable Design Flow Return Periods (Years)

S/No	Structure Type	Design Frequency	Check Frequency
1	Gutters and inlets	2	5
2	Side ditches and open channel	5	10
3	Pipe culverts	10	25
4	Box culverts (Total area of opening/s < 6.0 m^2)	25	50
5	Box culverts (Total area of opening/s > 6.0 m^2)	50	100
6	Short (6m < L ≤ 15 m) and medium (15 m < L ≤ 50 m) bridges	50	100
7	Long (L > 50 m) bridges	100	200

Where L is the length of bridge from abutment to abutment.

4.3 Applicable Design Flow Return Periods

The proposed design return periods/frequencies for different drainage structures in Kenya are presented in Table 4.1.

The Table 4.1 provides the design storm frequency/return period, which should be used for the design. The table also provides higher return periods to check frequency for flood conditions and impacts in case of extreme events, which may or may not be related to climate change. In this case, flood levels are determined using higher storm return periods so that the severe impacts on drainage structures and the environment can be determined.

This is the background for the introduction of Check Frequency. For example, culverts on primary roads should be designed for a return period of 25 years if they have opening greater than $6m^2$.

The impacts in the case of an extreme event are assessed by using a 50-year return period. If the extreme event could potentially cause severe damage, then mitigating measures should be put in place, such as enhanced protection works.

The span is the total clear opening of a structure. Table 4.1, provides the proposed design storm frequency/return period, which should be used for the design. The short span and the medium span bridges are often on the rural and urban roads, though they may be used in the main highways. Their recommended freeboard is 1.0 m in the case of major highways with no detour routes, and on ephemeral crossings up to 1.5 m is recommended where there are no vertical alignment limitations.

For the long bridge openings, it is recommended to have a minimum clearance of 1.5 m below soffit. If the extreme event especially for the bridge structures, could potentially cause severe damage, then mitigating measures should be put in place such as enhanced protection works, or increased capacity for drainage structure. The long bridges are expensive to put in place and recommended for the main highways and areas with highly vulnerable to flooding events with high impacts.

4.3.1 Use of Nominal Structures

The nature of the topography plays a critical role in the selection of structures that is to be placed on a crossing. Where vertical alignments is limited and we have flat terrains, we experience sheet flows in such locations. Such sheets flows in flat terrain can only be directed to flow directions by use of well-designed structures. At such locations, it is recommended that nominal structures of not less than 900 diameter are utilised to allow self-cleansing and ease maintenance of the structure. These could be placed in single and/or in multiples.

4.4 Hydrologic Analysis / Discharge Determination Methods

Discharge determination can be divided into two general categories:

i. Gauged sites - the site is at or near a gauging station and the streamflow, record is of sufficient length, then statistical analysis should be used to estimate peak flows.

ii. Ungauged sites - the site is not near a gauging station and no stream flow record is available.

Hydrologic procedures that can be used for both categories stated above will be discussed in the subsequent sections.

The following methods and sources can be used in determining peak flood discharges for design of road drainage structures as listed in Table 4.2.

Table 4.2 Application and Limitation of Flood Estimation Methods

Method	Hydrological Input Parameters	Recommended Max Area (km^2)	Return Period Limits (years)
Rational Method	Catchment area, watercourse length, average slope, catchment characteristics, rainfall intensity	< 0.5	2 – 200
SCS Method	Catchment area, watercourse length, length to catchment centroid (centre), mean annual rainfall, vegetation type, soil cover and synthetic regional unit hydrograph	No limitation, large areas	2 – 200
Synthetic Hydrograph Method	Catchment area, watercourse length, length to catchment centroid (centre), mean annual rainfall, vegetation type and synthetic regional unit hydrograph	Recommended up to 200km^2	2 – 200
Empirical Methods	Catchment area, watercourse length, distance to catchment centroid (centre), mean annual rainfall	No limitation, large areas	2 – 200
Statistical Method	Historical flood peak records	No limitation, large areas	2 – 200

The estimation of peak flows can be carried out using statistical or empirical methods. For the purpose of this manual and in general, the following guide could be used to select the most suitable method for use based on the road project:

i. Relate results from several methods.

ii. For the hydrological peak flows, the peak discharge is adequate for design of structures such as storm drains, open channels, culverts, and bridges. However, in areas with known storage like dams, if need be complex analysis like flood routing through and application of flood hydrograph would be done.

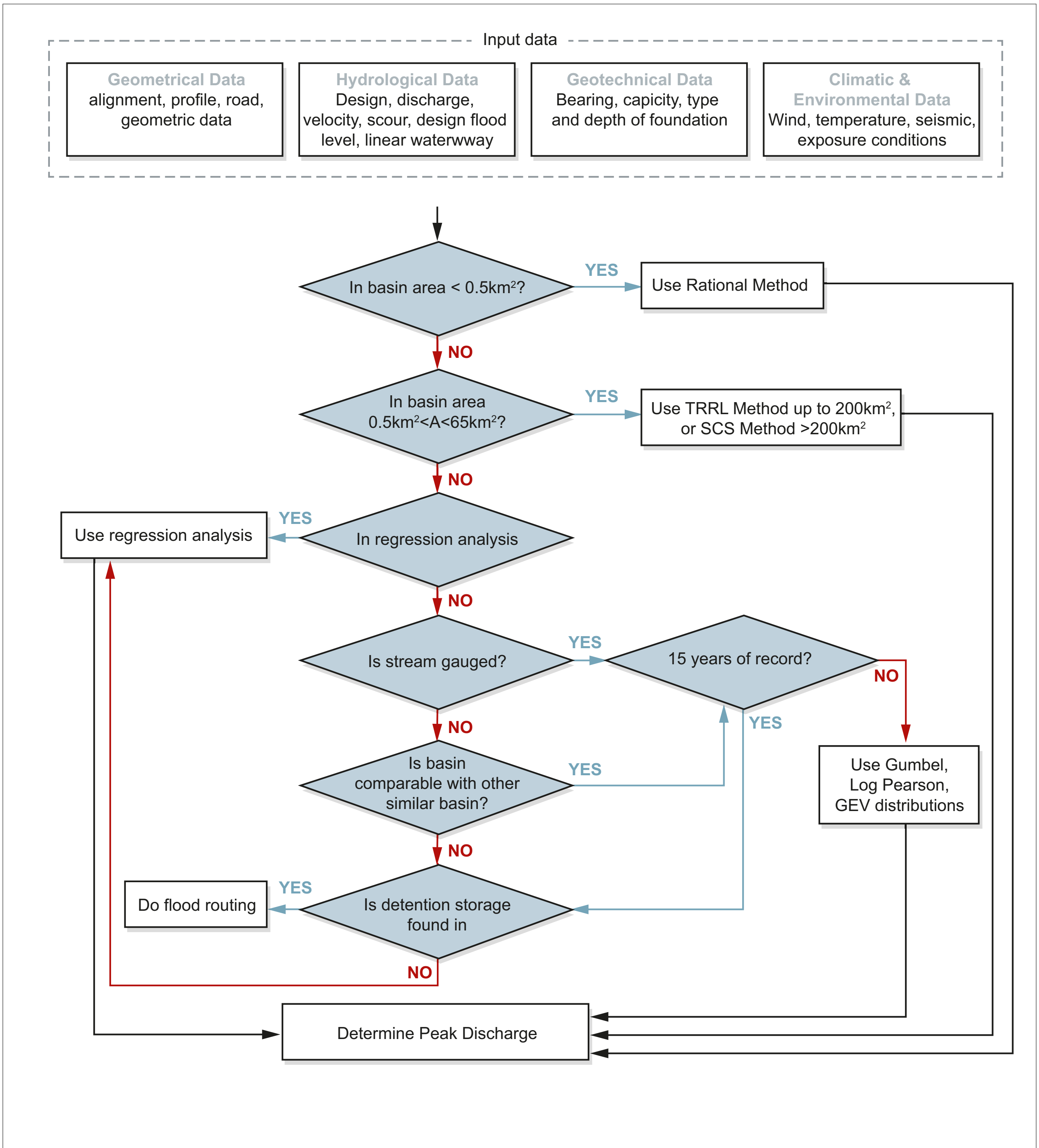
iii. At most of the times use the discharge that appears to best reflect local project conditions. Averaging of results of several methods is not recommended; and rather prudent to elaborate the reasons supporting the selection of the results method.

iv. The hydrologist should ensure that the selected hydrologic method is appropriate for the catchment conditions and that sufficient data is available for analysis. Whenever possible, the method should be calibrated to local conditions and flood history using the local knowledge and onsite interviews.

4.4.1 Hydrologic Analysis Procedure Flowchart

The hydrologic analysis procedure flowchart Figure 4.1 shows the steps needed for the hydrologic analysis and the designs that will use the hydrologic estimates.

Figure 4.1 Determining Peak Discharge Charts



5 Flood Estimation for Gauged Catchments

5.1 General

The use of measured river flow data is the first choice for hydraulic design of drainage structures, especially large bridges. However, the availability of measured water levels and river flow in Kenya varies over space and time. Generally, there are more hydrometric stations in the western part of the country and Upper Tana Basin than towards the coast. In areas where irrigations schemes are in operation, more accurate data on river flow and, possibly, information on peak discharges are available.

For the design of large structures, the optimum use of measured river flow data is strongly recommended. Flood water runoff estimation methods solely based upon empirical rainfall – runoff models (as described in Chapter 6 of this Manual) are widely utilised with some caution due to under estimation or overestimation information for safe design.

5.2 Sources of Stream Flow Data in Kenya

The road designer will need to acquire a record of the annual peak flows for the appropriate gauging station. The main state agencies that are the sources of river data are:

i. The Ministry of Water and Irrigation – main database offices.

ii. The Water Resources Authority (WRA) offices.

5.3 Frequency and Statistical Analyses of Stream Flow Data

5.3.1 Stream Flow Data

The analysis of gauged data is done by statistical methods provided sufficient data are available at the site to permit a meaningful statistical analysis to be made. It is suggested that at least 15 years of record are necessary to warrant a statistical analysis by method presented therein. Where we have series of stream flow observations made and stream gauge data obtained, it is necessary to use these data, to develop a peak discharge versus frequency relation for peak runoff from the catchment.

5.3.2 Peak Flow Frequency Analysis Concepts

Future floods cannot be predicted with certainty. Therefore, their magnitude and frequency are derived using probability concepts. To do this, a sample of flood magnitudes are obtained and analysed for the purpose of estimating a population that can be used to represent flooding at a location. The assumed population is then used in making projections of the magnitude and frequency of floods. It is important to recognise that the population is estimated from sample information and that the assumed population, not the sample, is then used for making statements about the likelihood of future flooding. The purpose of this section is to introduce concepts that are important in analysing sample flood data to identify a probability distribution that can represent the occurrence of flooding.

Where a river gauging record covers a sufficient period, it is possible to develop a peak stream-flow frequency relation by statistical analysis of the series of recorded annual maximum flows. Such flow data can be further utilised to make basin and sub basin relationships productively in three distinct ways:

i. Where the road drainage crossing is near the gauging station on the same stream and catchments, the discharge can be used directly for a specific frequency (T-year discharge) from the peak stream flow frequency relationship.

ii. Where the drainage structure crossing is within the same basin and or sub basin but not proximate to the gauging station, transposition of gauge analysis results is possible.

iii. Where the drainage crossing is not within a gauged basin, it is possible to develop the flood-frequency from data from a group of several gauging stations based on either a hydrologic region (e.g., regional regression equations), or similar hydrologic characteristics.

5.3.3 Site Curve Development

Where data is available, we can develop a peak stream flow versus frequency curve for a site by statistical means provided the following requirements are met:

i. There is a sufficient peak discharge sample – a sufficient statistical sample of annual peak discharges must be available. This usually means a minimum of ten years of data. Some statisticians prefer a sample of 20 or more years. However, sometimes 20 years of data may not be available and shorter periods would have to be used. The uncertainty in the results using short periods of data should therefore be highlighted.

ii. There is no significant change in the channel/basin – no significant changes in the channel or basin should have taken place during the period of record. If significant changes did occur, the resulting peak-stream flow frequency relation could be flawed unless the rating curve has been adjusted. Sudden changes like the urbanisation character of the watershed should be taken into consideration.

iii. There are no physical flow regulations existing, like dams and or abstraction – a series of observed data from a catchment within which there have been, are, or will regulate physical flow regulations.

iv. That data is a representative of catchment - the flow data must be representative of the sub basin.

5.3.4 Application and Limitation of Stream Flow Data Sets

For the road flood hydrology purpose, statistical analysis of streamflow data is normally applied where we have quality and adequate data from River gauging stations (RGS). For this particular reason the manual guides on the minimum application data availability depending on the desired frequencies. This is presented in Table 5.1.

Table 5.1 Proposed Minimum River Flow Records Lengths

S/No	Design Frequency (Yrs.)	Minimum flow records period (Yrs.)
1	10	10
2	25	15
3	50	25
4	100	40

Where adequate data are not available, the basis for the design peak discharge could be data from several stream flow-gauging stations. For instances where the planned crossing analysis of flows, design peak discharge could be on the same stream and near an active or discontinued stream flow-gauging station with an adequate length of record. The catchment area ratio could therefore be applied upon confirmation of the catchment homogeneity.

Having determined that a suitable stream gauge record exists, it is therefore necessary to determine if any structures crossing or increased land use such us urbanisation may affect the peak discharges at the planned structure crossing. Below are some guidelines put in place when considering peak flow discharges;

i. The period of record similar to design crossing site – The period of flow record for the gauging station's maximum annual peak discharges should represent the catchment conditions as that of the planned design site. To do this by analysing only the streamflow data may be difficult. A comparison with rainfall data over the same period would help in identifying high events which correspond to observed peaks. If such rainfall events are not observed, yet streamflow peaks are, they could thereafter be excluded from the data.

ii. The factors affecting peak flow discharge – The most typical factors affecting peak discharges are regulation by dams, reservoirs abstraction points and urbanisation. Increased impervious catchment affects the peak flows. The existence of major reservoirs, dams and water abstractions points or other flood control structures have impacts on the runoff characteristics of streams.

iii. The length of flow records – The length of discharge record should be adjusted to include only those records that have been collected subsequent to the impoundment of water by reservoirs, major water abstractions and any major land use change.

