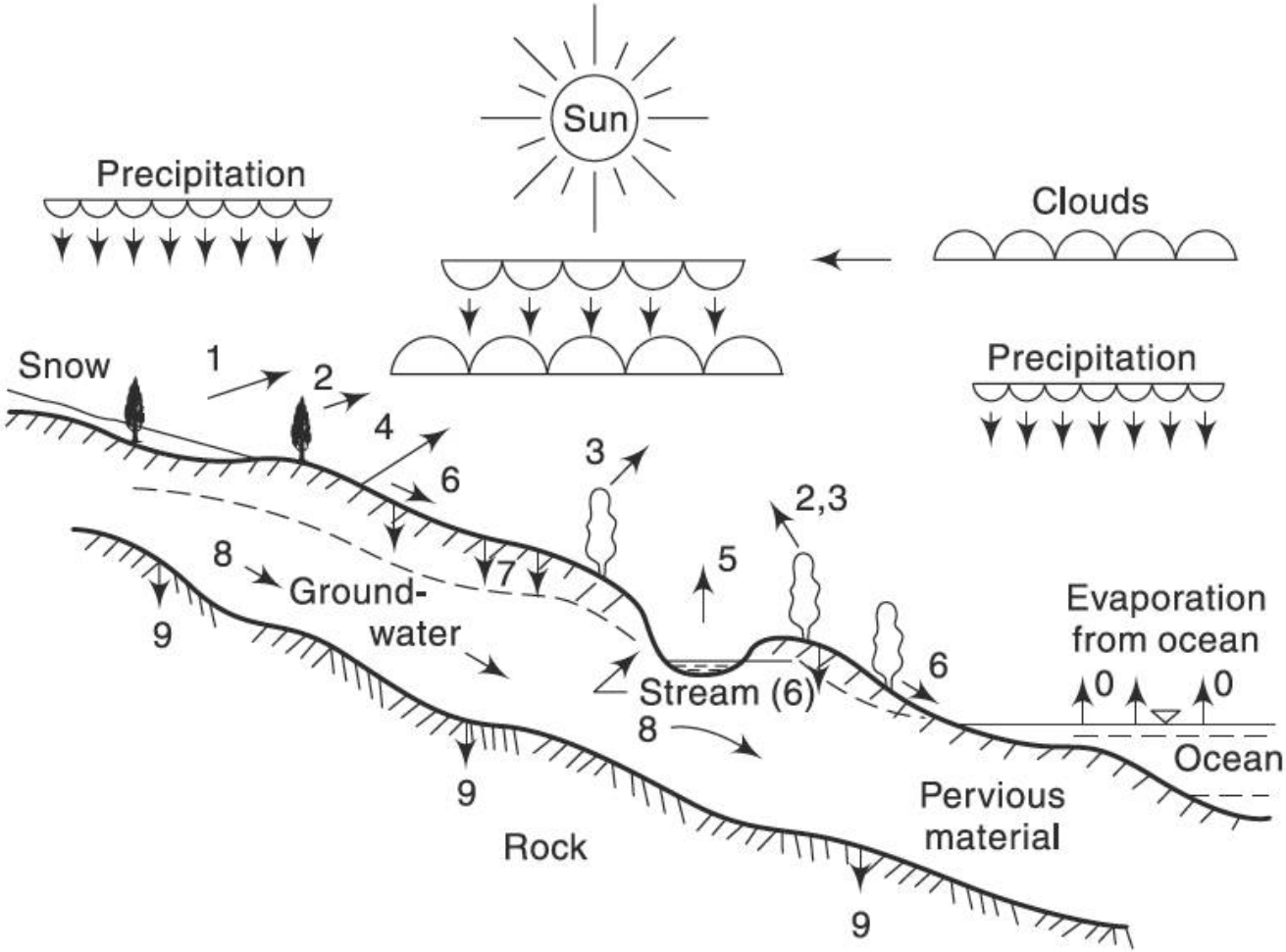
LECTURE ON ENGINEERING HYDROLOGY

As Prepared By-

Prof. K. Subramanya

11-11-2020



0 = Evaporation from ocean
1 = Raindrop evaporation
2 = Interception
3 = Transpiration
4 = Evaporation from land
5 = Evaporation from water bodies
6 = Surface runoff
7 = Infiltration
8 = Groundwater
9 = Deep percolation