5.3.5 Flow Data Gaps in Annual Maximum Series

Data gaps will always be present in any data series despite best efforts by the authority to prevent them. Sources of the data gaps could be from and not limited to the following:

i. Staff gauges could be gauges washed away by extreme flows.

ii. Vandalised equipment's.

iii. Resources challenges by the agencies.

iv. Lack of staff on site.

Missing records in the annual maximum flood series can be in-filled where the extra data points can be estimated with sufficient accuracy to contribute additional information. This works best when we have lengthy period of data sets.

a) Method 1: Assessment can be made from the monthly instantaneous maximum flow data sets with monthly maximum mean data sets at the same station for years with data gaps should be identified. If a missing month of instantaneous maximum flow corresponds to a month of very low maximum mean daily flow, then that should be taken to indicate that the annual maximum does not occur during that missing month and this could be an error indicator. When we have corresponding months then the data sets can be utilised.

b) Method 2: This method involves the use of a linear regression of the annual maximum mean flow series against the annual instantaneous maximum series of the same station. Regression equations developed should be used for filling gaps in the instantaneous monthly records. This is applicable to observed data sets.

c) Method 3: The use of long-term annual averages. Where we have long term data sets, the mean annual flow can be used to infill single missing year data flows.

5.4 Flow Data Procedure Analysis

5.4.1 Data Preparations

Before carrying out flow data analysis, it is necessary to arrange it in a systematic manner. Data can be arranged in a number of ways depending on the specific characteristics that are to be examined. This kind of arrangement of data by a specific characteristic is called a distribution or a series. The most common arrangement of hydrologic data is by magnitude of the annual peak discharge. This arrangement is called an annual series. Another method used in flood data arrangement is the partial-duration series. This procedure uses all peak flows (for instance all flows above the discharge of approximately bank-full stage) above some base value.

Partial-duration series are used primarily in defining annual flood damages when more than one event that causes flood damages can occur in any year. The partial-duration series avoids a problem with the annual-maximum series. Annual maximum series analyses ignore floods that are not the highest flood of that year even though they are larger than the highest floods of other years. While partial-duration series produce larger sample sizes than annual maximum series, they require a criterion that defines independence of the discharges to be considered for the frequency analysis.

The difference between the results of the two methods is largely in at the low flows and becomes very small at the higher peak discharges. If the recurrence interval of these peak flows is computed as the order divided by the number of events (not years), the recurrence interval of the partial-duration series can be computed in terms of the annual series by the equation:

$$T_B = \frac{1}{lnT_A - ln\,(T_A - 1)}$$

Equation 5.1

Where,

T_B and T_A are the recurrence intervals of the partial-duration series and annual series respectively.

Comparison between analyses results of the two methods shows that the maximum deviation between the two series occurs for flows with recurrence intervals less than 10 years. At this interval the deviation is about 5 % and for the 5-year discharge, the deviation is about 10 %. For the less frequent floods, the two series approach one another.

When using the partial-duration series, one must be especially careful that the selected flood peaks are independent events. This is a difficult practical problem since secondary flood peaks may occur during the same flood due to high antecedent moisture conditions. In this case, the secondary flood is not an independent event. One should also be cautious with the choice of the lower limit or base flood since it directly affects the computation of the properties of the distribution (i.e. the mean, the variance and standard deviation, and the coefficient of skew) all of which may change the peak flow determinations. For this reason, it is probably best to utilise the annual series and convert the results to a partial-duration series through use of Equation 5.1. For the less frequent events (greater than 5 to 10 years), the annual series is entirely appropriate and no other analysis is required.

5.4.2 Plotting Formulae

When making a flood frequency analysis, it is common to plot both the assumed population and the peak discharges of the sample. To plot the sample values on frequency paper or as computer chart in a logarithmic form, it is necessary to assign an exceedance probability to each magnitude. A plotting position formula is used for this purpose. A number of different formulas have been proposed for computing plotting position probabilities, with no unanimity on the preferred method. A general formula for computing plotting positions is:

$$P = \frac{i - a}{n - a - b + 1}$$

Equation 5.2

1
2
3
4
5
Flood Estimation for Gauged Catchments

Where,

i = The rank of the ordered flood magnitudes, with the largest flood having a rank of 1.
n = The record length.
a and b = Constants for a particular plotting position formula.

The Weibull, Pw ($a = b = 0$), Hazen, Ph ($a = b = 0.5$), and Cunnane, Pc ($a = b = 0.4$) are three possible plotting position formulas:

$$P_w = \frac{i}{n+1}$$ Equation 5.3(a)

$$P_h = \frac{i-0.5}{n}$$ Equation 5.3(b)

$$P_c = \frac{i-0.4}{n+0.2}$$ Equation 5.3(c)

The data are plotted by placing a point for each value of the flood series at the intersection of the flood magnitude and the exceedance probability computed with the plotting position formula.

5.4.3 Distribution Function

Flood frequency analysis is a technique to predict flows at different exceedance probabilities at a point of interest along a river.

Several frequency distributions are commonly used in the analysis of hydrologic data such as Normal Distribution, the Log-Normal Distribution, the Gumbel Extreme Value Distribution, and the log-Pearson Type III distribution.

A very good approximation for most common distribution function is the Simplified Frequency Formula as presented below:

$$Y_T = X + o * k$$ Equation 5.4

Where,

Y_T = Expected maximum event at given return period.
X = Mean value of sample.
o = Standard deviation of values in sample.
k = Frequency factor, depending on return period and sample size as show in Table 5.2.

Table 5.2 Gumbel k Values for Different Sample Size and Return Periods, After Chow (1)

Sample size n	Return Period (Yrs.)				
	2	5	10	25	50
10	-0.136	1.058	1.848	2.846	3.587
15	-0.144	0.967	1.702	2.631	3.320
20	-0.148	0.918	1.624	2.516	3.178
25	-0.151	0.887	1.575	2.444	3.088
30	-0.153	0.866	1.540	2.393	3.025
35	-0.154	0.850	1.515	2.355	2.978
40	-0.156	0.837	1.495	2.326	2.942
45	-0.157	0.827	1.479	2.302	2.913
50	-0.157	0.819	1.466	2.283	2.889

A worked example is presented in the Appendix A

5.5 Regional Flood Frequency Curve

Based on the probable flood discharges obtained for a number of rivers / streams, regional flood curves have been derived for major rivers in 5 drainage areas of Kenya.

The derivation of regional flood frequency curves used the following steps:

i. Probable flood discharges, which are extracted from maximum values among estimate from the statistical methods (Gumbel extreme, Log normal and Log Pearson type III distributions) are made non dimensional by dividing by the mean annual maximum flood at the station.

ii. Mean ratio for each return period are then plotted on a graph and a regional flood frequency curve is drawn out.

iii. The relation between mean annual flood and catchment area is also plotted.

Regional Flood Frequency curves are used to obtain preliminary estimates of floods of gauged or at times ungauged catchments having only a few years of records. The Kenyan Basin curves are presented in Table 5.3.

Table 5.3 Estimation of Probable Flood Discharges on Regional Flood Frequency Curve Basis

Major River Basin	Equation Deriving MAF	Multiplier to MAF for Estimation of Discharges of each Return Period *(Years)*				
		5	10	25	50	100
Nzoia (1)	$Q = 0.080A^{0.898}$	1.57	2.09	2.92	3.78	4.82
Yala (1)	$Q = 0.780A^{0.644}$	1.60	2.08	2.82	3.59	4.48
Nyando (1)	$Q = 0.093A^{0.960}$	1.70	2.35	3.28	4.33	5.58
Sondu (1)	$Q = 0.345A^{0.756}$	1.77	2.32	3.13	4.06	5.39
Kuja/Migori (1)	$Q = 0.205A^{0.849}$	1.48	1.84	2.37	2.83	3.33
Rift Valley Basin (2)	$Q = 0.030A^{1.069}$	1.71	2.40	3.49	4.58	6.00
Athi (3)	$Q = 0.249A^{0.835}$	1.87	2.62	3.79	5.29	7.22
Tana (4)	$Q = 0.480A^{0.794}$	1.52	1.93	2.52	3.08	3.71
Ewaso Ngiro North (5)	$Q = 0.812A^{0.564}$	1.92	2.63	3.79	5.35	7.45

MAF = Mean Annual Flood, Q = Flood Discharge (m^3/s), A = Catchment Area km^2

6 Flood Estimation for Ungauged Catchments

6.1 General

The estimation of storm water runoff from ungauged catchments using rainfall – runoff models is the most common exercise carried out by hydrologists as far as road flood drainage issues are concerned. This is due to very few catchments in Kenya having operational monitoring systems. The small and medium sized catchments often crossed or even created by road embankments are usually not measured and estimation techniques have to be applied.

The basis of all flood flow estimations should be the site visit, which represents an essential step in the design procedure as described earlier. High water marks should be identified and surveyed as part of the field inspection.

Interviews with local inhabitants usually provide information on historic flood events. It should be mentioned however, that only people who live near the proposed crossings can provide good quality information on the flooding behaviour of specific rivers. The observed high-water marks should be used as a calibration tool for all storm water run-off estimation results achieved on the basis of basic or more complex rainfall runoff models. Often existing structures upstream or downstream of the planned crossing point can provide further information on flood flow. For the rainfall runoff model to be carried out there are basic hydrological parameters that forms input to the various model. This is discussed in the subsequent Section 6.2.

6.2 Key Input Parameters for Hydrological Modelling

To carrying out rainfall runoff modelling, input parameters specific to the project catchments need to be obtained. The Hydrologist will have the responsibility to analyse the available information for use within a Project. The hydrological parameters forming inputs to design are presented in Table 6.1.

6.3 Key Hydrological Design Considerations

6.3.1 General

Selection of hydrologic input parameters in rainfall runoff models have a direct impact on the runoff. Rainfall records is key to rainfall runoff model. The lengthier the rainfall records, the more reliable the results will be.

6.3.2 Application and Limitation of Rainfall Data Sets

For the road flood hydrology purpose, where rainfall runoff model analysis is to be utilised, quality and adequate data from rainfall stations are required. For this particular reason the manual guides on the minimum application data availability depending on the desired rainfall frequencies. This is presented in Table 6.2.

Where adequate data are not available, the basis for the rainfall runoff model for peak discharge could be rainfall data from other neighbouring stations. The key thing to look at is the homogeneity of the catchment especially altitude and topography are characteristics that affect rainfall. Rainfall correlation of the catchment would be done for common year period data sets.

Some of the key hydrologic principles and concepts that affect runoff in a catchment are discussed in the subsequent sections.

Table 6.1 Key Input Hydrological Parameters

S/No	Key hydro-logical input parameter	Method of determination	Use on road flood hydrology
1	**Catchment area**	This is determined from the topographical or equivalent features, upon any part of water shed which rain falling will contribute to the discharge of the stream at the low point of interest It is obtained by delineating a watershed on topographic maps for the designated discharge crossing. Typical maps used are 1:50000 or 1:250000 topographical scale. Catchment delineating tools within a GIS environment, using remotely sensed digital elevation models can also be used.	The catchment area obtained is used for flood discharge calculations
2	**Catchment area characteristics**	They include the catchment slope, stream slope, vegetation cover, land use and soil types.	They are used to determine the time of concentration and the runoff factors
3	**Catchment slope**	This is the average slope of the catchment determined from the topographic maps from the horizontal distance and the main drop in height for the contours.	It is used to give indicators for the time of concentration and runoff factors
4	**Land use**	Detail of these are obtained from the land use maps, aerial photos and actual field visits.	The land use factor heavily influence runoff
5	**Soil types**	The data source is mainly from the soil maps and verification from the site visits.	Soil types affect's the runoff due to permeability factor
6	**Rainfall intensity**	This are commonly referred to as Intensity Duration Frequency (IDF) curves developed by the Kenya Meteorological Department (KMD) and can be used to give the rainfall intensities for various towns and locations in Kenya.	The values are used to determine rainfall intensity for the design return periods. These values are used for calculating design flood discharges especially for the urban areas using the Rational Method
7	**Time of concentration (Tc)**	It is usually determined from topographical maps as the distance from the crossing to the most remote point in the delineated catchment area. This is the time taken for the farthest drop of rain that is falling in the catchment area to reach the outlet crossing structure.	It is used for the calculation of flood peak discharges
8	**Runoff factor / coefficient**	Obtained from various publications and hydrological literature.	Used in the flow modelling for discharge calculations

Table 6.2 Proposed Minimum Rainfall Records

S/No	Design Frequency (Yrs.)	Minimum rainfall records period (Yrs.)
1	10	10
2	25	20
3	50	30
4	100	50

6.3.3 Catchment Abstractions

The existing catchment losses described as abstractions usually reduce the volume of water collected as runoff at a specific location. The six forms of abstractions that are often considered are outlined below:

a. Infiltration – this is the amount of precipitation that infiltrates into the surface within the catchment area. It is mainly affected by type of and its inherent characteristics, catchment slopes, and ground cover. Data on infiltration rates is not easy to came by as detailed topographical soil data etc is required. Often an experienced hydrologist of drainage engineer will make an informed decision.

b. Depression storages – is the precipitation stored in permanently low lying areas within the catchments.

c. Detention storage – is the precipitation stored temporarily in streams, channels, and reservoirs within the watershed. This are basically man-made interventions in the watershed.

d. Interception – this is the captures that are done by leaves, rooftops and pavements that are interceded before infiltration takes place.

e. Evaporation – this is the precipitation that returns to the atmosphere as water vapor. It is mainly controlled by exposed open water surface.

f. Transpiration – this is the water loss from vegetation and is mainly controlled by the vegetation density.

Existing abstractions occurring upstream of the crossing reduce the surface runoff at the exit. Large water dams could lead to massive damages in the events of flood outbursts and existing information such as spillway design floods should be considered to reduce the risks.

6.3.4 Catchment Area Data

Estimation of flows in ungauged catchments is dependent on the catchment data that is collected. The size of the catchment and its associated characteristics do not change once obtained. Other features like land use and infrastructure can vary.

The mapped-out watershed shape will also affect rainfall runoff rates. A long, narrow watershed is likely to experience lower runoff rates than a circular catchment of similar size and characteristics.

6.3.5 Land Usage

Catchment land use is a major factor that significantly affects runoff. The following are parameters that are subject to change with respect to land use that may affect flows:

i. Surfaces areas that are permeable and impermeable.

ii. Vegetation cover.

iii. Minor topographic features like hills.

iv. Catchment drainage systems from anthropogenic influences.

6.3.6 Soil Types and Groups

The soil drainage characteristics have an impact on the flows that are generated from a watershed. Existing soil properties influence the relationship between runoff and rainfall. This is largely because infiltration rates vary with different soil types.

From the site observations, soil drainage characteristics can have been classified in accordance with the (Transport and Road Research Laboratory) TRRL classification reproduced in Table 6.3.

Table 6.3 Soil Permeability Classification

Soil class	Description
Impeded	• Very low permeability. • Clay soils with high swelling potential. • Shallow soils over largely impermeable layer, very high-water table.
Slightly impeded Drainage	• Low permeability. • Drainage slightly impeded when soil fully wetted.
Well drained	• Very permeable. • Soil with very high infiltration rates such as sands, gravels and aggregated clays.

Permeability and infiltration can also be classified according to the US based method, i.e. Hydrologic Soils Groups. This is presented in Table 6.4. Further detailed soil maps can be obtained from the Soil Maps of Kenya publications.

Table 6.4 Hydrologic Soil Groups

S/ No	Soil class	Description
1	**Group A:** Sand, loamy sand or sandy loam	Soils having a low runoff potential due to high infiltration rate. These soils primarily consist of deep, well-drained sands and gravels.
2	**Group B:** Silt loam, or loam	Soils having a moderately low runoff potential due to moderate infiltration rates. These soils primarily consist of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures
3	**Group C:** Sandy clay loam	Soils having a moderately high runoff potential due to slow infiltration rates. These soils primarily consist of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.
4	**Group D:** Clay loam, silty clay loam, sandy clay, silty clay or clay	Soils having a high runoff potential due to very slow infiltration rates. These soils primarily consist of clays with high swelling potential, soils with permanently high-water tables, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

6.3.7 Catchment Slopes

Catchment slopes have a direct impact on the runoff coefficient. As the slope of the catchment increases, the selected runoff coefficient 'C' will also increase. This is because as the slope of the catchment area increases, the velocity of overland and channel flow will increase allowing less chances for water to infiltrate ground. Therefore, more of the rainfall will be converted into runoff from the catchment area.

6.3.8 Catchment Runoff Coefficients

The runoff coefficient commonly represented in hydrology as 'C' is a measure of response on the ground infiltration. It is normally given as a sum of factors on the average slope of a catchment, permeability of the soil and the vegetation.

When there are different land uses within a catchment, a composite runoff coefficient based on the percentage weights of each surface in the catchment area will have to be computed. The composite procedure can be applied to an entire catchment area and or as block to guide designer to selection of reasonable values of the coefficient for an entire drainage area. Different terrains may have varied runoff based on the topography. This is shown in Table 6.5.

Table 6.5 Recommended Runoff Coefficient for Terrain Type

Terrain Type	Soil Type			
	A	B	C	D
Flat, < 2%	0.04 – 0.09	0.07 – 0.12	0.11 – 0.16	0.15 – 0.20
Rolling, 2-6%	0.09 – 0.14	0.12 – 0.17	0.16 – 0.21	0.20 – 0.25
Mountain, 6-15%	0.13 – 0.18	0.18 – 0.24	0.23 – 0.31	0.28 – 0.38
Escarpment, > 15%	0.18 – 0.22	0.24 – 0.30	0.30 – 0.40	0.38 – 0.48

For sites that exhibits various surfaces especially in built up environment, the coefficients are presented in Table 6.6.

Table 6.6 Recommended Coefficients for Composite Runoff Analysis

Surface	Runoff Coefficients
Asphalt (street)	0.70 – 0.95
Concrete (street)	0.80 – 0.95
Drives and walks	0.75 – 0.85
Roofs	0.75 – 0.95

6.3.9 Diverted Flows

When we have flow diversion in a water catchment, it changes the time of travel and has an impact on the discharges rates. Where diversions are for abstraction purpose, they reduce the discharge and the out let and vice versa.

6.3.10 Channelisation

Channelisation are often done to improve the flow regimes in the urban areas and includes the following:

i. Improved open channels.

ii. Kerb and gutter street sections.

iii. Storm-drain systems.

The channelisation is served to make drainage more efficient in any catchment basin. This means that flows in these areas with urban channelisation are far greater with peak discharges occurring more quickly than where no significant channels that exist.

6.4 Hydrological Methods for Calculating Flows in Ungauged Catchments

The following main methods are commonly utilised in determining peak flood discharges for design of road drainage structures in Kenya as listed in Table 6.7. The Table 6.7 presents estimation of peak runoff rates more of the empirical methods.

The following guidelines have however been developed in order to allow the designer select flow estimation method based on the data availability:

i. To compare results from another method where applicable.

ii. Always use the discharge that appears to best reflect local project conditions for site specifics.

iii. The peak discharge is adequate for design of passage systems such as storm drains, open channels, culverts, and bridges. Where we have upstream storage such as dams, then lagging or attenuation of peak flows should be considered.

iv. The designer must ensure that the selected hydrologic method for flood estimation is appropriate for the basin conditions and that sufficient data is available to perform the required calculations. If possible, the method should be calibrated to local conditions and flood history that can be obtained from the local interviews with the areas residents.

Table 6.7 Commonly Applicable Methods for Ungauged Catchments in Kenya

Method	**Input data**	**Recommended maximum area** (km^2)
Specific Discharge Method	Specific discharge data from region, catchment area and related characteristics.	No limitation, large areas
Rational Method	Catchment area, watercourse length, stream slope, catchment characteristics, rainfall intensity	<0.5
Soil Conservation Services (SCS) **Method**	Catchment area, watercourse length and slopes, maximum daily precipitations, vegetation type, soil cover and type.	0.5 to 5000
East Africa Flood Method (EAFM)	Catchment area, watercourse length and slopes, maximum daily precipitations, vegetation type, soil cover and type, rainfall intensities, presence of lag features like swamps, dams etc.	0.5 to 200
Regional Curve method	Available developed curves for the basin.	No limitation, large areas
Slope area method (onsite MAF)	Marked historical flood peak.	No limitation, large areas

6.4.1 Hydrological Software's

There are several hydrological software that are available for use in hydrological analysis. Some are independent while others are inherently used together with other computer packages. Where river flow data is available statistical packages can be used. Where river flow data is not available, software based empirical methods such as Hydrological Modelling System (HEC – HMS), Soil Conservation Service (SCS) East Africa Flood Model (EAFM), the Rational analysis could be utilised.

6.5 Specific Discharge Method

The specific Discharge Method is based upon transferring the specific storm water discharge calculated as l/s/ha or $m^3/s/km^2$ from similar, gauged, catchments in the project region to the actual project site. Catchment size, form, exposure and slope should be of comparable nature for both catchments, as well as the overall climatic and topographic conditions. The un - gauged catchments is in some cases an upstream sub - catchment of a larger measured river basin. In this case the probable contribution of the sub - catchment to the total measured river flow can be estimated based on the basis of the respective surface areas of the catchments. However, specific basin characteristics have to be considered in order to avoid over - or under design. Catchment area ratio are fully utilised for this case.

6.6 Rational Method

The Rational Method is most accurate for estimating design storm peak runoff for areas up to 0.5 km^2. This method, while first introduced in 1889, is still widely used. Even though it has come under frequent criticism for its simplistic approach, no other drainage design method has achieved such widespread use.

6.6.1 Application Limitations

Some precautions should be considered when applying the Rational Method. This includes and is not limited to:

i. In the initial steps of applying the Rational Method, good topographic maps should be obtained and boundaries of the catchment area in question well defined. A field inspection of the area should also be made to determine if the natural drainage divides have been altered.

ii. In determining the runoff coefficient C value for the catchment area, thought shall be given to future changes in land use (deforestation, crop land, buildings) that might occur during the service life of the proposed facility that could result in an inadequate drainage system. Also, the effects and the life span of upstream detention structures must be considered. Restrictions to the natural flow such as highway crossings and dams that exist in the catchment area shall be investigated to see how they affect the design flows.

6.6.2 Rational Method Characteristics

Characteristics of the Rational Method that generally limits its use include:

i. The rate of runoff resulting from any rainfall intensity is a maximum when the rainfall intensity lasts as long or longer than the time of concentration. That is, the entire catchment area does not contribute to the peak discharge until the time of concentration has elapsed.

This assumption limits the size of the drainage basin that can be evaluated by the Rational Method. For large catchment areas, the time of concentration can be so large that constant rainfall intensities for such long periods do not occur, and shorter more intense rainfalls can produce larger peak flows.

ii. The fraction of rainfall that becomes runoff (C) is independent of rainfall intensity or volume.

This assumption is only reasonable for impervious areas, such as streets, rooftops, and parking lots. For pervious areas, the fraction of runoff does vary with rainfall intensity and the accumulated volume of rainfall.

Thus, the application of the Rational Method requires the selection of a coefficient that is appropriate for the storm, soil, and land use conditions. Many guidelines and tables have been established and can always be referenced to.

6.6.3 Equation for Rational Method

The rational formula estimates the peak rate of runoff at any location in a catchment area as a function of the catchment area, runoff coefficient, and the mean rainfall intensity for a duration equal to the time of concentration. The rational formula is expressed as:

$$Q = 0.00278\, CIA \qquad \text{Equation 6.1}$$

Where,

Q = Maximum rate of runoff, m^3/s.

C = Runoff coefficient, representing a ratio of runoff to rainfall.

I = Average rainfall intensity for a duration equal to the time of concentration T_C, for a selected return period, mm/hr.

A = Catchment area tributary to the design location, km^2.

6.6.4 Time of Concentration T_C

The time of concentration is the time required for water to flow from the hydraulically most remote point of the catchment area to the point under investigation. Use of the Rational Method requires the time of concentration tc for each design point within the catchment area. The duration of rainfall is then set equal to the time of concentration, and is used to estimate the design average rainfall intensity

i. Pipe or open channel flow time can be estimated from the hydraulic properties of the conduit or channel. An alternative way to estimate the overland flow time is to estimate overland flow velocity and divide the velocity into the overland travel distance.

For design conditions in rural and agricultural areas which do not involve complex drainage conditions, like steep slopes and mixed land use, the following two equations are recommended for use in Kenya.

The key formula for calculation of the Time of Concentration are the Kirpich Formula and the Hathway Formula that are presented in the subsequent section;

6.6.4.1 Kirpich Formula

$$T_C = 0.0663 * L^{0.77} * S^{-0.385} \qquad \text{Equation 6.2}$$

Where,

T_C = Time of concentration (hr).

L = Main stream length (km).

S = Overall catchment slope in m/m.

6.6.4.2 Hathway Formula

$$T_C = 1.44 \left(\frac{L.N}{\sqrt{S}}\right)^{0.47} \qquad \text{Equation 6.3}$$

Where,

T_C = Time of concentration (minutes).

L = Catchment length (metres).

S = Catchment slope (m/m).

N = Catchment roughness factor, see Table 6.8.

Table 6.8 Catchment Roughness Factor in Hathways Formula

Soil types	N
Smooth and impermeable	0.02
Bare and compacted	0.10
Plantations and agricultural areas	0.20
Bush and shrubs, low vegetation	0.40
Forest	0.60

Usually the Kirpich Formula provides shorter T_C, and thus results in more conservative and costlier design parameters. For catchment areas with considerable vegetated areas, the Hathaway Formula is recommended. Calculation of Time of concentration for well-defined water courses.

In a very well-defined watercourse, channel flow occurs. The recommended empirical formula for calculating the time of concentration in natural channels was developed by the US Soil Conservation Service. This can be done using the following formulae.

$$T_C = \left(\frac{0.87L2}{1000S_{ave}} \right)^{0.47} \quad \text{Equation 6.4}$$

Where,

Tc = Time of concentration (hrs)

L = Hydraulic length of catchments measured along flow path from the catchment boundary to the point where the flood needs to be determined (km)

S_{ave} = Average slope (m/m).

L and S_{ave} are determined from topographical maps.

6.6.4.4. Sources for Calculating Time of Concentration

Three common errors should be avoided when calculating TC:

i. First, application of simplified general equations such as Kirpich for determining tc can result in too short of a time of concentration particularly when the average basin slope varies significantly from the mean channel slope as in steep mountainous areas. Neglecting the overland flow time can also dramatically shorten the time of concentration thus increasing the design peak runoff. Computing TC for two reaches of main channel, from the low point to the 0.85 point, then from there to the end of the channel, has been found to give better results.

ii. Second, in some cases runoff from a portion of the catchment area that is highly impervious may result in a greater peak discharge than would occur if the entire area were considered. In these cases, adjustments can be made to the catchment area by disregarding those areas where flow time is too slow to add to the peak discharge. Sometimes it is necessary to estimate several different times of concentration to determine the design flow that is critical for a particular application.

iii. When designing a drainage system, the overland flow path is not necessarily perpendicular to the contours shown on available mapping. Especially in urban areas, the land will be graded, and swales will intercept the natural contour and conduct the water to the streets, which reduces the time of concentration. Care shall be exercised in selecting overland flow paths in excess of 100 metres in urban areas and 200 metres in rural areas.