Fig. 1.1 *The Hydrologic Cycle*

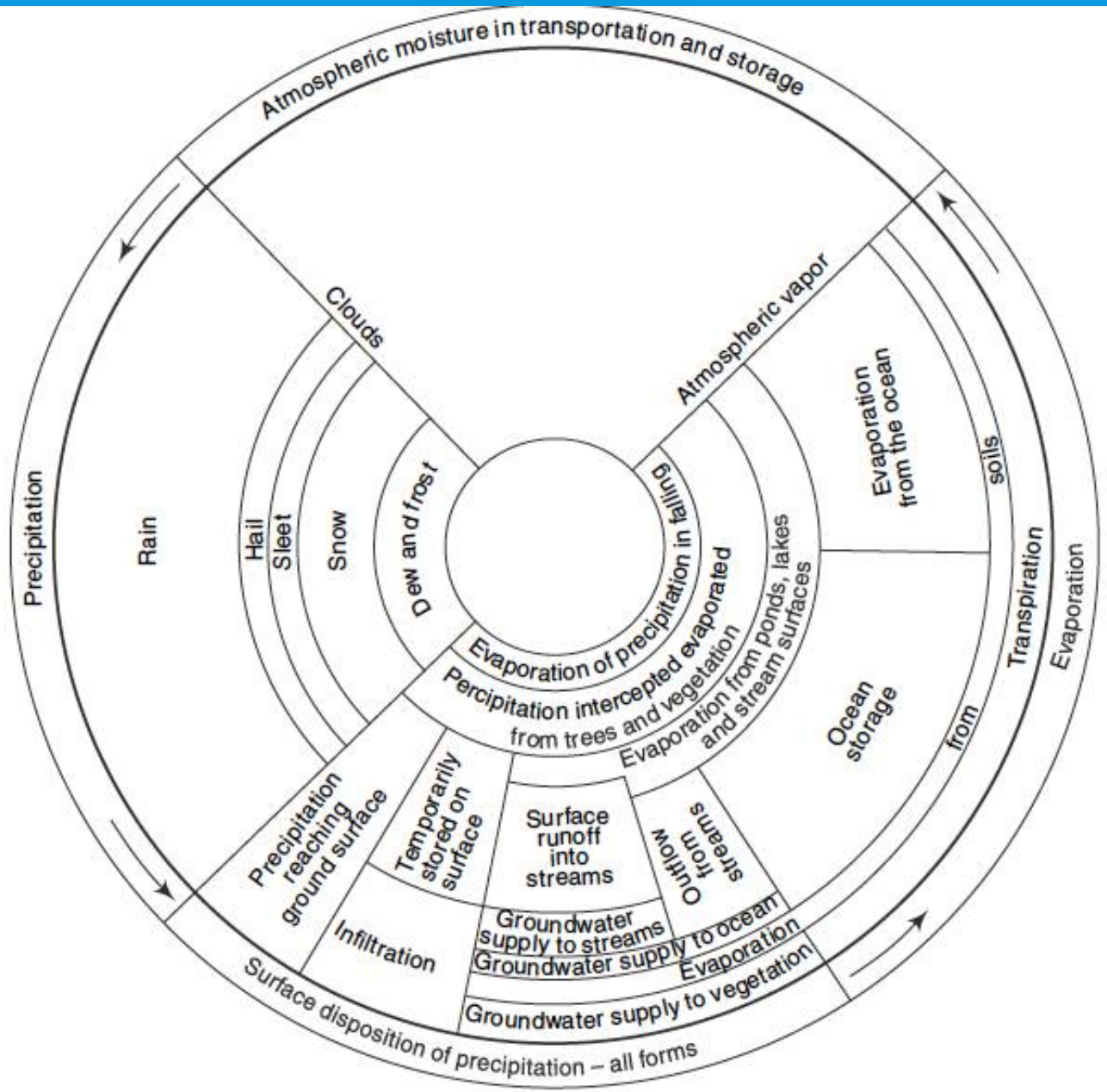


Fig. 1.2 *Horton's Representation of the Hydrological Cycle (Ref: 1).*

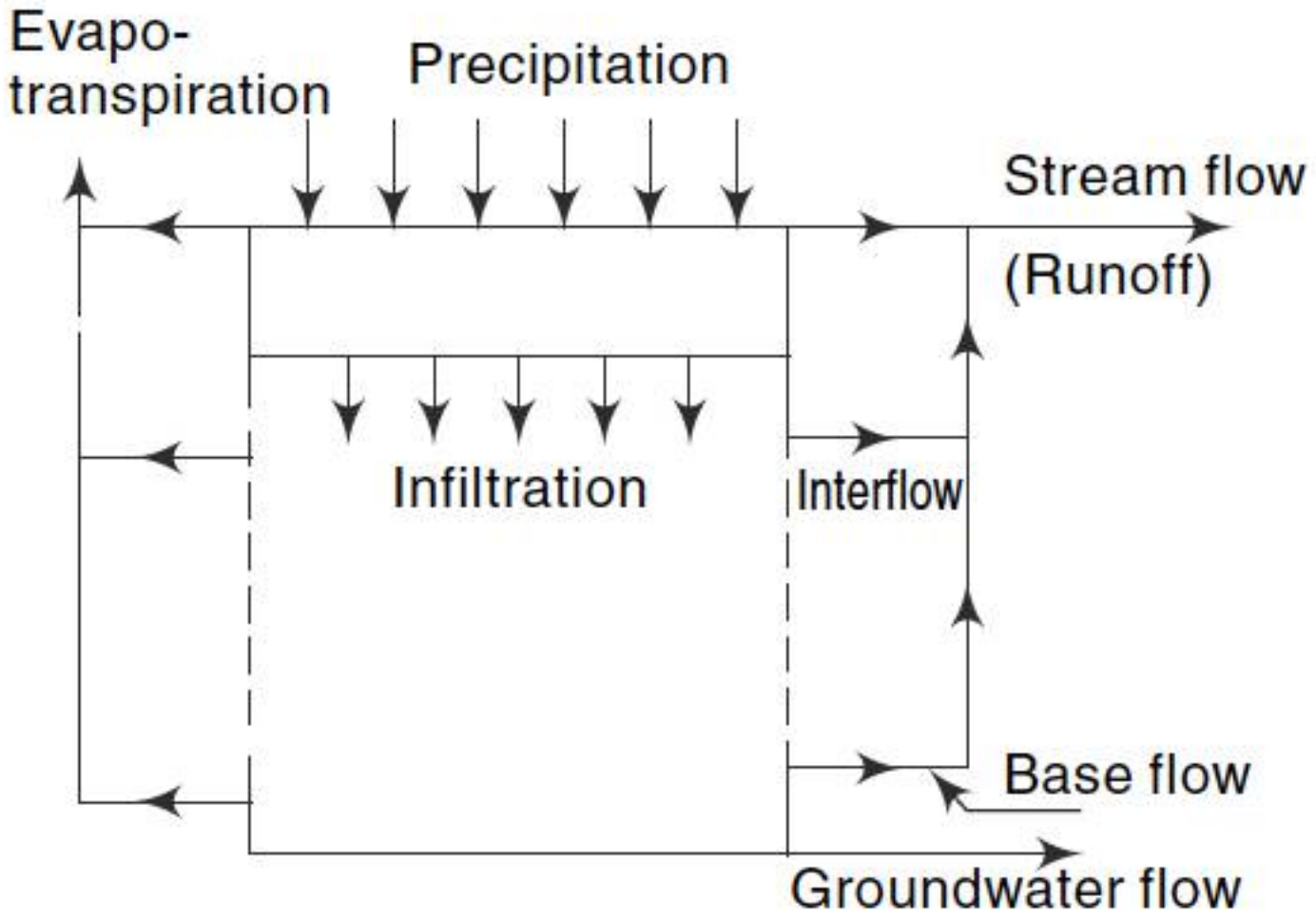


Fig. 1.3 ***Transportation Components of the Hydrologic Cycle***

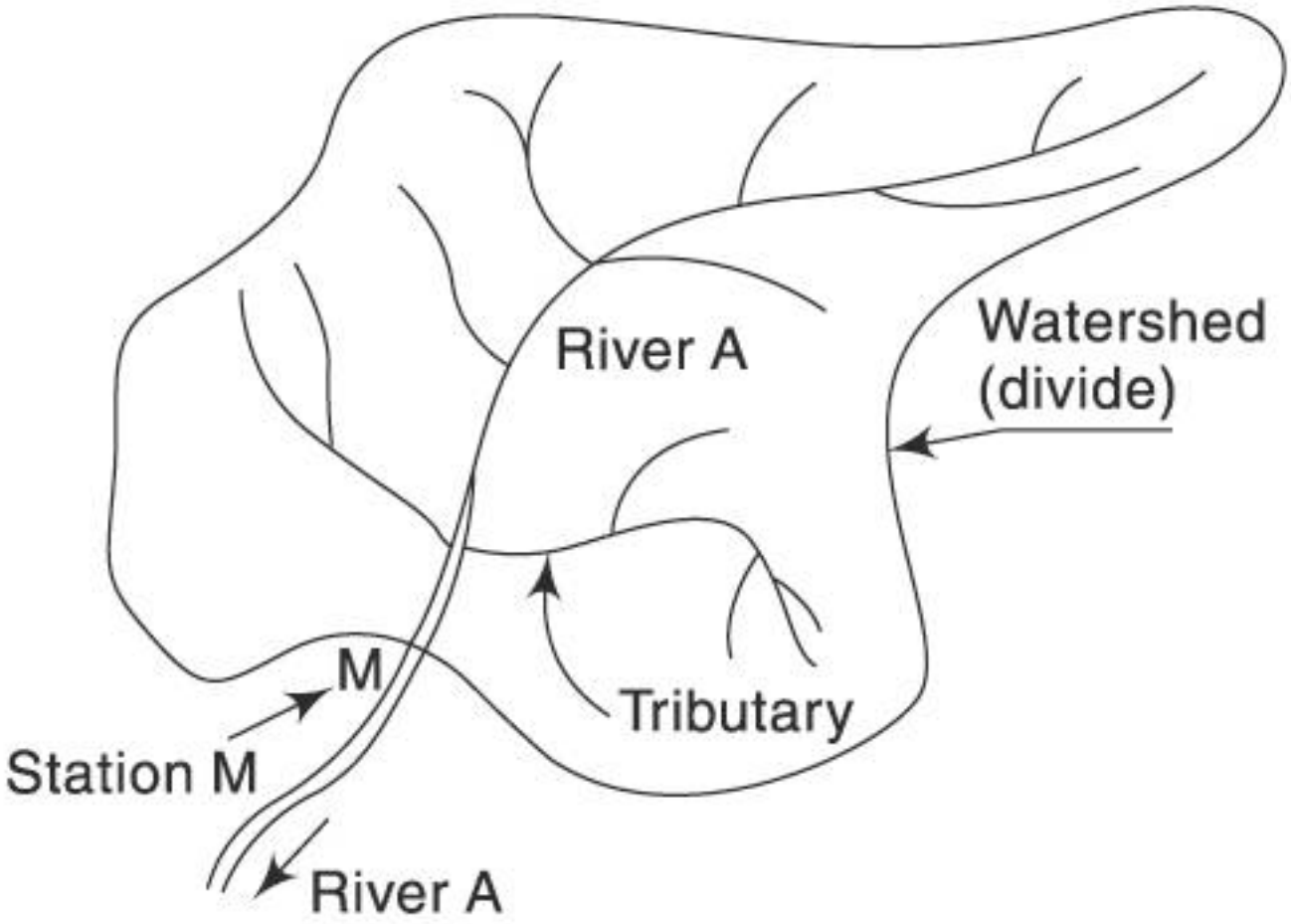


Fig. 1.4 *Schematic Sketch of Catchment of River A at Station M*

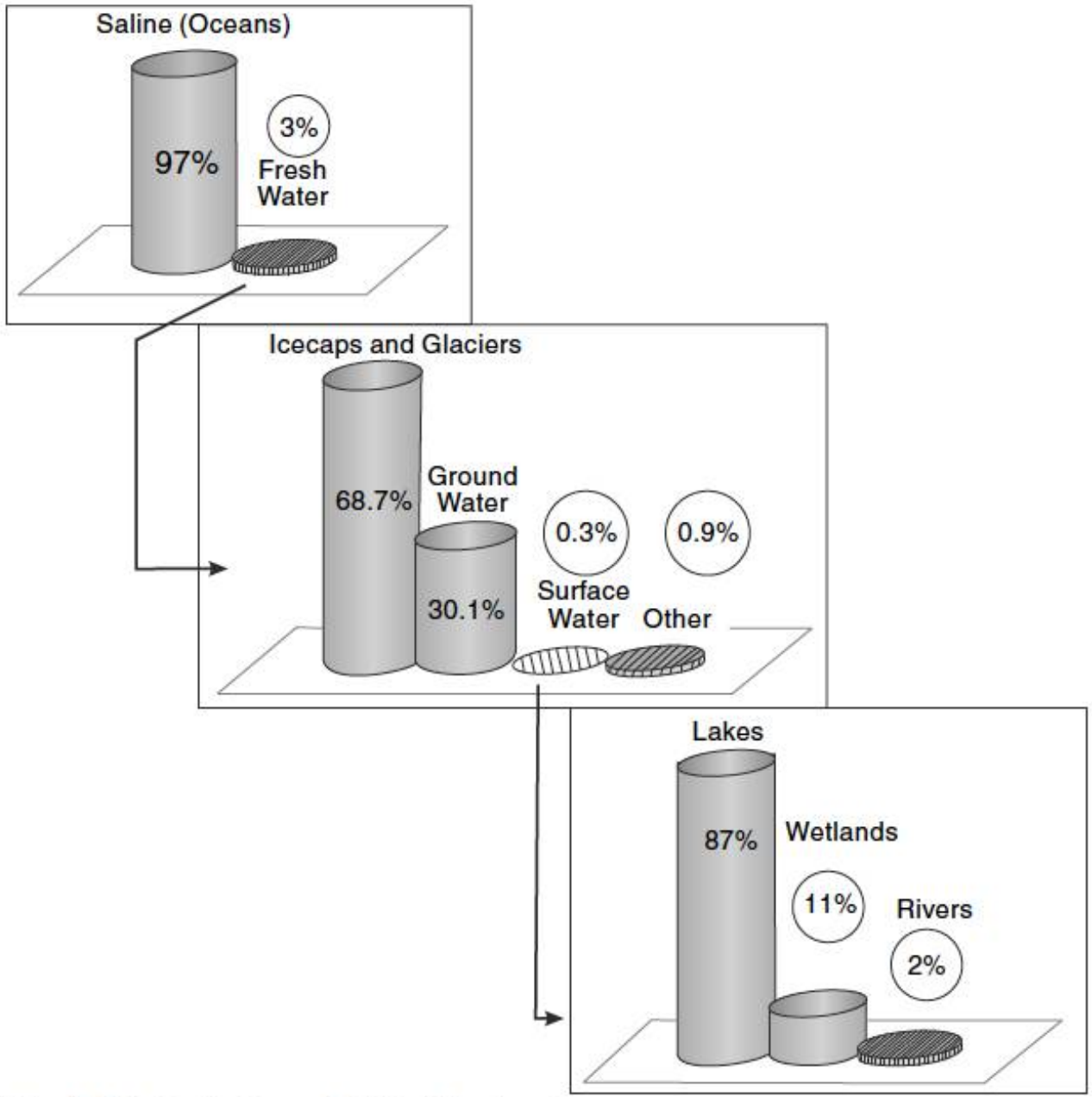


Fig. 1.5 *Distribution of Global Freshwater*