6.6.5 Rainfall Intensity, I

The rainfall intensity (I) is the average rainfall rate in mm/hr. Once a particular return period has been selected for design and a time of concentration calculated for the catchment area, the rainfall intensity can be determined from Rainfall-Intensity-Duration curves. Rainfall-Intensity-Duration curves for use in Kenya can found in the 'Rainfall Frequency Atlas of Kenya'. In addition the derived values and formula from the EAFM as developed by the TRRL with regional constants could be used.

However, from the daily 24 hr annual maximum recorded precipitation, a specific site intensity can be calculated using the formula below:

$$I = \left(\frac{374.0410 * T^{0.206252}}{t^{0.61885}}\right)^{0.47} \qquad \text{Equation 6.5}$$

A sample of the calculated rainfall intensity duration curve is presented in the Appendix A.2.

6.6.6 Runoff Coefficient, C

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 designer.

In determining the run-off coefficient, the designer should use his knowledge of local conditions to take account of the following parameters:

i. Catchment area.

ii. Slope.

iii. Soil type.

iv. Vegetation.

v. Land use and probable changes during the design life of the road.

It is stressed that future changes in land use can have a dramatic effect on the runoff from a catchment and careful consideration should be given to possible changes in vegetation cover or future developments within the catchment.

6.6.7 Undeveloped Basins and Natural Catchments

Runoff coefficients for most natural catchments in Kenya were developed through research carried out in the 1970s by TRRL.

It is recommended to use the Contributing Area Coefficient (CA) as described in main TRRL references. For typical rural areas catchment, the Table 6.9 could be used to guide and arriving on the appropriate runoff coefficient.

Table 6.9 Recommended Runoff Coefficient C for Rural Catchment

Factor		Description	Runoff coefficient
C_s	Average slope of catchment	< 3.5% Flat	0.05
		3.5% - 10% Soft to moderate	0.1
		10% - 25% Rolling	0.15
		25% - 45% Hilly	0.2
		> 45% Mountainous	0.25
C_p	Permeability of soil	Well drained soil e.g. sand and gravel	0.05
		Fair drained soil e.g. sand and gravel with fines	0.1
		Poorly drained soil e.g. silt	0.15
		Impervious soil e.g. clay, organic silts and clay	0.25
		Water-logged black cotton soil	0.5
		Rock	0.4
C_v	Vegetation	Dense forest/thick bush	0.05
		Sparse forest/dense grass	0.1
		Grassland/scrub	0.15
		Cultivation	0.2
		Space grassland	0.25
		Barren	0.3

The runoff coefficient (C) is the sum of the runoff factors given in Equation 6.6.

$$C = Cs + Cp + Cv$$

Equation 6.6

The results of using the Rational Formula to estimate peak discharges is very sensitive to the parameters that are used especially the runoff factor 'C'. The designer must use sound practicable engineering rationale in estimating values that are used in the method.

6.6.8 Urban Land Use

For urban land use the recommended coefficients are presented in Table 6.10.

Table 6.10 Recommended Runoff Coefficient C for Various Urban Land Uses

	Urban Land Use	Runoff coefficient
Business	Downtown areas	0.70-0.95
	Neighbourhood areas	0.50-0.70
Residential	Single-family areas	0.30-0.50
	Multi units, detached Multi units, attached	0.40-0.60
	Suburban	0.25-0.40
	0.5 hectare lots or more	0.30-0.45
	Apartment dwelling areas	0.50-0.70
Industrial	Light Areas	0.50-0.80
	Heavy areas	0.60-0.90
	Railroad yard areas	0.20-0.40
	Unimproved areas	0.10-0.30
Recreational	Parks, cemeteries	0.10-0.25
	Playgrounds	0.20-0.40

6.6.9 Limitations of the Rational Method

1. The Rational Method is most appropriate for catchment area up 0.5 km^2 due to:

   a. The rate of runoff resulting from any rainfall intensity is a maximum when the rainfall intensity lasts as long as or longer than the time of concentration. That is, the entire catchment area does not contribute to the peak discharge until the time of concentration has elapsed.

   b. This assumption limits the size of the drainage basin that can be evaluated by the Rational Method. For large catchment areas, the time of concentration can be so large that constant rainfall intensities for such long periods do not occur, and shorter more intense rainfalls can produce larger peak flows. Further, in semi-arid and arid regions, storm cells are relatively small with extreme intensity variations thus making the Rational Method inappropriate for catchment areas greater than 0.5 km^2.

2. The frequency of peak discharges is the same as that of the rainfall intensity for the given time of concentration. Frequencies of peak discharges depend on rainfall frequencies, antecedent moisture conditions in the catchment area, and the response characteristics of the drainage system. For small and largely impervious areas, rainfall frequency is the dominant factor. For larger drainage basins, the response characteristics control. For catchment areas with few impervious surfaces (little urban development), antecedent moisture conditions usually govern, especially for rainfall events with a return period of 10 years or less.

3. The fraction of rainfall that becomes runoff (C) is independent of rainfall intensity or volume. This assumption is only reasonable for impervious areas, such as streets, rooftops, and parking lots. For pervious areas, the fraction of runoff does vary with rainfall intensity and the accumulated volume of rainfall. Thus, the application of the Rational Method requires the selection of a coefficient that is appropriate for the storm, soil, and land use conditions. Many guidelines and tables have been established, but seldom, if ever, have they been supported with empirical evidence.

4. The peak rate of runoff may be insufficient information for design. Modern drainage practice includes detention of urban storm runoff to reduce the peak rate of runoff downstream. Using only the peak rate of runoff, the Rational Method severely limits the evaluation of design alternatives available in urban and in some instances, rural drainage design.

6.6.10 Modified Rational Method

The rational method, as the name applies, is a modified version of the rational method. To take care of the rise in significance of the routing effect of catchments, commonly known as coefficient of storage C_S, depending on the nature of the catchment. This can be compared to lag in the wetland areas. For ease of calculations, the Modified Rational Formula is multiplied by a factor, commonly referred to as a frequency factor C_F, for various return periods. These are presented in the Table 6.11.

Table 6.11 Hydrological Frequency Factor (C_f) for Different Return Period

Recurrence interval (years)	Cf
5	1.0
10	1.0
25	1.10
50	1.20
100	1.25

6.7 TRRL Method

6.7.1 General

The Transport Road Research Laboratory (TRRL) Method, commonly known as East Africa Flood Method (EAFM), which has been for a long time, the most widely used flood estimation method for ungauged catchment in the East African Region.

The TRRL East African Flood Model was developed by the UK Transport and Road Research Laboratory based on rainfall / runoff studies for a range of selected East African catchments. The TRRL method is based upon the Hydrograph Method, which attempts to relate the form of a typical hydrograph to the estimated peak discharge. Additional information on hydrographs, unit hydrographs and the attached flood estimation methods can be found in detail in the key two TRRL publications reports 706 and 626 that are customised for the East Africa region.

The model is made up of two parts, a linear reservoir model and a flood model, as follows:

i. The linear reservoir part of the model describes the land phase of the flood cycle. This is the time between the rainfall reaching the ground and the water entering the stream system.

ii. The flood routing part of the model routes the flood down the watercourse to the catchment outfall. The model assumes that a storm rainfall of a given return period results in a peak flood of equal return period.

The application of the model requires the selection of a range of parameters for each catchment which include:

i. **Standard contributing area coefficient C_S** - the standard runoff factor for a wet zone grassed catchment. The coefficient varies with soil type and average catchment slope.

ii. **The land use factor C_L** - this factor adjusts the runoff factor according to land usage relative to a catchment with short grass cover.

iii. **The catchment wetness factor C_W** - a measure of the antecedent wetness of the catchment.

iv. **Lag time k** - the time for the recession curve of outflow from a linear reservoir to fall to one third of its initial value. This parameter is strongly dependent on the vegetation cover.

Details of standard coefficients and formulae used in this flood model are detailed in the TRRL publications.

Adapted to African conditions, it has proven applicable to use the relatively stable ratio of the peak flow (Q) divided by the average flow ($Qave$) measured over the base time as means for calculating peak discharge.

$$F = \frac{Q}{Qave}$$

Equation 6.7

Where,

F = Peak flow factor.

The peak flow can therefore be estimated, if the average flow during the base time of the hydrograph can be calculated.

1
2
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Flood Estimation for Ungauged Catchments

The total volume of runoff is given by:

$$RO = (P - Y)CA * A * 10^3 (m^3) \qquad \text{Equation 6.8}$$

Where,

RO = Runoff volume m^3.

P = Rainfall (mm) during time period equal to the base time.

Y = Initial retention (mm).

CA = Contributing area coefficient.

A = Catchment area (km^2).

If the hydrograph base time is measured to a point on the recession curve at which the flow is one tenth of the peak flow, then the volume under the hydrograph is approximately 7 per cent less than the total run off given by Equation 6.6.

The average flow (Q_{ave}) is therefore given by:

$$Q_{ave} = 0.93 * \frac{RO}{3600 T_B} \qquad \text{Equation 6.9}$$

Where,

T_B = Hydrograph base time (hrs)

Estimates of Y and C_A are required to calculate RO and lag time K to calculate T_B.

6.7.2 Initial Retention (Y)

In arid and semi-arid zones, an initial retention of 5 mm could be considered. Elsewhere zero initial retention could be assumed.

6.7.3 Contributing Area Coefficient (C_A)

Contributing area coefficient is a coefficient that reflects the effects of the catchment wetness and the land use. A grassed catchment at field capacity is taken as a standard value of contributing area coefficient. The design value of the contributing area coefficient could be estimated from the following equation.

$$C_A = C_S * C_W * C_L \qquad \text{Equation 6.10}$$

Where,

C_S = The standard value of contributing area coefficient for a grassed catchment at field capacity.

C_W = The catchment wetness factor.

C_L = The land use factor.

The three factors are given in Tables 6.12, 6.13, and 6.14.

Table 6.12 Standard Contributing Area Coefficient (wet zone catchment, short grass cover)

Catchment Slope	Soil Type		
	Well Drained	Slightly Impeded Drainage	Impeded Drainage
Very Flat < 1.0 %		0.15	0.30
Moderate 1-4 %	0.09	0.38	0.40
Rolling 4-10 %	0.10	0.45	0.50
Hilly 10-20 %	0.11	0.50	
Mountainous >20 %	0.12		

Table 6.13 Catchment Wetness Factor - Cw

Rainfall zone	Catchment Wetness Factor	
	Perennial Streams	Ephemeral Streams
Wet Zone	1.0	1.0
Semi Arid Zone	1.0	1.0
Dry Zones (except West. Uganda)	0.75	0.50
West Uganda	0.60	0.30

Table 6.14 Land Use Factor (base assume short grass cover)

Land Use	Land Use Factor
Largely bare soil	1.50
Intense cultivation (particularly in valleys)	1.50
Grass cover	1.00
Dense vegetation (particularly in valleys)	0.50
Ephemeral steam, sand filled valley	0.50
Swamp filled valley	0.33
Forest	0.33

6.7.4 Catchment Lag Time (K)

The appropriate value of lag time can be estimated from Table 6.15. In assessing which category to place a given catchment, it should be remembered that generally only small areas either side of the stream are contributing to the flood hydrograph. It is these areas, therefore, which must be assessed.

Table 6.15 Catchment Lag Time

Catchment Type	Lag Time (K) in hrs
Arid	0.1
Very steep small catchments (slope > 20 %)	0.1
Semi-arid scrub (large bare soil patches)	0.3
Poor pasture	0.5
Good pasture	1.5
Cultivated land (down to river bank)	3.0
Forest, overgrown valley bottom	8.0
Papyrus swamp in valley bottom	20.0

6.7.5 Base Time

The method of estimating the base time is derived as described in Section 6.7.1 of this manual, it is made of three parts;

i. The rainfall time.

ii. The recession time for the surface flow.

iii. The attenuation of the flood wave in the stream.

The rainfall time (T_P) is the time during which the rainfall intensity remains at high level. This can be approximated by the time during which 60 per cent of the total rainfall occurs. Using the general East African depth duration equation as given in TRRL publications.

$$I = \frac{a}{(T + 1/3)^n}$$

Equation 6.11

Where,

I = Intensity (km).

T = Duration.

a and n = Constants.

The time to give 60 % of the total rainfall is given by solving the below equation.

$$0.6 = \frac{T}{24}\left(\frac{24.33}{T + 0.33}\right)^n$$

Equation 6.12

Table 6.16 Rainfall Time (T_P) for East African 10 Year Storms

Zone	Index 'n'	Rainfall time (T_p) (hr)
Inland zone	0.96	0.75
Coastal zone	0.76	4.0
Kenya Aberdare Uluguru Zone	0.85	2.0

Values for the various rainfall zones of East Africa are given in Table 6.16.

The time for the outflow from a linear reservoir to fall to 1/10th of its initial value is 2.3K, where K is the reservoir lag time. The recession time for surface flow is therefore 2.3K.

The flood wave attenuation (T_A) can be estimated from Equation 6.13.

$$T_A = \frac{0.028L}{\bar{Q}^{\frac{1}{4}} * S^{\frac{1}{2}}}$$

Equation 6.13

Where,

L = Length of main stream (km).

Q_{ave} = Average flow during base time (m³/s).

S = Average slope along main stream.

The base time is, T_B is estimated from Equation 6.14.

$$T_B = T_P + 2.3K + T_A$$

Equation 6.14

The average flow Q_{ave} can be estimated. It is noted that Q_{ave} appears in Equation 6.13 as part of T_A , so an iterative trial and error solution is required. If initially T_A is assumed zero, two iterations could be adequate.

Knowing $Qave$ and F, the peak flow is calculated using Equation 6.7.