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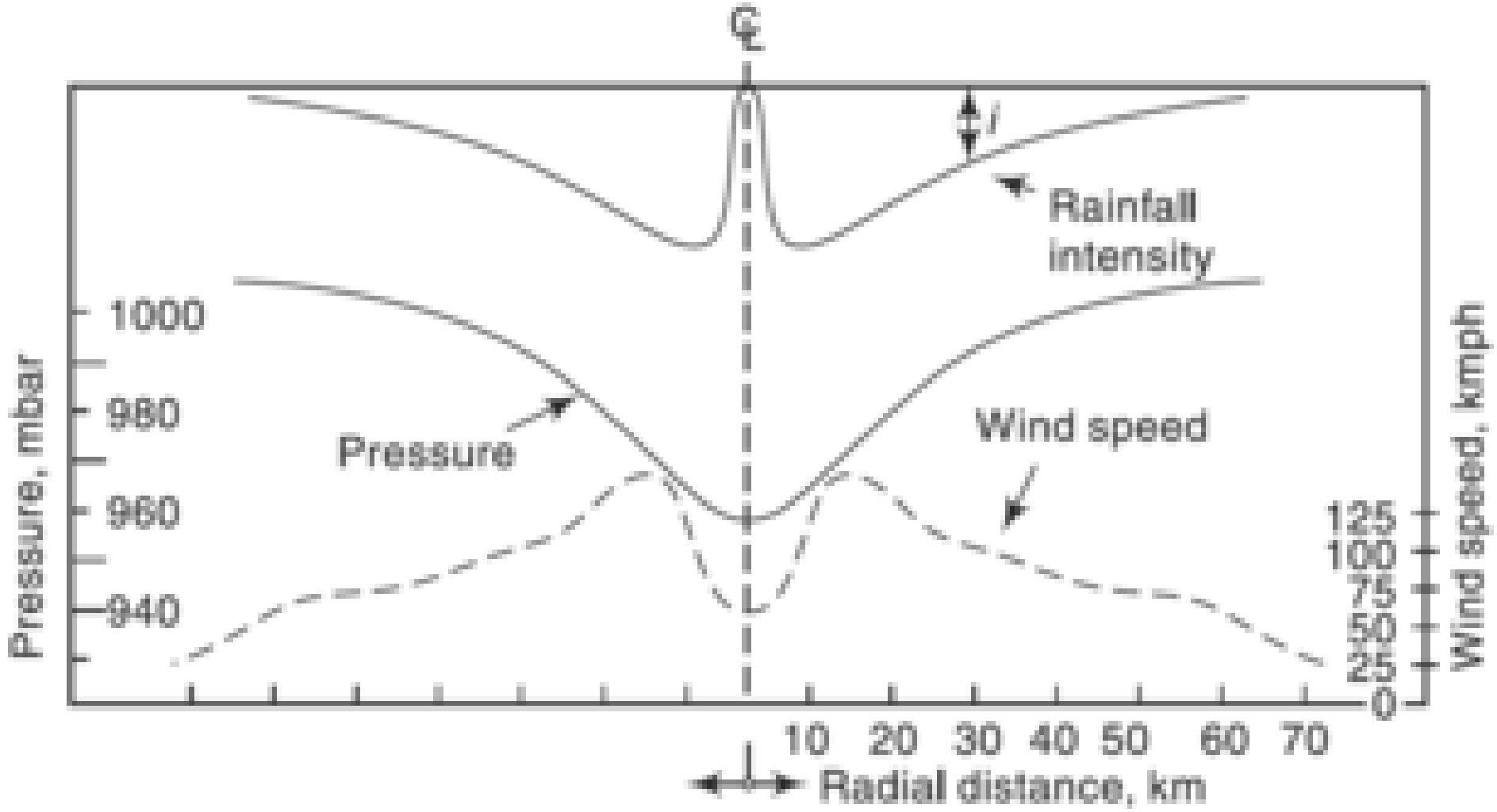

Fig. 2.1 *Schematic Section of a Tropical Cyclone*

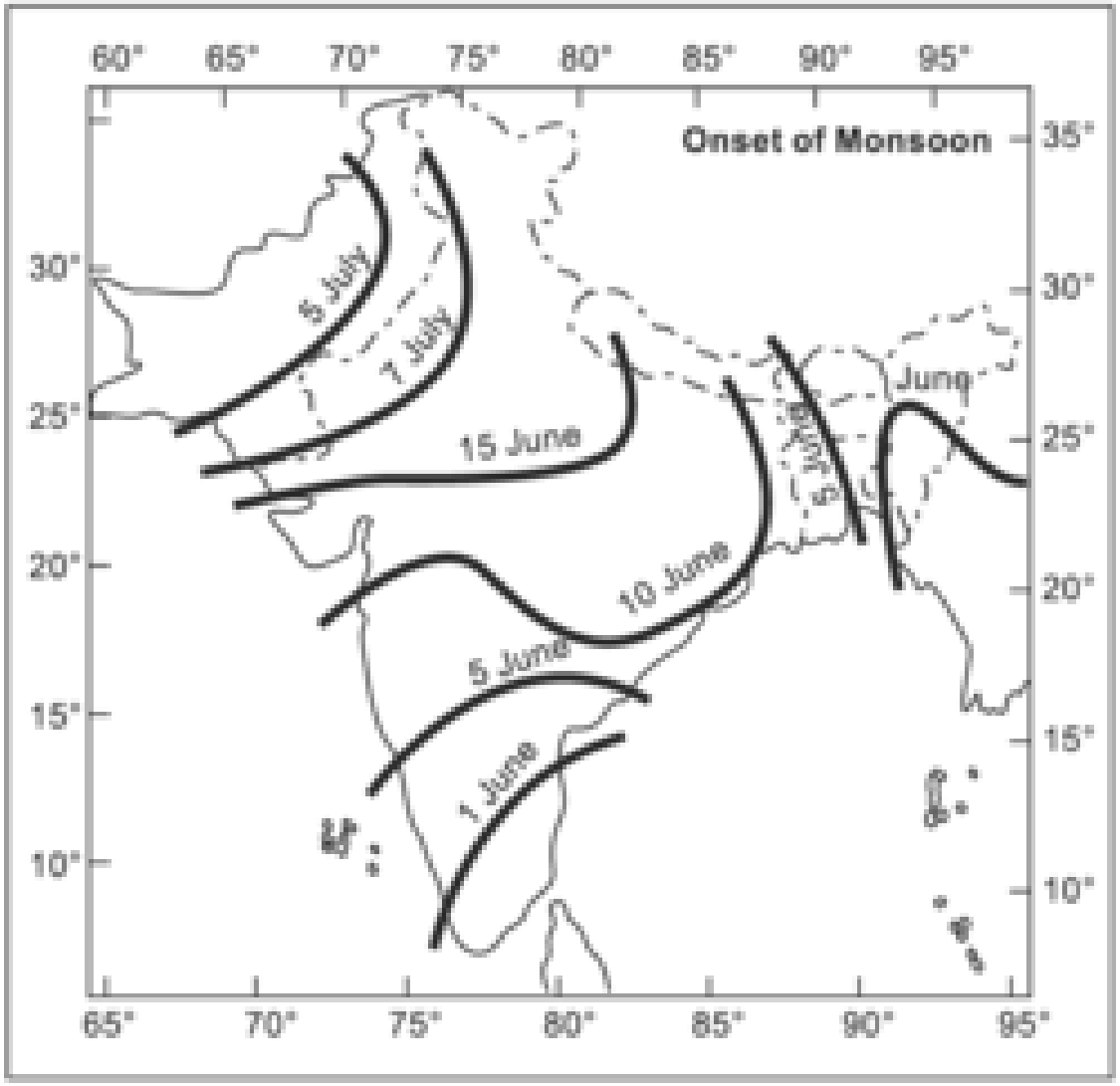

Fig. 2.2 *(a) Normal Dates of Onset of Monsoon (b) Normal Dates of Withdrawal of Monsoon*

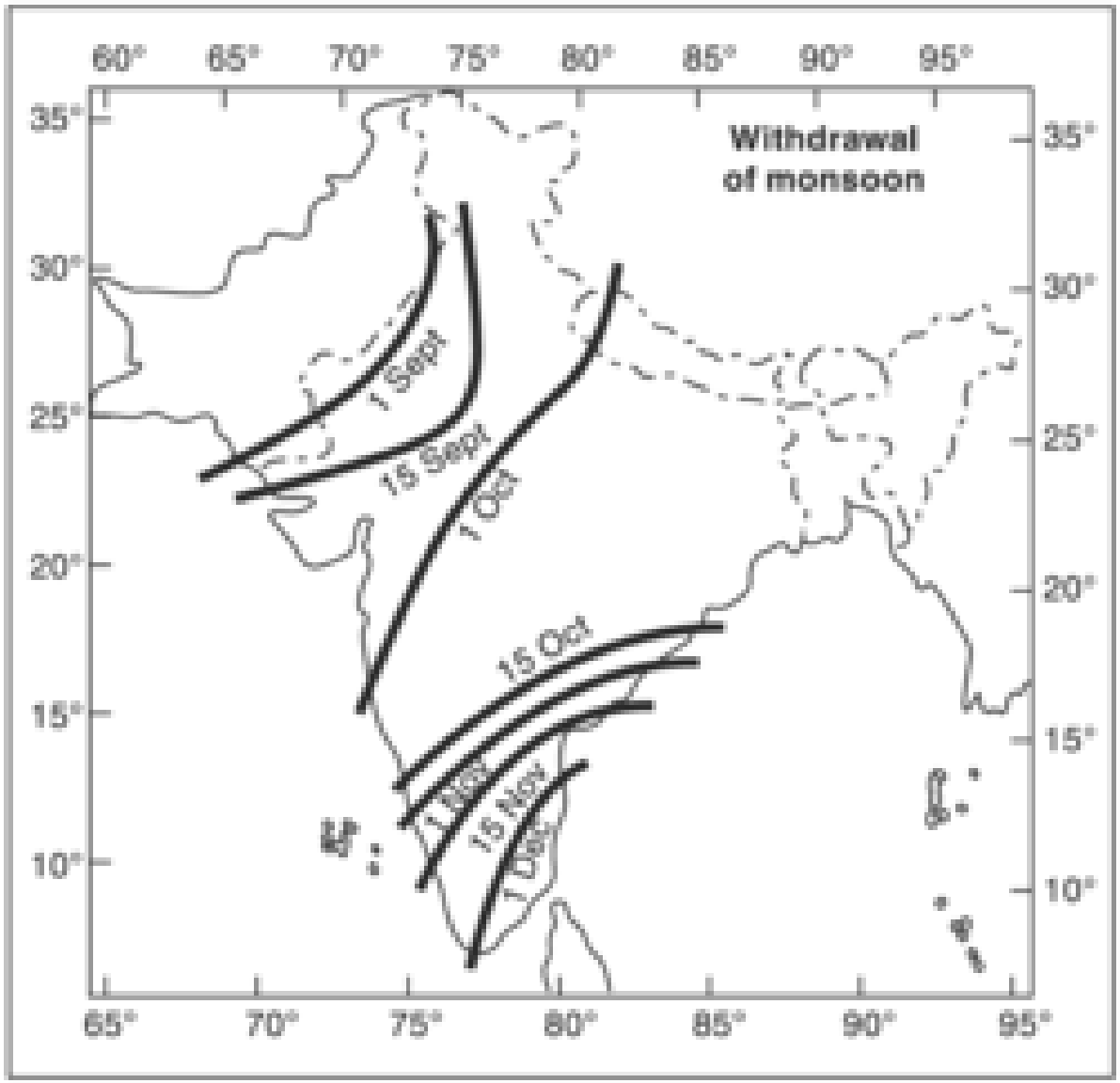

Fig. 2.2 *(a) Normal Dates of Onset of Monsoon (b) Normal Dates of Withdrawal of Monsoon*