6.7.6 Area Reduction Factor

Most of the time, the recorded rainfall is point rainfall at a particular station. For flood studies, the volume of rainfall is required and rainfall variability in space should be considered. In the TRRL method, calculating the point rainfall and multiplying this by an area reduction factor to allow for partial variability can estimate the volumetric rainfall input to a catchment. Daily point rainfall of average recurrences interval 2 years and 10:2 ration for different zones in East Africa are presented in Figure 6.1 and Figure 6.2 respectively.

The use of an Area Reduction Factor ARF is advised. The following formula is widely used.

$$ARF = 1 - 0.04T^{1/3} A^{1/2}$$

Equation 6.15

Where,

T = Duration.

A = Catchment area in km².

A worked example is presented in the Appendix A.3.

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Figure 6.1 Daily Point Rainfall of Average Recurrence Interval 2 Years

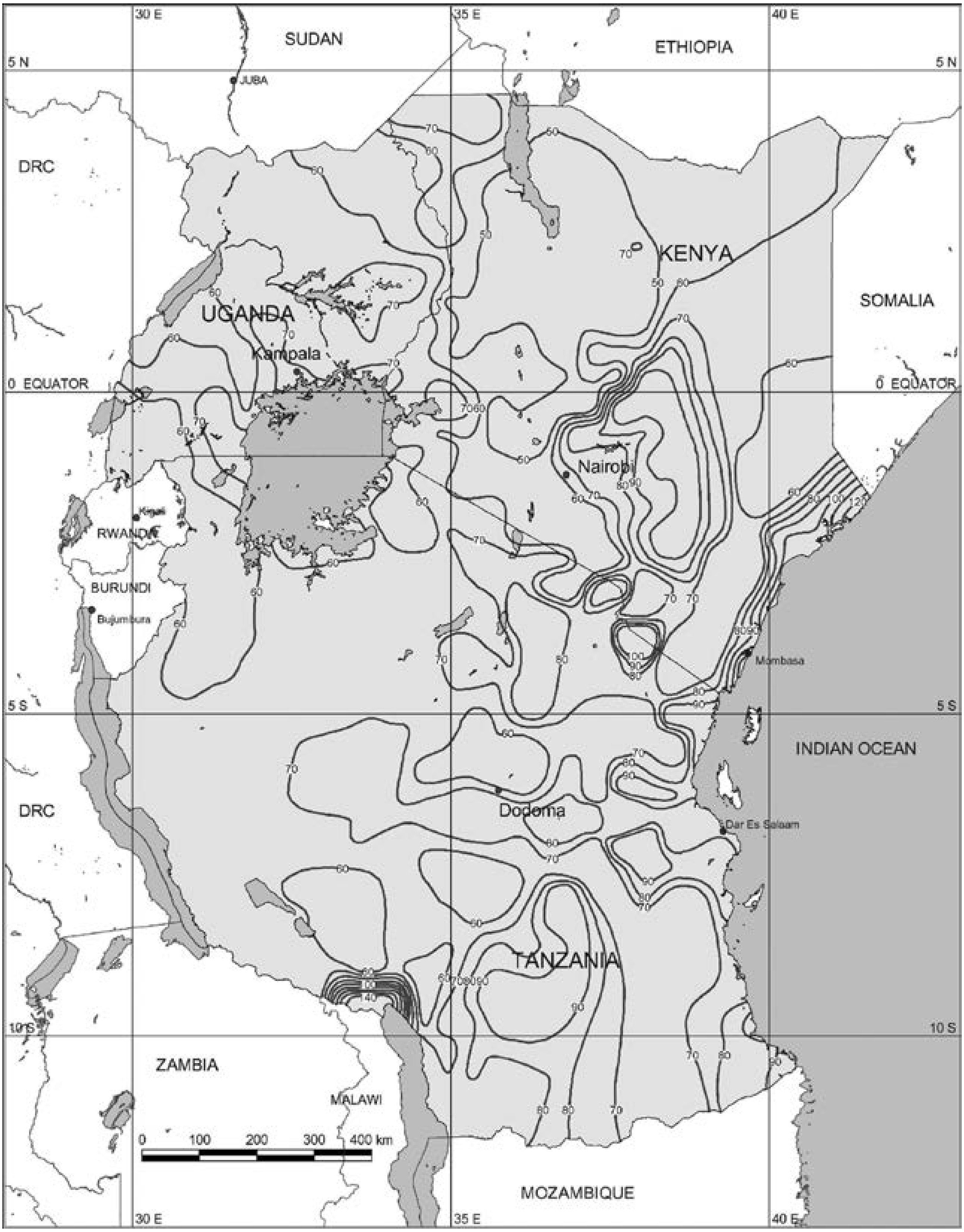
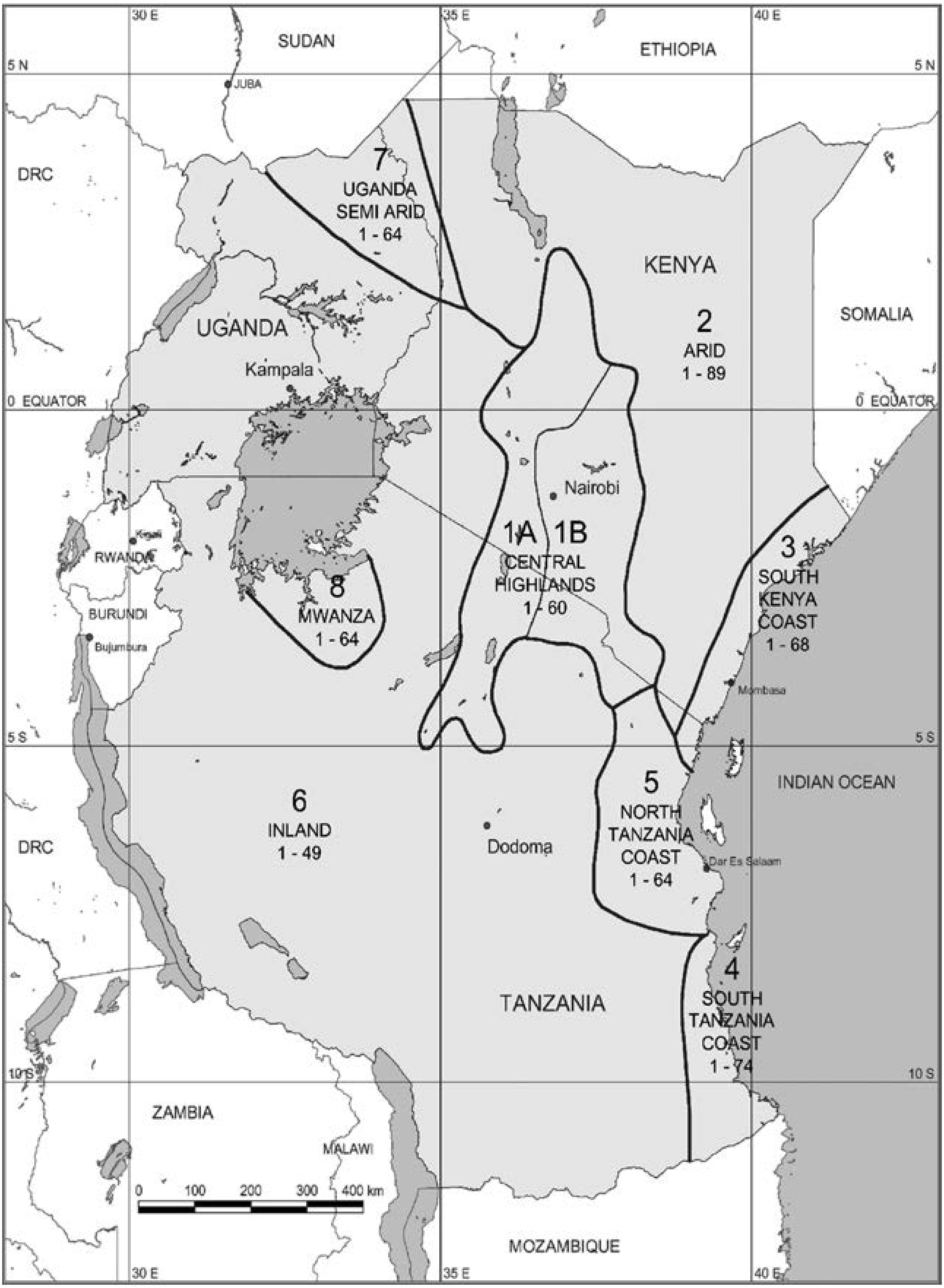


Figure 6.2 Ratio for Different Rainfall Zones in East Africa



6.8 Soil Conservation Service Method

6.8.1 General

The Soil Conservation Service (SCS) method techniques developed by the U. S. Soil Conservation Service for calculating rates of runoff require the same basic data as the Rational Method: catchment area, a runoff factor, time of concentration, and rainfall.

The SCS approach is more sophisticated, in that it also considers the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that decreases during the course of a storm. With the SCS method, the direct runoff can be calculated for any storm by subtracting infiltration and other losses from the rainfall to obtain the precipitation excess. The SCS method is most suited for computing flood peaks and runoff volumes for large catchments areas has been applied widely in Kenya and the region.

6.8.2 Procedure for Determining Peak Flood Discharge Using SCS Method

For determining flood using SCS method, the following procedure is basically adopted to estimating peak discharge:

i. Determine the catchment area (km^2);

ii. Determine the time of concentration, with consideration for future characteristics of the watershed;

iii. Determine the soil type, soil group, and land use and curve number of the watershed area; determine the hydrologic region, check the AMC and convert the CN value if required to wet or dry condition.

iv. Determine the 24hr rainfall depth and calculate the Ia/P ratio;

v. Using the equation provided (Equation 6.25) calculate the unit peak discharge; and

vi. Calculate the peak discharge for the watershed for the desired frequency using (Equation 6.26).

6.8.3 Rainfall Storm Determination

The SCS method is based on a 24-hour storm event which has a Type II time distribution. The Type II storm distribution is a 'typical' time distribution which the SCS has prepared from rainfall records. The Type II rainfall distribution will usually give a higher runoff than a Type I distribution. To use this distribution, it is necessary for the user to obtain; the 24-hour rainfall value for the frequency of the design storm desired, followed then multiply this value by 24 to obtain the total 24-hour storm volume in millimetres.

6.8.4 Rainfall – Runoff Equation

To estimate runoff, a relationship between accumulated rainfall and accumulated runoff was derived by SCS from experimental plots for numerous hydrologic and vegetative cover conditions. Data for land-treatment measures, such as contouring and terracing, from experimental catchment areas were included. The equation was developed mainly for small catchment areas for which daily rainfall and catchment area data are ordinarily available. It was developed from recorded storm data that included total amount of rainfall in a calendar day but not its distribution with respect to time.

The SCS runoff equation is therefore a method of estimating direct runoff from 24-hour or 1-day storm rainfall.

The equation is:

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \qquad \text{Equation 6.16}$$

Where,

Q = Accumulated direct runoff, mm.

P = Accumulated rainfall (potential maximum runoff), mm.

Ia = Initial abstraction including surface storage, interception, and infiltration prior to runoff, mm.

S = Potential maximum retention, mm.

The relationship between I_a and S was developed from experimental catchment area data. It removes the necessity for estimating I_a for common usage. The empirical relationship used in the SCS runoff equation is:

$$Ia = 0.2S$$

Equation 6.17

Substituting 0.2S for I_a in Equation 6.16, the SCS rainfall-runoff equation becomes:

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

Equation 6.18

The maximum potential retention S, is related to the soil and cover conditions of the catchment area through the Curve Number, CN.

CN has a range of 0 to 100, and S is related to CN by:

$$S = \frac{25400}{CN} - 254$$

Equation 6.19

Where,

CN = Curve number.

S = Potential maximum retention, mm.

6.8.5 Introducing Area Reduction to the Rainfall – Runoff Equation

The U.S. Soil Conservation Service developed a synthetic unit hydrograph procedure guide that has been used widely for flood estimations rural and urban hydrographs. The unit hydrograph used by the SCS method is based upon an analysis of a large number of natural unit hydrographs for various regions.

Thus soil conservation service method can be utilised together with the unit hydrograph method for flow estimation, the calculation guide is outlined below;

The method utilises the basic catchment characteristics, catchment area, stream length, stream slopes.

The key step start with the calculation of time of concentration of the unit hydrograph that is determined using the Kirpich formula as earlier outlined in this manual. The storm duration forms the key input for determination of the runoff hydrograph.

The storm duration is determined by the equation:

$$D = 2(Tc)^{0.5}$$

Equation 6.20

Where,

D = Storm duration in hrs.

1
2
3
4
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6
Flood Estimation for Ungauged Catchments

In order to determine the excess rainfall which results in runoff (RO) the following equation is utilised:

$$RO = \frac{(h - 0.2S)^2}{(h + 0.2S)}$$ Equation 6.21

Where,
RO = runoff (excess rainfall) in mm
h = maximum rainfall for the design duration
S = potential retention given by the formula: 25400/CN - 254

The CN number is selected according to the soil group, and land cover of the drainage area as observed from the site.

To customise the US formula, the Area Reduction Factor (ARF) is applied as for the case of East Africa Flood Method in the TRRL. The rainfall analysis done is usually relates to point rainfall. For flood prediction purposes, the catchment averaged rainfall is needed. This will be less than the rainfall at a point, and it reduces as catchment area increases. The catchment average rainfall can be determined from the point rainfall by applying an area reduction factor.

To calculate the time to peak for the hydrograph, the formulae below is used.

$$T_p = 0.5D + (0.6T_c)$$ Equation 6.22

Where,
T_p = Time to peak of hydrograph (hrs).
D = Duration of storm (hrs).
T_c = Time of concentration (hrs).

The base time of hydrograph T_b (hrs) is calculated by the equation below;

$$T_b = 2.67\ T_p$$ Equation 6.23

The hydrograph peak is obtained by the following formulae:

$$Q_p = \frac{220}{T_p}$$ Equation 6.24

Where,
Q_p = Peak discharge (m³/s).
T_p = Time to peak of hydrograph (hrs).