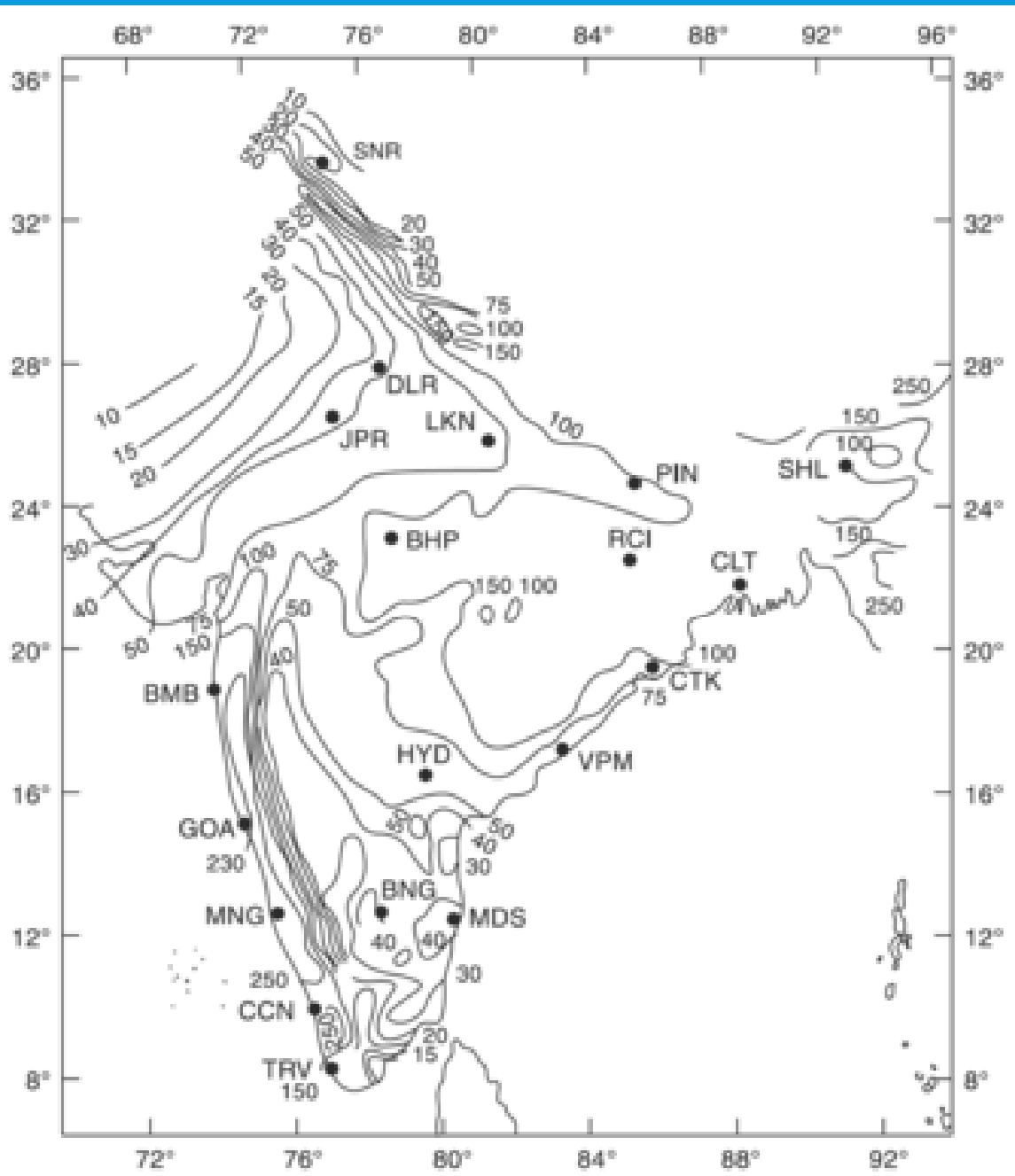

Fig. 2.3 *South-west Monsoon Rainfall (cm) over India and Neighbourhood*

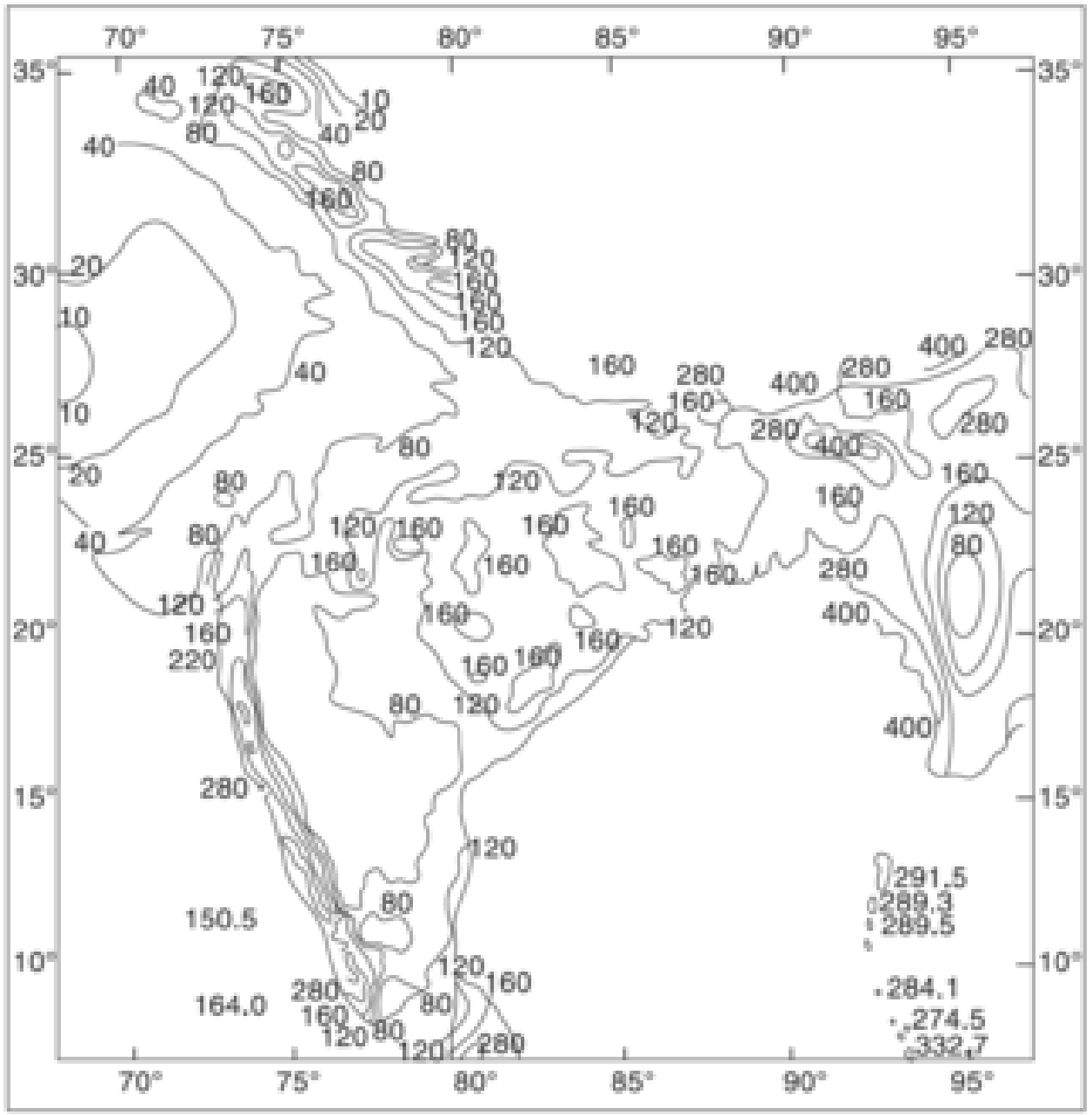

Fig. 2.4 *Annual Rainfall (cm) over India and Neighbourhood*

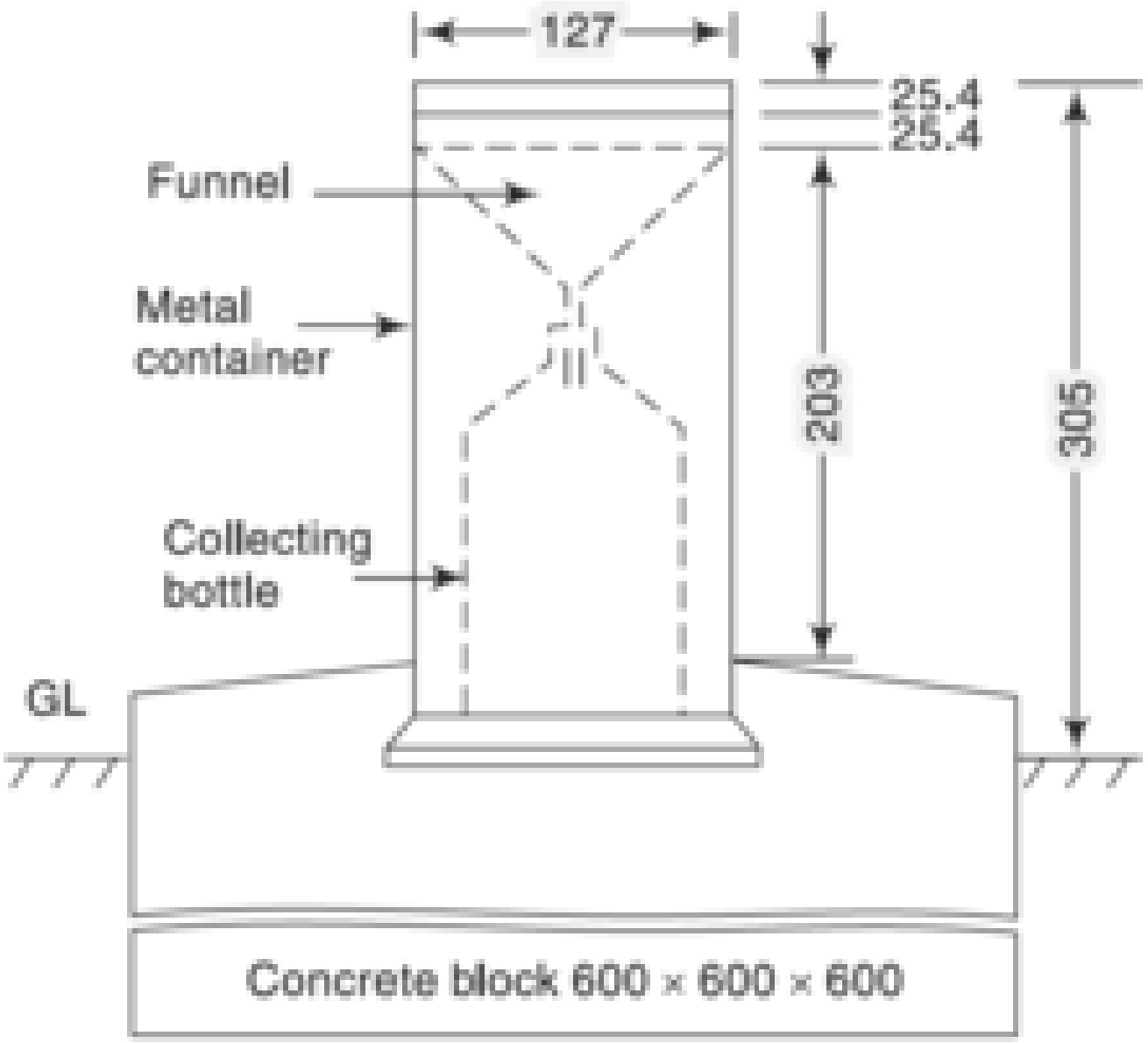

Fig. 2.5 *Nonrecording Raingauge (Symons' Gauge)*

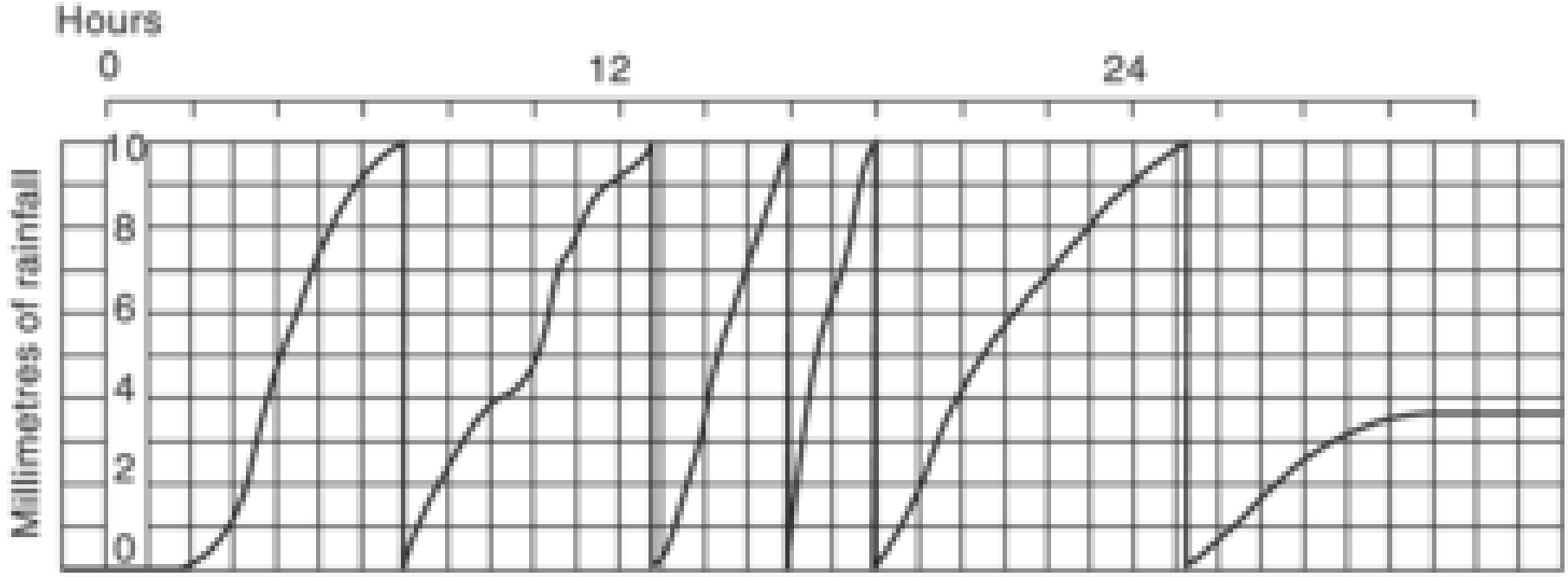

Fig. 2.6 *Recording from a Natural Syphon-type Gauge (Schematic)*

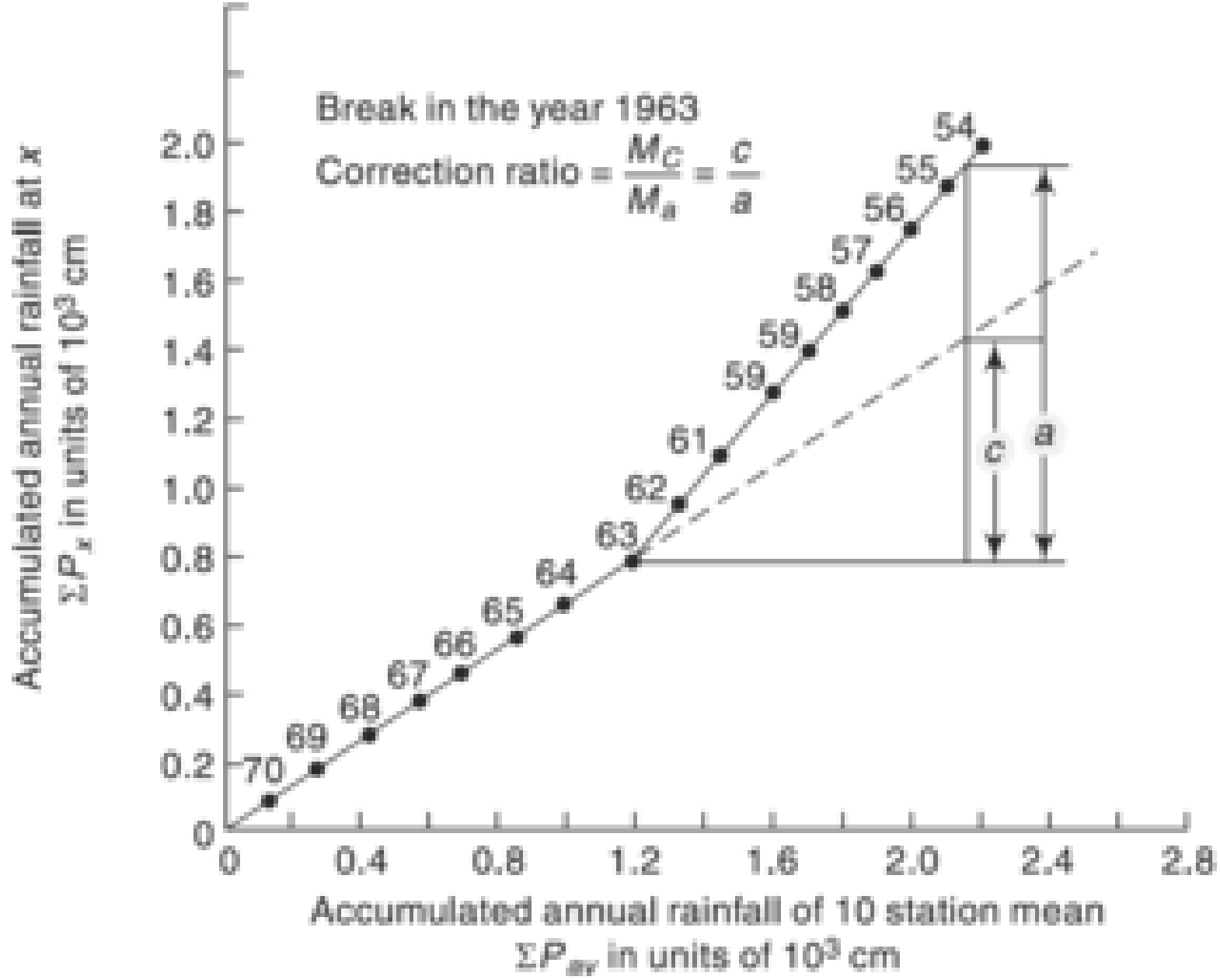