6.8.6 Peak Discharge Estimates from the SCS

The following equations are used for the estimation of the peak discharge in the SCS method.

$$Q_p = q_u * A_y$$ Equation 6.25

Where,
Q_p = Peak discharge, m³/s.
q_u = Unit peak discharge, m³/s/km²/mm.
A = Drainage area, km².
y = Depth of runoff, mm.

The unit peak discharge is obtained from the following equation, which requires the time of concentration (tc) in hours and the initial abstraction rainfall (Ia/p) ration as input:

$$q_u = a(10^{C_0 + C_1 log t_c + C_2 (log t_c)^2})$$ Equation 6.26

Where,
Q_p = Unit peak discharge, m³/s/km²/mm
C_0, C_1 and C_2 = Regression coefficients given in Table 6.17 for various Ia/p ratios:
$\propto$ = Unit conversion factor equal to 0.000431 in SI unit.

Table 6.17 Coefficients for SCS Peak Discharge Method

Rainfall Type	Ia/P	C0	C1	C2
I	0.1	2.3055	-0.5143	-0.1175
	0.2	2.23537	-0.5039	-0.0893
	0.25	2.18219	-0.4849	-0.0659
	0.3	2.10624	-0.4570	-0.0284
	0.35	2.00303	-0.4077	0.01983
	0.4	1.87733	-0.3227	0.05754
	0.45	1.76312	-0.1564	0.00453
	0.5	1.67889	-0.0693	0.00000
IA	0.1	2.03250	-0.3158	-0.1375
	0.2	1.91978	-0.2822	-0.0702
	0.25	1.83842	-0.2554	-0.0260
	0.3	1.72657	-0.1983	0.02633
	0.5	1.63417	-0.0910	0.0000
II	0.1	2.55323	-0.6151	-0.1640
	0.3	2.46532	-0.6226	-0.1166
	0.35	2.41896	-0.6159	-0.0882
	0.4	2.36409	-0.5986	-0.0562
	0.45	2.29238	-0.5701	-0.0228
	0.5	2.20282	-0.5160	-0.0126
III	0.1	2.47317	-0.5185	-0.1708
	0.3	2.39628	-0.512	-0.1325
	0.35	2.35477	-0.4974	-0.1199
	0.4	2.30726	-0.4654	-0.1109
	0.45	2.24876	-0.4131	-0.1151
	0.5	2.17772	-0.3680	-0.0953

6.8.7 Soil Properties

The basin soil characteristics influence the relationship between rainfall and runoff by affecting the rate of infiltration. The SCS has divided soils into four hydrologic soil groups based on infiltration rates (Groups A, B, C, and D), described in Section 6.3.6 of this manual.

6.8.8 Runoff Curve Numbers CN

The following pages give a series of tables related to runoff factors. Table 6.18 through Table 6.21 give curve numbers for various land uses. These tables are based on an average antecedent moisture condition, i.e. soils that are neither very wet nor very dry when the design storm begins. Curve numbers shall be selected only after a field inspection of the catchment area and a review of cover type and soil maps. Table 6.22 gives conversion factors to convert average curve numbers to wet and dry curve numbers. Table 6.23 gives the antecedent conditions for the three classifications.

The following considerations should be made in determining appropriate CN values:

i. Care shall be taken in the selection of curve numbers (CNs). Use a representative average curve number, CN, for the catchment area.

ii. Selection of overly conservative CNs will result in the estimation of excessively high runoff and consequently excessively costly drainage structures. Selection of conservatively high values for all runoff variables results in compounding the runoff estimation.

iii. It is better to use average values and design for a longer return period. Often the runoff computed using conservative CNs for a ten-year storm will greatly exceed the computed runoff for average CNs for a 25 or even 50-year storm. The hydrologic designer could consider doing both in making the most appropriate selection of design discharge.

Table 6.18 Runoff Curve Numbers (CN) for Soil Groups – Urban Areas[1]

Cover Type	Hydrologic Condition	Average % impervious area[2]	Curve numbers for hydrologic soil groups			
			A	B	C	D
Open space (lawns, parks, cemeteries, etc.)[3]	Poor condition (grass cover <50%)		68	79	86	89
	Fair condition (grass cover 50% to 75%)		49	69	79	84
	Good condition (grass cover >75%)		39	61	74	80
Impervious areas	Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads	Paved; curbs and storm drains (excluding right-of-way)		98	98	98	98
	Paved; open ditches (including right-of-way)		83	89	92	93
	Gravel (including right-of-way)		76	85	89	91
	Dirt (including right-of-way) desert		72	82	87	89
Urban areas	Natural desert cover		63	77	85	88
Urban districts	Commercial and business industrial		89	92	94	95
Residential districts (by average lot size)	0.05 hectare or less	65	77	85	90	92
	0.1 hectare	38	61	75	83	87
	0.135 hectare	30	57	72	81	86
	0.2 hectare	25	54	70	80	85
	0.4 hectare	20	51	68	79	84
	0.8 hectare	12	46	65	77	82
Developing urban areas	Newly graded areas (pervious areas only, no vegetation)		77	86	91	94

1 Average runoff condition, and $I_a = 0.2S$.
2 The average per cent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. If the impervious area is not connected, the SCS method has an adjustment to reduce the effect.
3 CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.

Table 6.19 CN for Cultivated Agricultural Land

Cover Type	Treatment[2]	Hydrological condition[1]	Curve numbers for hydrologic soil groups			
			A	B	C	D
Fallow	Bare soil Crop residue cover (CR)	–	77	86	91	94
		Poor	76	85	90	93
		Good	74	83	88	90
Row Crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
	Small grain SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
	Close-seeded SR or broadcast	Poor	66	77	85	89
		Good	58	72	81	85
	Legumes or C Rotation	Poor	64	75	83	85
		Good	55	69	78	83
	Meadow C&T	Poor	63	73	80	83
		Good	51	67	76	80

1 *Average runoff condition, and* $I_a = 0.2S$.

2 *Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.*

3 *Hydrologic condition is based on a combination of factors that affect infiltration and runoff, including **(a)** density and canopy of vegetative areas, **(b)** amount of year-round cover, **(c)** amount of grass or closed-seeded legumes in rotations, **(d)** percentage of residue cover on the land surface (good > 20%), and **(e)** degree of roughness.*

Poor: *Factors impair infiltration and tend to increase runoff.*

Good: *Factors encourage average and better than average infiltration and tend to decrease runoff.*

Table 6.20 CN for Soil Groups in Agricultural Land

Cover Type	Hydrological condition[1]	Curve numbers for hydrologic soil groups A	B	C	D
Pasture, grassland, or range- continuous forage for grazing[2]	Poor Fair Good	68 49 39	79 69 61	86 79 74	89 84 80
Meadow-continuous grass, protected from grazing	–	35	59	72	79
Brush-weed-grass mixture with brush the major element[3]	Poor Fair Good	48 35 30[4]	67 56 48	77 70 65	83 77 73
Woods-grass combination[5]	Poor Fair Good	57 43 32	73 65 58	82 76 72	86 82 79
Woods[6]	Poor Fair Good	45 36 30[4]	66 60 55	77 73 70	83 79 77
Farms – buildings, lanes, driveways, and surrounding lots	–	66	74	80	82

1 *Average runoff condition, and $I_a = 0.2S$.*

2 *Poor: < 50% ground cover or heavily grazed with no mulch Fair: 50 to 75% ground cover and not heavily grazed Good: > 75% ground cover and lightly or only occasionally grazed.*

3 *Poor: < 50% ground cover Fair: 50 to 75% ground cover Good: > 75% ground cover*

4 *Actual curve number is less than 30; use CN = 30 for runoff computations.*

5 *CNs shown were computed for areas with 50% grass (pasture) cover. Other combinations of conditions may be computed from CNs for woods and pasture.*

6 *Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning. Fair: Woods grazed but not burned, and some forest litter covers the soil. Good: Woods protected from grazing, litter and brush adequately cover soil.*

Table 6.21 CN Values for Arid and Semiarid Rangelands

Cover Type	Hydrological condition[2]	Curve numbers for hydrologic soil groups			
		A[3]	B	C	D
Mixture of grass, weeds, and low- growing brush, with brush as the minor element	Poor Fair Good		80 71 62	87 81 74	93 89 85
Mountain brush, mixture of small trees and brush	Poor Fair Good		66 48 30	74 57 41	79 63 48
Small trees with grass understory brush	Poor Fair Good		75 58 41	85 73 61	89 80 71
Brush with grass understory	Poor Fair Good		67 51 35	80 63 47	85 70 55
Desert shrub brush	Poor Fair Good	63 55 49	77 72 68	85 81 79	88 86 84

1 *Average runoff condition, and $I_a = 0.2S$.*

2 *Poor: < 30 % ground cover (litter, grass, and brush overstory) Fair: 30 to 70 % ground cover Good: > 70 % ground cover*

3 *Curve numbers for Group A have been developed only for desert shrub*

Table 6.22 Conversion of Average CN to Dry and Wet Condition CN

CN For Average Conditions	CN Dry	CN wet
100	100	100
95	87	98
90	78	96
85	70	94
80	63	91
75	57	88
70	51	85
65	45	82
60	40	78
55	35	74

Table 6.23 Rainfall Groups for Antecedent Soil Moisture Condition

Antecedent Condition	Conditions Description	Growing Season Five-Day Antecedent Rainfall	Dormant Season Five-Day Antecedent Rainfall
Dry	An optimum condition of catchment area soils, where soils are dry but not to the wilting point, and when satisfactory ploughing or cultivation takes place.	Less than 36 mm	Less than 13 mm
Average	The average case for annual floods.	36 to 53 mm	13 to 28 mm
Wet	When a heavy rainfall, or light rainfall and low temperatures, have occurred during the five days previous to a given storm.	Over 53 mm	Over 28 mm

7 Climate Resilience and Adaptation

7.1 General

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and / or the variability of its properties, and that persists for an extended period, typically decades or longer (IPCC). These could be seen as a long-term shift in the pattern of behaviour of the atmosphere over time as a result of natural processes or human induced activity.

Some of the key distinct aspects associated with climate change include the following:

1. Climate variation – this refers to short-term changes to the climate e.g. where parameters like rainfall, temperature increases for a few months, years and then decreases suddenly. This phenomenon may repeat itself in an unpredictable manner over time;
2. Climate anomaly – this refers to an irregular or unusual climate and unexpected phenomenon that occurs for a short period say a couple of months, years, in a unique way e.g. arid regions received very high rainfall which is normally expected of wet regions in different seasons.
3. Climate change – Mainly is a permanent shift in climatic parameters, which in the near future can be considered unalterable.

Due to climate change, extreme weather events like storms and heavy rainfall will increase, and the road transport infrastructure has to be adapted to them. Extreme weather is an important factor that impacts the reliability and safety of the road network. In the toad flood hydrology and investigations, the key aim would be on how to control the environment to ensure that its aggressiveness is minimised. To do so in a sufficiently effective manner the behavior of the environment must be reasonably predictable so that risks can be evaluated and rational decisions. This can only be done with development of a risk matrix that can be modelled to forecast changes in climate over a long period. Armed with the knowledge then road designers can make projections of future climate change and related socio-economic developments, decisions and development of the road transport system that is resilient to climate change may be identified.

7.2 Climate Change Indicators

Climate change has a great impact to existing infrastructure and thus all planned and designed infrastructure requires lots of consideration. Incorporation of climate change thus remains an important technical aspect in the provision of safe roads. There are several indicators about the changes which takes regarding to climatic conditions under which roads are operating which are impacting directly on the performance of such road and related infrastructure. Some of the key factors are:

1. Extreme rainfall – Studies in Kenya have shown that the actual annual rainfall has not increased significantly and, in some cases, may have decreased in some locations. We however have some areas with isolated enhanced intensity of rainfall. There have been increased damage or wash away of roads and drainage structures in the past in many regions in the Country. Based on these past observations, it is clear that road networks and relocated have become more vulnerable to damages Over time these will be faced with extremely high cost of maintenance and untenable.
2. Changing or rising sea levels – Kenya has a coastline and rising sea levels which will affect coastal areas and the roads built along the coastline. This may also include the inundation of land where urban or settlements have been established. The receding ocean levels at times have impact on the planning of coastal activities.
3. Extreme High temperatures – The temperatures are becoming extreme in some areas, and this is detrimental to the performance of roads because high temperatures cause accelerated deterioration of bituminous surface. This leads to premature crack initiation, development of potholes and ultimately premature failures of the pavement. In the Northern frontier in Kenya, the temperatures records reveal more extreme heat waves.

4. Increased frequent extreme weather conditions – Ihis is critical in the design of drainage structures. In the past, recorded hydrological years include 1961/62, 1978/79, 1997/98 El Nino and the more recent 2010 floods. The key aspect needed to be considered is Rainfall intensity duration frequency (IDF) charts – these may need to be reviewed regularly in light of the changing climatic conditions from time to time.
5. Storm return periods, also referred to as flood return periods or storm frequency, should be reviewed because climate change has generally shortened the return periods of some of the destructive floods, which in turn make road infrastructure more vulnerable through significant increases in risks of damage. Such data for updates can be obtained from the Kenya Meteorological Department offices.

7.3 Nationally Determined Contributions for Climate Change and Mitigation

7.3.1 National Overview

Over the past decade, Kenya has been experiencing successive impacts of climate change resulting to great socio-economic losses estimated at 3–5% of the Gross Domestic Product (GDP) annually, and impeding development efforts. The situation is exacerbated by the country's dependence on climate sensitive natural resources. Despite the country's negligible contribution to global greenhouse gas (GHG) EMISSIONS (less than 0.1% in 2018), Kenya has put up ambitious policies and measures to pursue her low carbon climate resilient development pathway to realise Vision 2030.