Fig. 2.7 *Double-mass Curve*

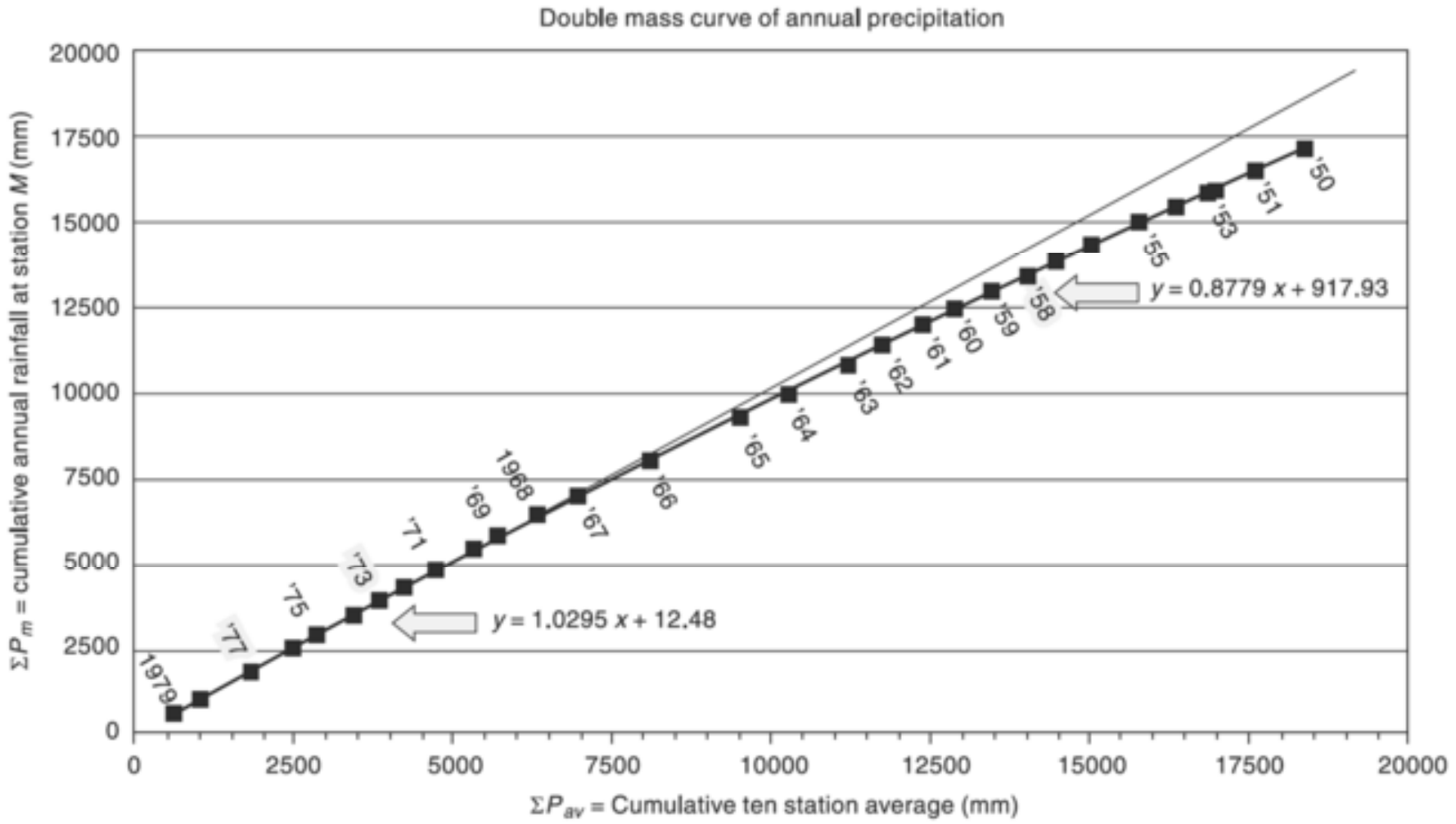

Fig. 2.8 *Double-Mass Curve of Annual Rainfall at Station M*

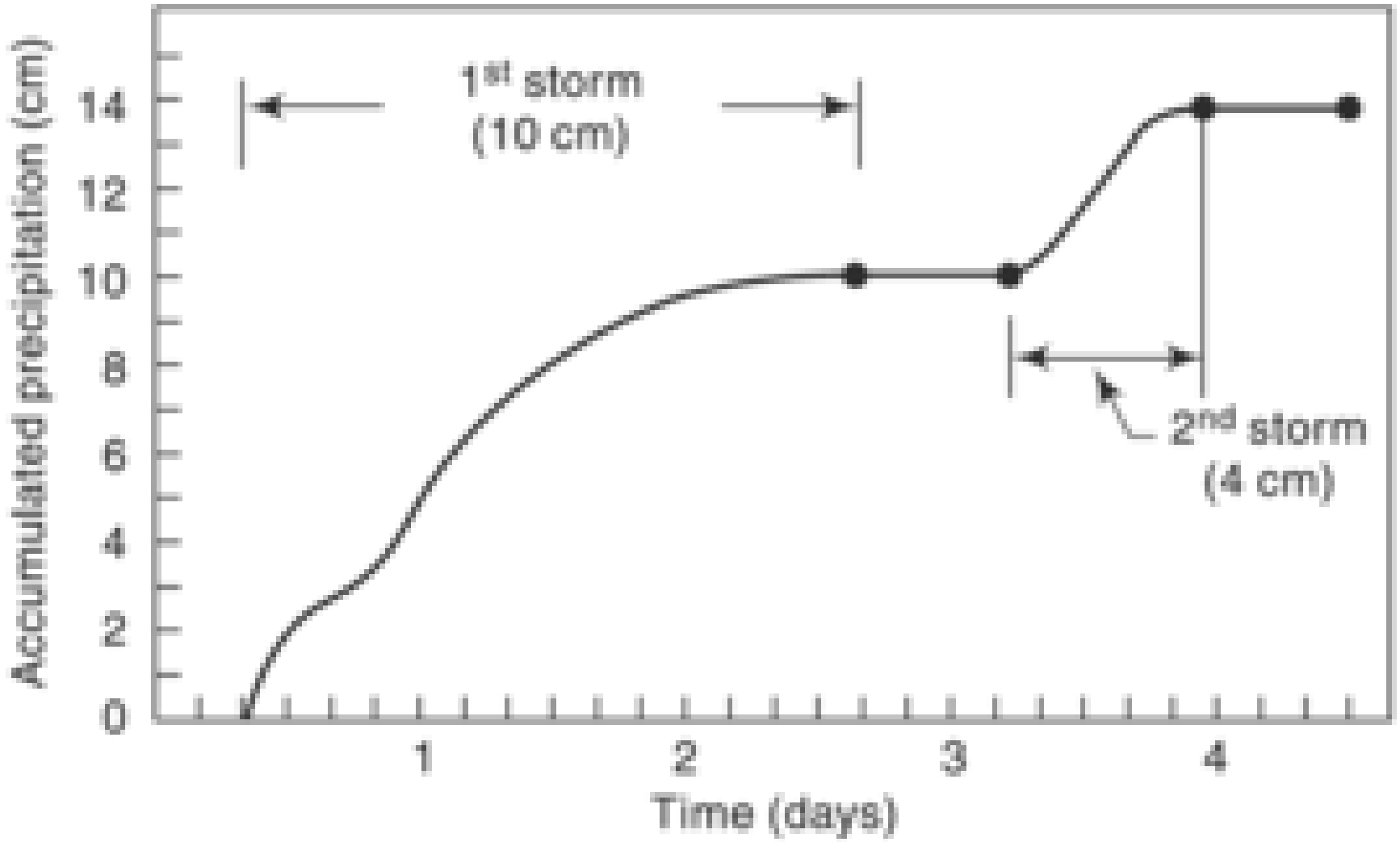

Fig. 2.9 *Mass Curve of Rainfall*

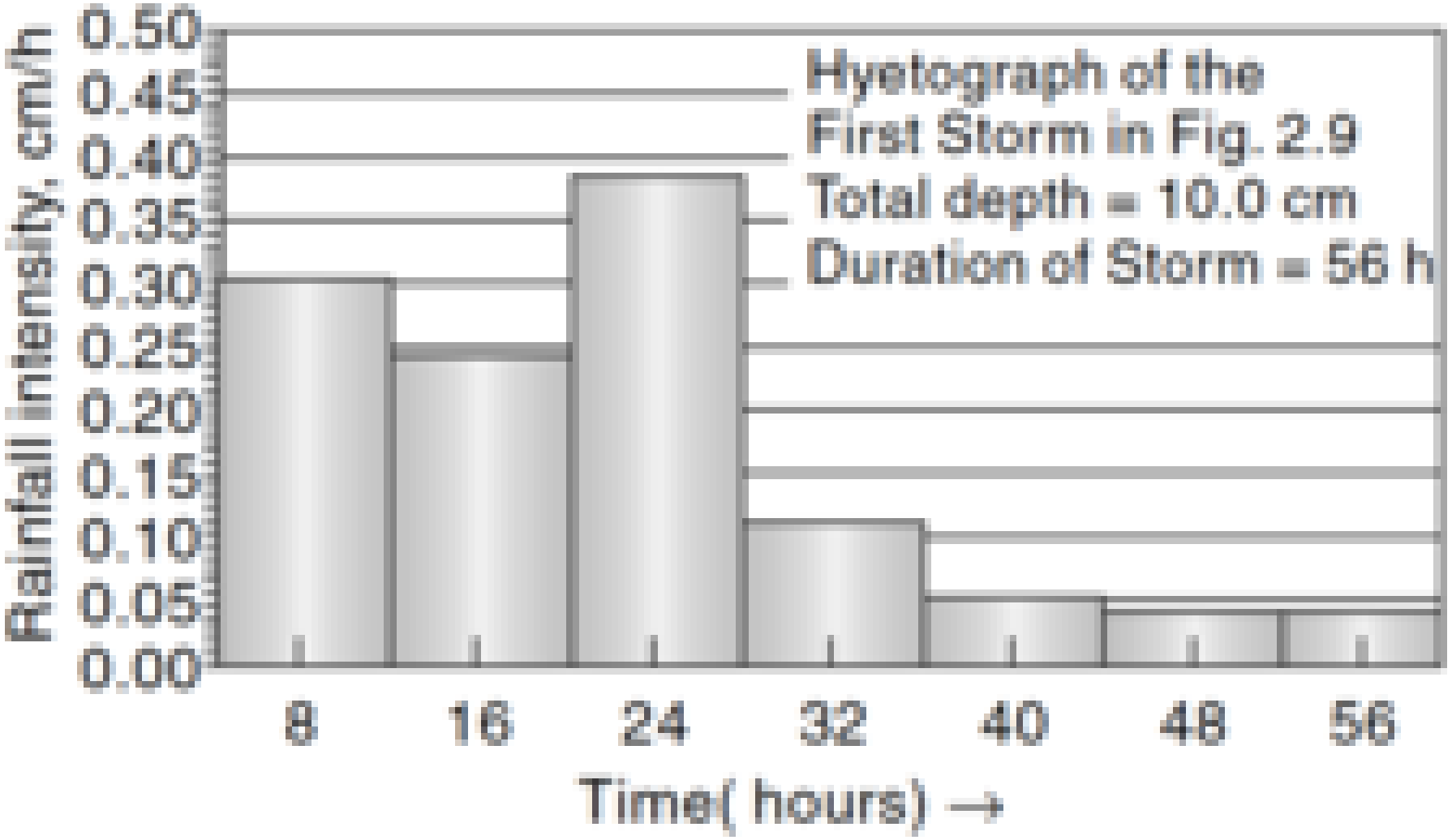

Fig. 2.10 ***Hyetograph of a Storm***

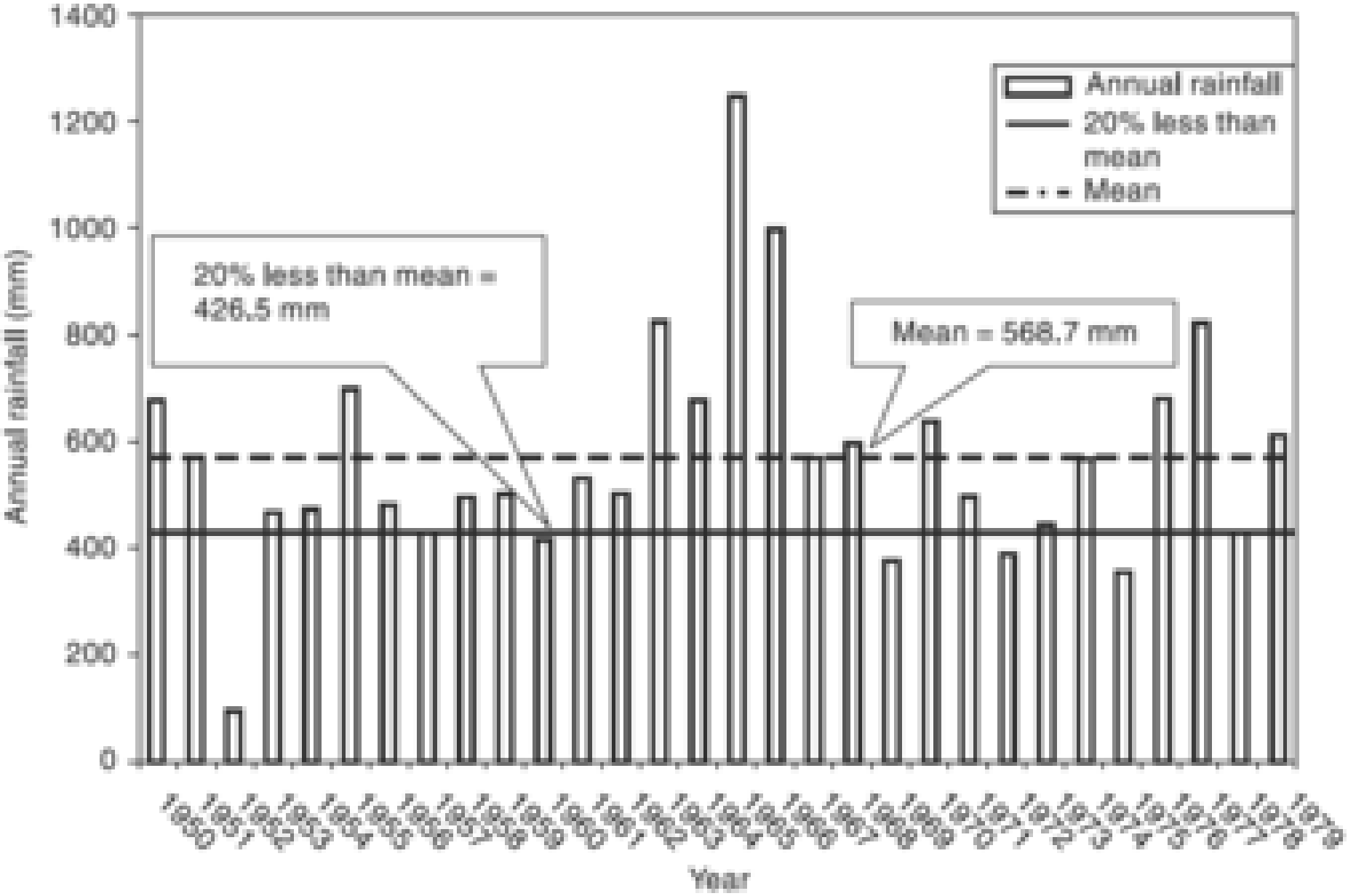

Fig. 2.11 *Bar Chart of Annual Rainfall at Station M*

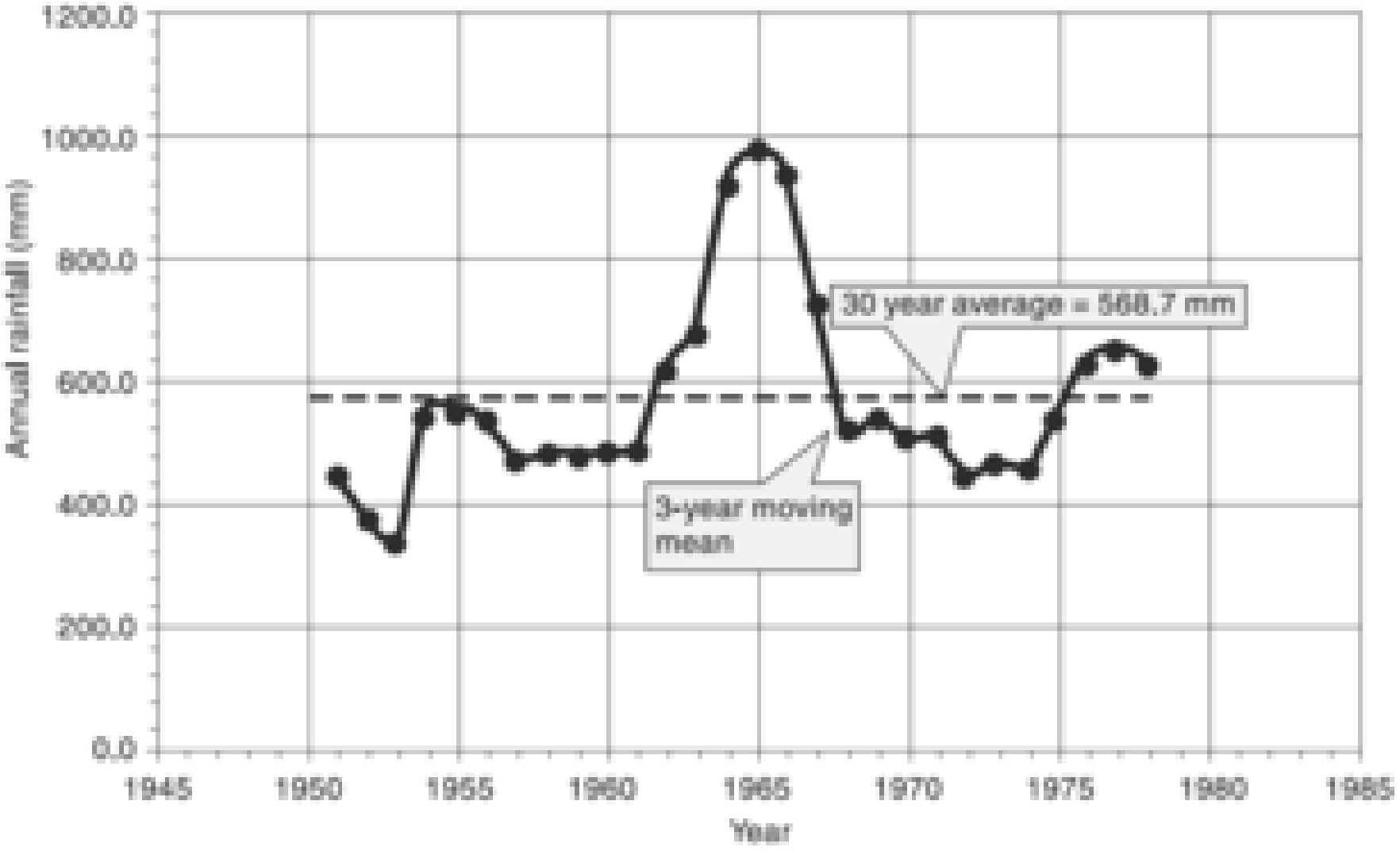

Fig. 2.12 *Three-year Moving Mean*