The frequency and intensity of extreme weather events have increased in Kenya over the past decade. Prior to 2010, Kenyan sectors had ad-hoc responses to extreme weather events and other climate change impacts. The response included distribution of famine relief, El Nino Response programmes, and Animal off-take programs, among others, Kenya developed a National Climate Change Response Strategy (NCCRS) In 2010, the first National Climate Change Action Plan (NCCAP) in 2013, and a National Adaptation Plan (NAP) in 2015. The strategy and plans jointly provide a vision for low carbon and climate resilient development pathway, while a National Climate Change Framework Policy was adopted and climate Change Act 2016 enacted to facilitate the effective response to climate change. Kenya has operationalised these policies and plans through the implementation of climate change actions in various sectoral plans, programmes and projects such as afforestation and reforestation, geothermal and other clean energy development, energy efficiency, climate smart agriculture, and drought management amongst others.

Kenya submitted her Nationally Determined Contribution (NDC) in 2016, the NDC sets out both adaptation and mitigation contribution based on conditional support. The mitigation contributions intended to abate greenhouse gas (GHG) emissions by 30% by 2030 relative to the business-as-usual scenario.

7.3.2 Legislative and Policy Framework

The Kenya Vision 2030, the long-term national development blueprint encapsulates flagship programmes and projects with aspects of adaptation and mitigation, The National Climate Change Response Strategy (NCCRS), which was developed in 2010, was the first national policy document on climate change. It aimed to advance the integration of climate change adaptation and mitigation into all government planning, budgeting and development objectives.

In addition to the Kenya Vision 2030 and climate change-related policies, the country has put in place several sectoral polices to support implementation of climate change adaption and mitigation actions. Some of the key policies:

- The National Policy on Climate Finance;
- Climate Risk Management Framework;
- The National Livestock Policy 2015;

- National Oceans and Fisheries Policy 2008;
- The Agricultural Sector Transformations and Growth Strategy (ASTGS) (2019-2029);
- The Kenya Climate Smart Agricultural Strategy (2017 -2028);
- The Reducing Emissions from Deforestation and Forest Degradation (REDD+),
- The National Drought Management Authority (NDMA)Act (2016);
- The Water Act,(2016);
- Forest Conservation and Management Act (2016) among others.

For the purpose of hydrological surveys, it is recommended that the user should utilise where applicable the relevant current legal provisions.

Table 7.1 Key Climatic Threat Factors Contributing to Threat on Road Infrastructure

Antecedent Condition	Conditions Description	Growing Season Five-Day Antecedent Rainfall	Dormant Season Five-Day Antecedent Rainfall
Flooding of the road surface	Flooding due to failure of installed structure in on the river and canal crossing	Low road surface level	Rivers and streams with blocked in let structures blocked. Water depths from flooding easily build up
	Other sources of flooding like overland flows and sudden precipitation	Poor distribution and hydraulic capacity of openings	Very flat topography with no depressions, coupled with vast catchment areas
Erosion of road embankments and foundations	Overloading of hydraulic structures crossing the road	Distribution and hydraulic capacity of culverts crossings *(return period for design rainfall event: shorter return period, i.e. higher vulnerability)*	Topography effects that have higher vulnerability
		Maintenance frequency for culverts, ditches *(i.e. less frequent higher vulnerability)*	Higher catchment areas relating to drainage capacity
			Geology - more erosive material *(i.e. higher vulnerability)*
	Erosion of road bases and road embankments	Culverts *(i.e. higher vulnerability where culverts cross the road)*	Topography that proximity to river or water mass smaller vertical distance *i.e. higher vulnerability)*
		Distribution of erosion protection works	Vegetation less vegetation *(i.e. higher vulnerability)*
		The existing geology of road base/ embankment and/or surrounding soil that's more erosive material *(i.e. higher vulnerability)*	Observed erosion *(i.e. higher vulnerability)*
		Topography of road mainly the embankment higher or steeper slope *(i.e. higher vulnerability)*	
		Periodic maintenance and frequency - less frequent *(i.e. higher vulnerability)*	
	Bridge scour	Bridge or pier and or abutment Periodic maintenance frequency *(i.e. less frequent, higher vulnerability)*	Topography effects including - proximity to river or sea water mass

Table continues to next page...

Table 7.1 continued...

Key Threat	Sub Threat	Road Factors That Contributes to Vulnerability	Other Factors that Attribute to Vulnerability
Landslide, mudflow, ground subsidence and collapse	External slides, ground subsidence or collapse affecting the road	Embankment failure due to various factors (*i.e. higher vulnerability)*	Geological effects, like clay soils with silt, topography with higher slopes, existing cavities and erosion pose higher vulnerability
	Slides of the road embankment	Embankment geology - soil type clay and silt are have higher vulnerability	Topography with higher steep slopes poses high vulnerability
		Embankment topography higher slope angle means higher vulnerability	
		Observed erosion on the sides (*i.e. higher vulnerability)*	
	Debris flow/ Mud flows	Road base material the finer material has higher vulnerability	Vegetation decrease related causes are of higher vulnerability
		Embankment with less vegetation have higher vulnerability	Section with poor geology are prone to debris flow and mudflows, poses higher vulnerability
	Rockfall	Manmade cracks: resulting from road cut and blasting more cracks pose higher vulnerability	Underlying poor geology areas with poor topography larger slope angle and height poses higher vulnerability
		Rock mass quality in road cut - lower quality has higher vulnerability	
		Topography of road cut with larger slope angle and height has higher vulnerability	
Loss of driving ability due to Extreme weather events	Reduced visibility	Topography in low-lying areas equates to more vulnerability	Topography in low-lying areas equates to more vulnerability
	Reduced visibility during heavy rain including splash and spray	Pavement transverse slope angle - lower slope angle is more vulnerable to splash and spray	Topography, especially on the highlands that have heavy clover near road sides, are more vulnerable
	Reduced vehicle control	Wet surfaces – very vulnerable on wet season	Vegetation forest, less vulnerable
	Decrease in skid resistance on pavements from slight rain after dry period	Existence of ruts/tracks	Land use agriculture or urban or wasteland has higher vulnerability

7.3.3 Adaptation and Loss Damages

All sectors of the Kenyan economy are vulnerable to climate change. The Kenyan GDP is relies on climate sensitise sectors such as agriculture, tourism, and manufacturing. Adaptation thus, is the highest priority for Kenya, not only through preventing further losses and damages, but underpinning infrastructure and economic development while safe guarding lives and social development. Changes in land use and land cover has the greatest impact on the hydrological cycle that requires concerted efforts. Some of the key actions that can be done include:

i. Focusing our economic development plans on climate-positive growth, including expansion of just energy transitions and renewable energy generation for industrial activity, climate-aware and restorative agricultural practices, and essential protection and enhancement of nature and biodiversity.

ii. Strengthen actions to halt and reverse biodiversity loss, deforestation, desertification, as well to restore degraded lands to achieve land degradation neutrality.

7.4 Climate and Drainage Designs

Historical hydrological flows and rainfall enable hydrologist and other practitioners utilise the data to predict the number of times or likelihood that a storm of a particular intensity is likely to occur, say, every 100 years (Q_{100}) or every 50 years (Q_{50}) or every 25 years (Q_{25}) etc. Forecasting or predicting the exact time an event is likely to occur is may not be possible but calculating a probability of occurrence is all that is needed to determine the risk of it occurrence.

Extreme large structures are very expensive and this may not be the solution, the risk of failure of the structure and the severity is critical to arriving to such costly infrastructure.

Engineering structures can fail but the consequences may not be severe; for example, may not be at risk or the repairs may not be expensive. Rational decisions can be made concerning the design options but only if the probability of failure of an engineering structure can be calculated.

Vulnerability assessment analyses the expected impacts, risks and the adaptive capacity of a region or sector to the effects of climate change. Vulnerability assessment encompasses more than a simple measurement of the potential harm caused by events resulting from climate change; it includes an assessment of the region's or sector's ability to adapt.

Due to the climatic and topographical features highlighted above, the most likely effects of climate change on the road infrastructure in Kenya can largely be classified as below:

i. Flooding of the road surface.
ii. Accidents resting from the in ability to drive or poor visibility ability due to extreme weather events.
iii. Total destruction of the structure like wash away of culvers and bridges.
iv. Erosion of road embankments and foundations.
v. Landslide, ground subsidence or collapse.
vi. Loss of road structures integrity.
vii. Loss of pavement integrity.
viii. Total loss of communication and disruption of travels leading to economic and social loss.

7.5 Climate Change Resilience Matrix and Infrastructure

During planning, design, construction and normal routine maintenance of road infrastructure's climate change needs to be considered. Measures should be put in place to ensure infrastructure is climate resilient in order to minimise risks.

A simple risk matrix framework could be considered. This is based on the likelihood and the impact or the severity of the event. The Table 7.1 illustrates the threat and factors contributing to the road infrastructure.

In addition to identification of threats from the climate changes, there is a need to create a strategy to activate a drainage framework for action in order to avert dangers to the public, natural habitats and the national economy resulting from weather related drivers. This framework is intended to make it easier to identify climate related impacts and adaptation needs, and to plan and implement measures. The Table 7.2 below presents a draft for climate change adaptation measures.

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Climate Resilience and Adaptation

Table 7.2 Climate Change Adaptation Measures

Classification / Type	Measures
Legislation, regulations	Establish a guideline for standardised inspection of drainage structures like culverts and bridges
	Have revised standards for design of large structure culverts and bridges
	Have revised standards for road design, avoiding build-up of water level differences by maximisation of vertical alignments
Capacity Building	Plan, prepare and carry out education to road users in flood prone areas
Maintenance and management	Cleaning out watercourses and structures of flood prone areas ahead of predicted heavy rainfall
	Clear natural blockages such as shrubs and weeds at the crossings
	Carry out inspection and clean watercourses regularly especially at the urban centres
	Take measures to reduce downstream sedimentation and clear debris and sediment from the outlet to enhance free flows
	Carrying out inspection for bridge foundations and surroundings (over and under water) regularly
Planning	On urban planning avoid urbanisation and watersheds diversions of flows in vulnerable areas
	Build dams, reservoirs and retaining ponds to buffer the floods upstream on existing towns like Narok
	Avoid deforestation in the catchment area, and promote afforestation
	Construct flood retention walls to protect the road from flooding wherever possible
	Carrying out risk assessment of identified flood areas
	Develop plans and routines for the priority of securing areas prone flooding and those affected by sea level rise like the coastal regions
Resilient construction	Avoid deforestation in the catchment area
	Foster and cover slope with vegetation
	For the very steep embankments cover slope with rock blanket
	Install telemetry weirs or gauges towards storage facilities to easily raise alarm
	Large sizes of culverts can be replaced with small bridges (culverts greater than 6.0 m^2 opening could be considered for this)
	Resize drainage systems to meet threats
	Put in place efficient drainage systems
	Construct a catch ditch at the toe of the slope areas
Traffic Management	Access restriction in case of severe flood
	Lane closure on the flooded areas
	Real time traffic information
	Rerouting and guidance of traffic
	Reroute the traffic
	Enforce Speed limits
	Prepare and update traffic management plans
Robust construction	Build flood walls to protect road from flooding
	Cover road embankment with geotextile, rock blanket or vegetation
	Use geo-synthetics for improving slope stability and erosion protection
	Use appropriate vegetation for improving slope stability and erosion protection
	Develop binders that are more resilient to stripping
	Increase the thickness of structural layers
	Dredge the channel to increase depth and/or width
	Pave the inlet or the outlet of the culvert
	Flatten the road embankment
	Extend the footing to support the slope
	Install a bulkhead to support the slope and protect it from erosion
	Install debris basins to collect debris

7.6 Anticipated Risks and Adaptation Measures on Road Infrastructure

The recent observed changes in climate have direct and indirect impacts on road infrastructure projects. Based on future global warming trends, road infrastructure will be affected by the combined influence of changes in temperature, wind and rainfall weather events. Change in these climatic parameters will lead to the modification of weather and hydrology which in turn impacts on lifespan of the road infrastructure. Climate change can accelerate deterioration of the road surfaces, increase risks for damages due to extreme hydrological events, interrupt flow of traffic and increase road accidents. Based on this, the impacts of climate change need to be integrated into the design and operation of road project. The key observed changes are:

a. The observed extreme rainfall events are becoming more frequency with reported incidence of damaging to roads and bridges. Thus, the design of the road, bridges and culverts must factor in the occurrence of extreme hydrologic events, particularly flash floods that are common in the predominantly semi-arid region and the Northern frontier. Bridges will need to be designed in such a way as to withstand the anticipated risk of damage due the occurrence of extreme flows. It is worthy to note that these extreme flood events are associated with heavy sediment transported load that is usually deposited in river channels, under the bridges and in culverts. These reduces the designed capacities of bridges and culverts leading to the flooding of the highway in affected areas over times. Scouring of bridge piers will need to be carefully assessed in line with more frequent flooding.

b. Apart from rainfall, the other factor on climate change is extreme temperature variations. Higher temperatures lead to rapid expansion as a result of intense heating and contraction due to rapid cooling affecting mainly the asphalt. These rapid changes in temperature can damage road surface particularly in high traffic areas where pressure on the road surface is high. In this regard, the asphalt or bitumen that will be used in the construction of the proposed highway must meet industry quality requirements and new specifications.

c. Recent observed droughts have increased the risk of wildfires raising serious road safety concerns due to reduced visibility, smoke inhalation and risks of motor vehicles especially for the highly flammable petrol propelled engines. Road side reserve vegetation should be well maintained.

d. High temperature experienced in most areas along the proposed highway may limit construction activities, leading to changes on work schedules. To resolve this, palling should be changed such that heavy and strenuous works are undertaken early in the morning and late afternoon or evening. For assignments that must be undertaken at night, provision must be made for appropriate lighting and gear in order to comply with occupational health and safety of workers as per the Osh Act.

e. In the recent past wind patterns and intensity of high magnitude winds associated with storm events have become more frequency. Such strong crossroad winds pose significant safety to motorists driving at high speed on the roads. These winds may make it difficult for motorists to control their vehicles leading to road crashes and damage to road infrastructure. Strong winds may also generate heavy dust along the highway leading to reduced visibility that may also lead to road safety concerns. Based on this, the design of roads should integrate the possible effects of increased magnitude of wind events along the highway by creating good road reserve with good buffer vegetation.

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Appendix A

Appendix A1: Application Example Maximum Discharge Calculations for Gumbel Equation

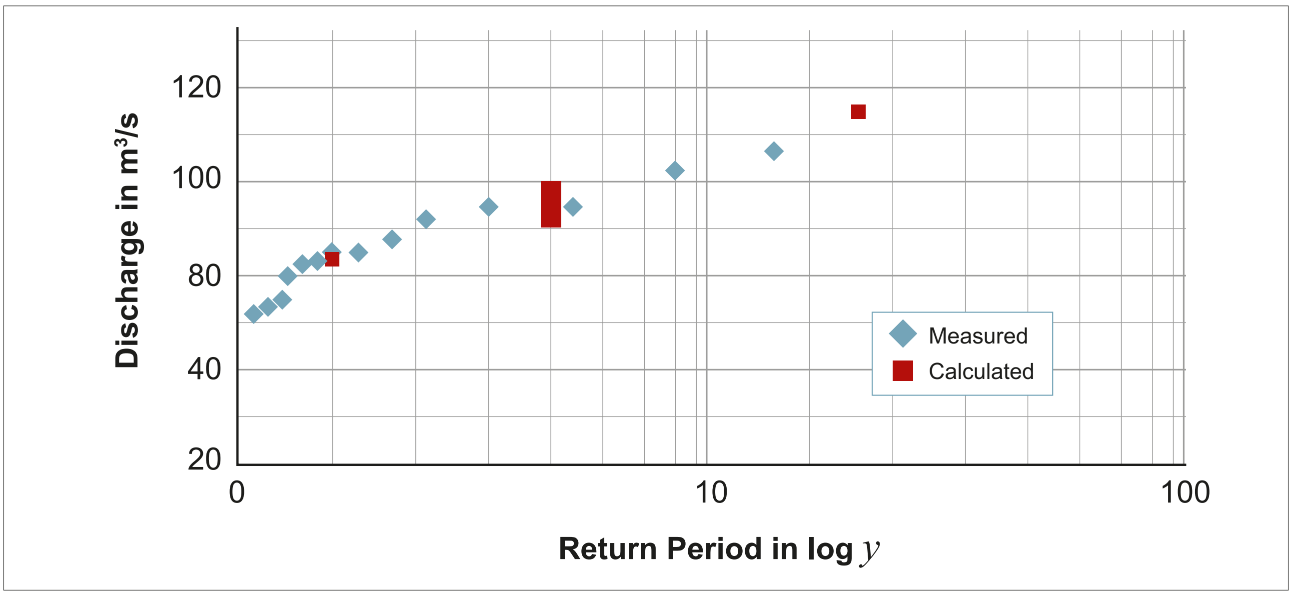
Gumbel k values for different Sample Size and Return Periods, after Chow (1).

Rank (i)	Year	Max measured flow in the year m³/s	Probability $P=i(15+1)$	Return 1/P Years
1	1987	94	0.0625	16.0
2	1988	83.7	0.125	8.0
3	1981	68.9	0.1875	5.3
4	1986	68.5	0.25	4.0
5	1984	64.9	0.3125	3.2
6	1980	55.5	0.375	2.7
7	1983	48.9	0.4375	2.3
8	1977	47.9	0.5	2.0
9	1989	44.6	0.5625	1.8
10	1990	43.7	0.625	1.6
11	1979	38.9	0.6875	1.5
12	1978	28.9	0.75	1.3
13	1985	27.4	0.8125	1.2
14	1976	23.9	0.875	1.1
15	1982	22.6	0.9375	1.1
16	1975	17.6	1	1.0
T return	**K for N = 15**	**$Qest=48.47+k*22.56$**		
2	-0.144	45.5		
5	0.967	70.6		
10	1.702	87.1		
25	2.631	108.1		
50	3.32	123.6		

Length of period = 15 years. Mean measured maximum instantaneous discharge = 48.74m³/s. Standard deviation = 22.56m³/s

A graphical presentation of the measured and the calculated flood flow for different return period is presented in Figure A1 below.

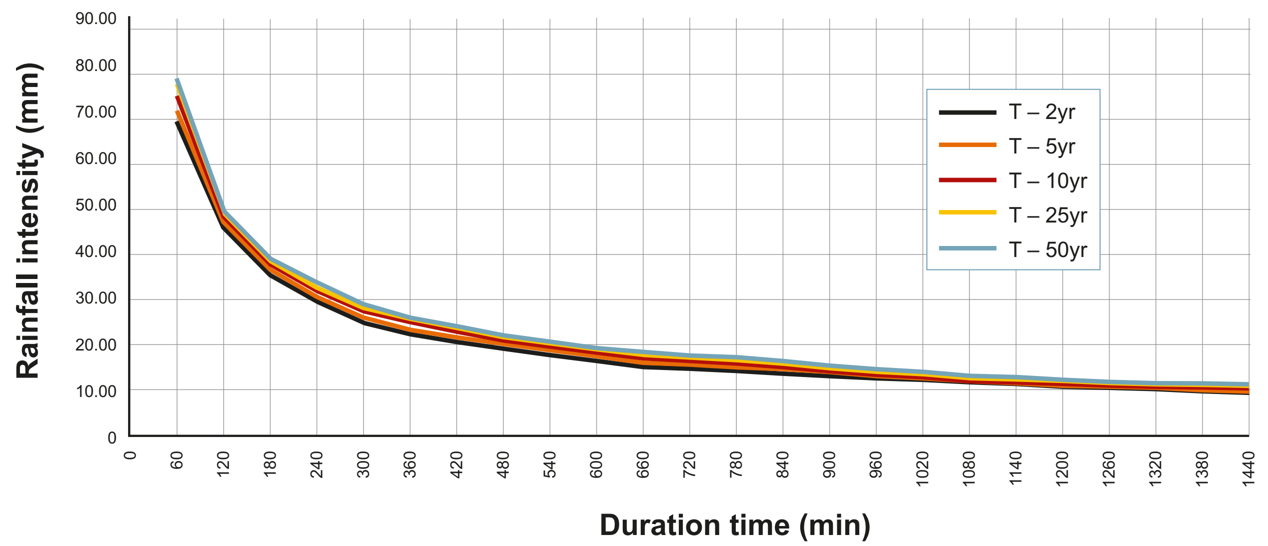
Figure A1 Measured and Calculated Flood Flow For Different Return Periods



Appendix A2: Example Worked Out IDF from Sample 24 hr Max Annual Daily Rainfall

T – Period	Rd (mm)	t (min)	*T* – 2Yr	*T* – 5Yr	*T* –10Yr	*T* – 25Yr	*T* – 50Yr	*T* – 100Yr
2	61	60	69.30	72.79	74.99	77.42	79.01	80.49
5	77.4	120	45.13	47.40	48.83	50.42	51.45	52.41
10	89.4	180	35.11	36.88	37.99	39.23	40.03	40.78
25	104.4	240	29.39	30.87	31.80	32.83	33.50	34.13
50	115.2	300	25.60	26.88	27.70	28.60	29.18	29.73
100	126	360	22.87	24.02	24.74	25.55	26.07	26.56
		420	20.78	21.83	22.49	23.22	23.70	24.14
		480	19.14	20.10	20.71	21.38	21.82	22.22
		540	17.79	18.69	19.25	19.88	20.28	20.66
		600	16.67	17.51	18.04	18.62	19.00	19.36
		660	15.71	16.50	17.00	17.56	17.92	18.25
		720	14.89	15.64	16.11	16.63	16.98	17.29
		780	14.17	14.88	15.33	15.83	16.16	16.46
		840	13.53	14.22	14.65	15.12	15.43	15.72
		900	12.97	13.62	14.03	14.49	14.79	15.06
		960	12.46	13.09	13.48	13.92	14.21	14.47
		1020	12.00	12.61	12.99	13.41	13.68	13.94
		1080	11.59	12.17	12.54	12.94	13.21	13.46
		1140	11.20	11.77	12.12	12.52	12.77	13.01
		1200	10.85	11.40	11.74	12.13	12.38	12.61
		1260	10.53	11.06	11.40	11.77	12.01	12.23
		1320	10.23	10.75	11.07	11.43	11.67	11.88
		1380	9.95	10.46	10.77	11.12	11.35	11.56
		1440	9.70	10.18	10.49	10.83	11.05	11.26

Figure A2 Sample of Developed Intensity Duration Curve



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Appendices

Appendix A3: Example Adopted & Applied from TRRL Laboratory Report 706

A 10 year average recurrence interval design flood is required for a catchment that has the following details.

a. Area: 10 square kilometres
b. Land slope: 6 %
c. Channel slope: 3%
d. Channel length: 4 km
e. Grid reference: 5°S 35°E
f. Catchment type: Poor pasture

From Table 6.12, standard contributing area coefficient C_S = 0.45

From Table 6.13, catchment wetness factor CW = 0.5

From Table 6.14, land use factor C_L = 1.0

From Table 6.15, lag time (K) = 0.5 h

Therefore, the design value for C_A = 0.23

Initial retention Y = 0

From Table 6.16, T_P = 0.75 hrs.
Using Equation 6.14 with T_A = 0 T_B = 0.75 + 2.3 (0.5) = 1.9 hrs.
Rainfall during base time is given by:

$$R_{TB} = \frac{T_B}{24}\left(\frac{24.33}{T_B + 0.33}\right)^c * R^{10}/24$$

Where,
$R^{10}/24$ = daily rainfall of 10 years average recurrence interval and C = 0.96 from Table 6.16.

Using rainfall maps:
Figure 6.1: Daily point rainfall of Average recurrence interval 2 year = 63 mm,
Figure 6.2: 10:2 yr ratio = 1.49

Remark: *For rainfall base data of longer return period use of the Rainfall Frequency Atlas of Kenya is recommended.*

Daily rainfall of average recurrence interval 10 yr = (63*1.49) = 94 mm

$$R_{1.9} = \frac{1.9}{24}\left(\frac{24.33}{1.9 + 0.33}\right)^{0.96} * 94 = 73.9\text{mm}$$

Area Reduction Factor is given by $ARF = 1 - 0.04T^{1/3} A^{1/2} = 0.84$

Average Rainfall P = 73.79 x 0.84 = 61.98

$RO = C_A\,(P - Y)\,A*10^3$

$$\overline{Q} = \frac{0.93*RO}{3600*T_B}\ 19.38\ \text{m}^3/\text{s}$$

$$T_A = \left(\frac{0.028L}{Q^{1/4}*S^{1/2}}\right) = 0.31\ \text{hrs}$$

T_B (2nd *approximation*) = 1.9 + 0.31 = 2.21 hrs

$$R_{2.21} = \frac{2.21}{24}\left(\frac{24.33}{2.21 + 0.33}\right)^{0.96} * 94 = 75.5\ \text{mm}$$

ARF = 0.84

Therefore P = 63.63 mm

$\overline{Q}$ = 17.11 m³/s

T_A = 0.32 hrs (No changes)

Therefore Q = $F*\overline{Q}$

For K less than 0.5 hour, F = 2.8

For K more than 1 hour F = 2.3

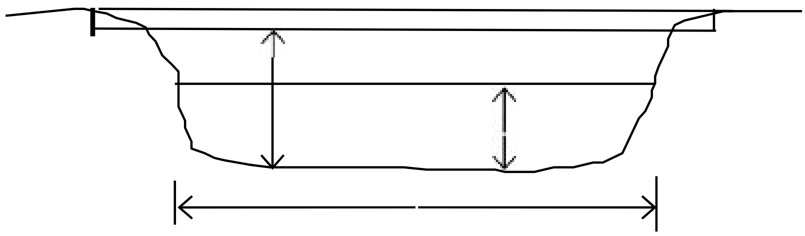
For the case at hand therefore F = 2.8

Therefore Q = 2.8*17.11 = 47.91 m³/s

Appendix A4: Field Drainage Survey Form

Structure

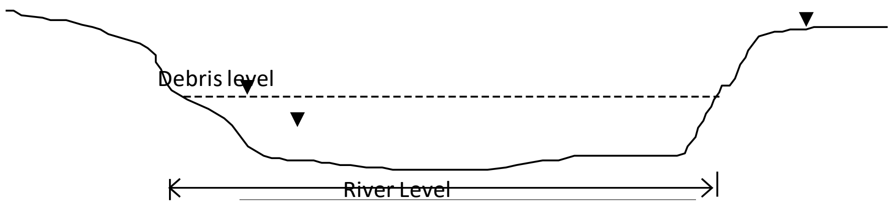
Project Name:		**BC No. of Cells:**	
Dimensions:		**Bridge No. of Cells:**	
Sketch:			



Wing Walls:	Yes		No	
Condition of inlet:				C -Clear S - Scoured V - Vegetated B - Blocked C - Clean S - Silted (¼,½,¾)
Condition of outlet:				
Condition of bed:				

Stream upstream

Bed material: *(sand/gravel/cobbles/bouldery/ vegetated/grass/bush)*		**Banks:**	**Sloping/vertical**	
			Bare/grassed/bushy	
Flows: *(seasonal/perennial)*		**Evidence of flood debris:**		
Sketch:				



Catchment

Predominant land usage: *(forest/cultivated/scrub/bush)*		**Predominant vegetation cover:** *(forest/crops/bush/bare)*	
Predominant soil type: *(impermeable/semi permeable/ permeable)*		**Terrain:** *(flat/rolling/hilly/mountainous)*	

Reported and known key flooding historical events from the locals

Appendix B

Appendix B: Hydro Meteorological Data Records

User to obtain data from the Kenya Meteorological Department.

Appendix C

River Flow Data Records

User to obtain data from the Water Resources Authorities.