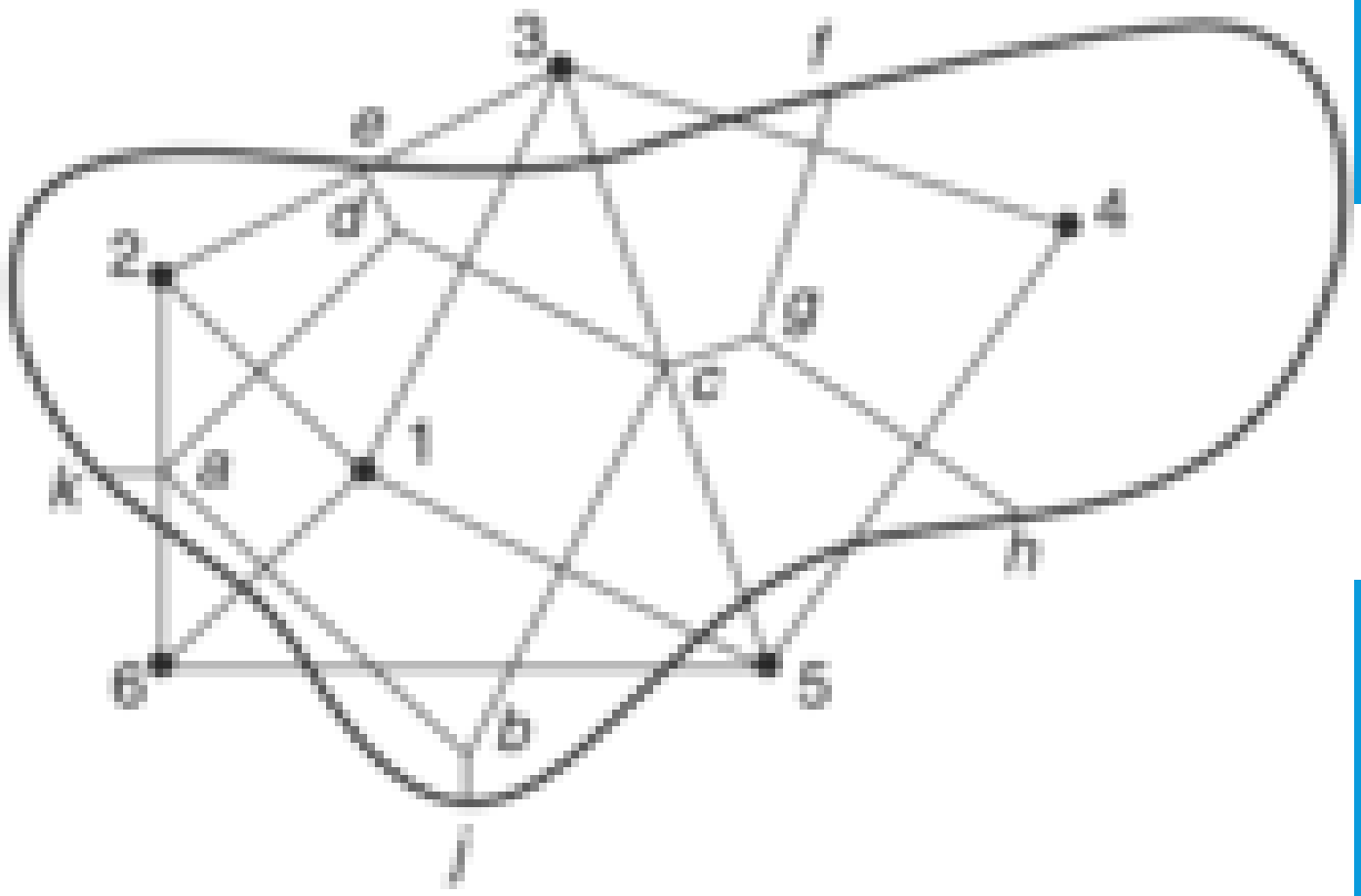

Fig. 2.13 *Thiessen Polygons*

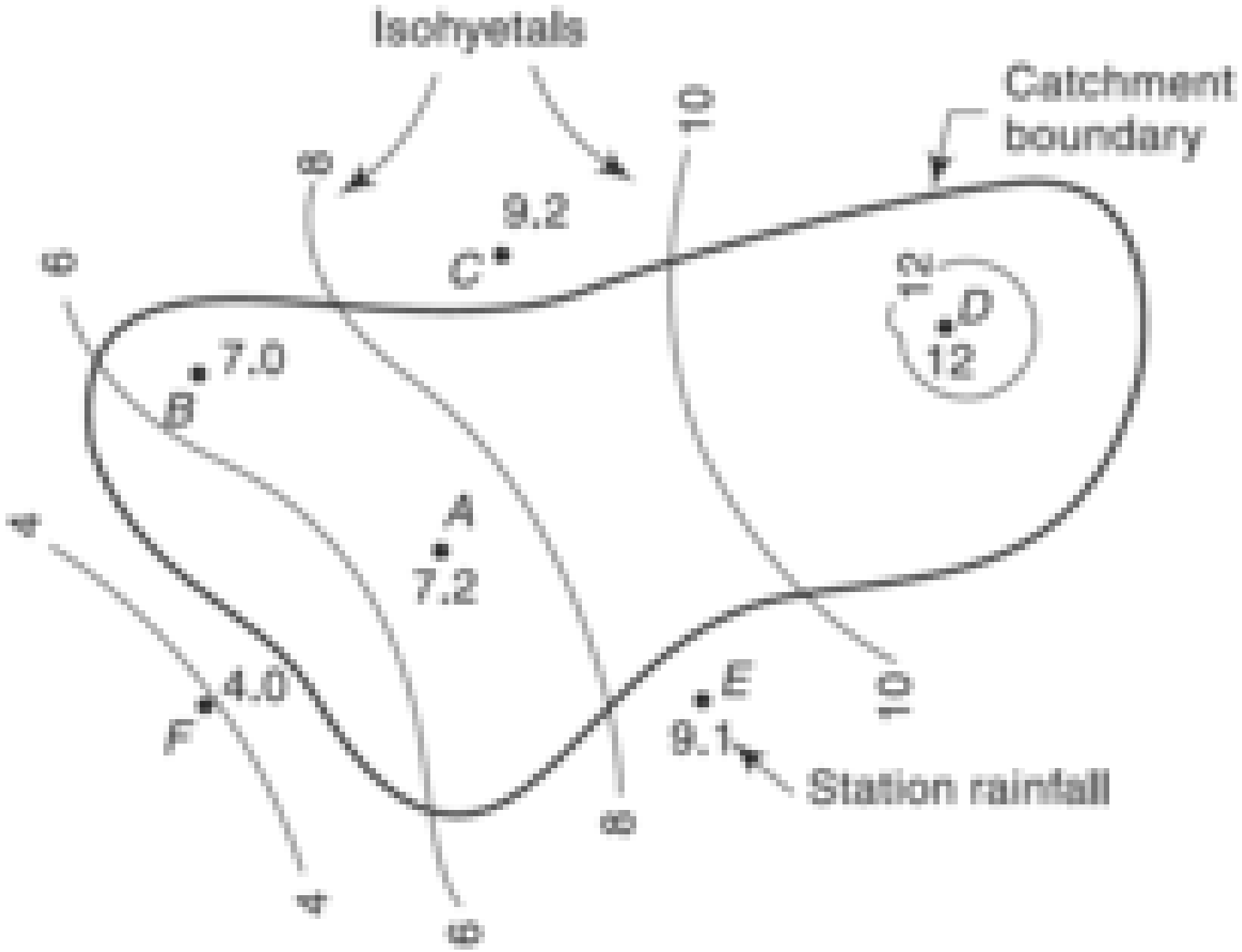

Fig. 2.14 *Isohyetals of a Storm*

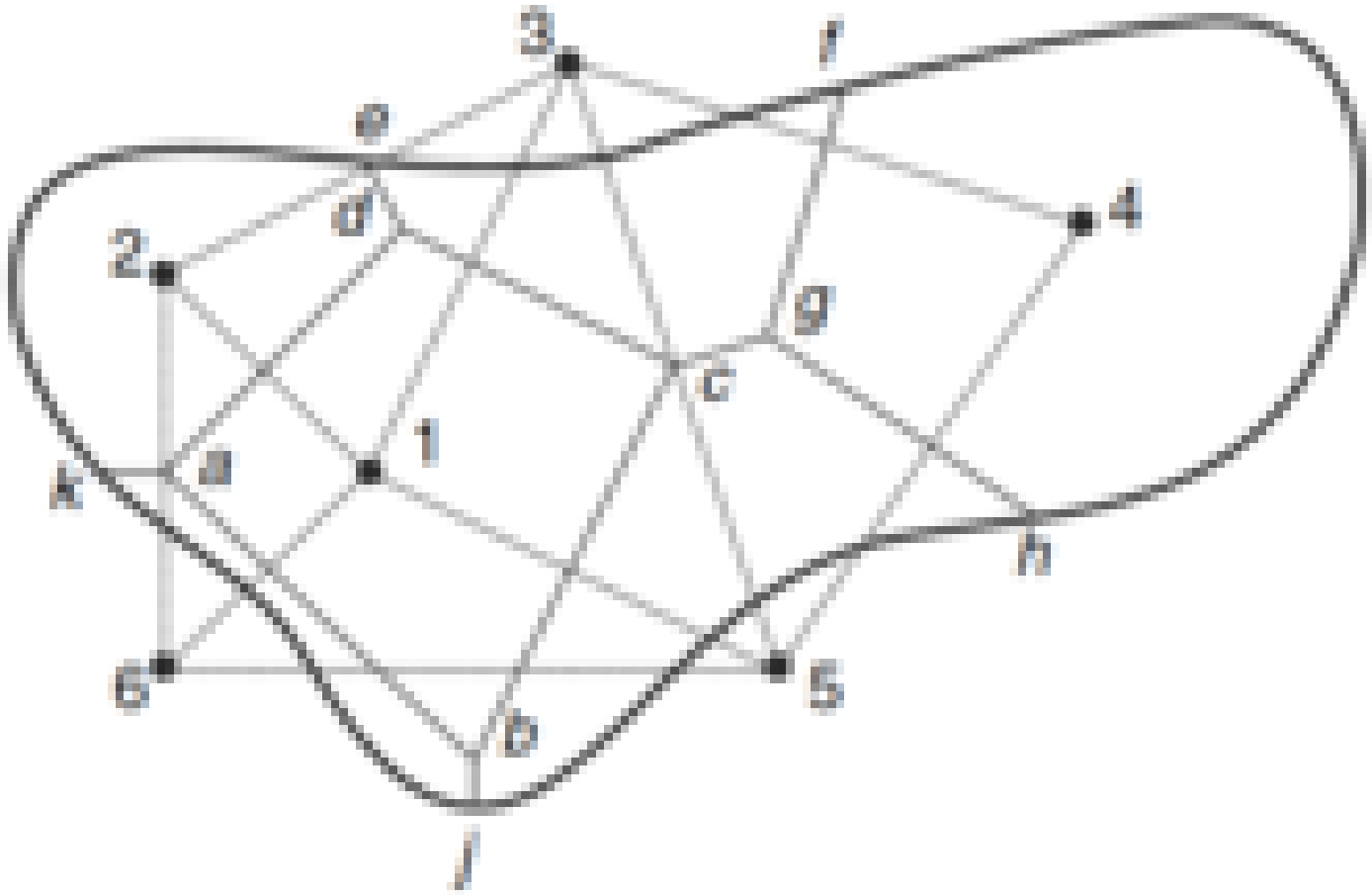

Fig. 2.15 *Thiessen Polygons of Example 2.5*

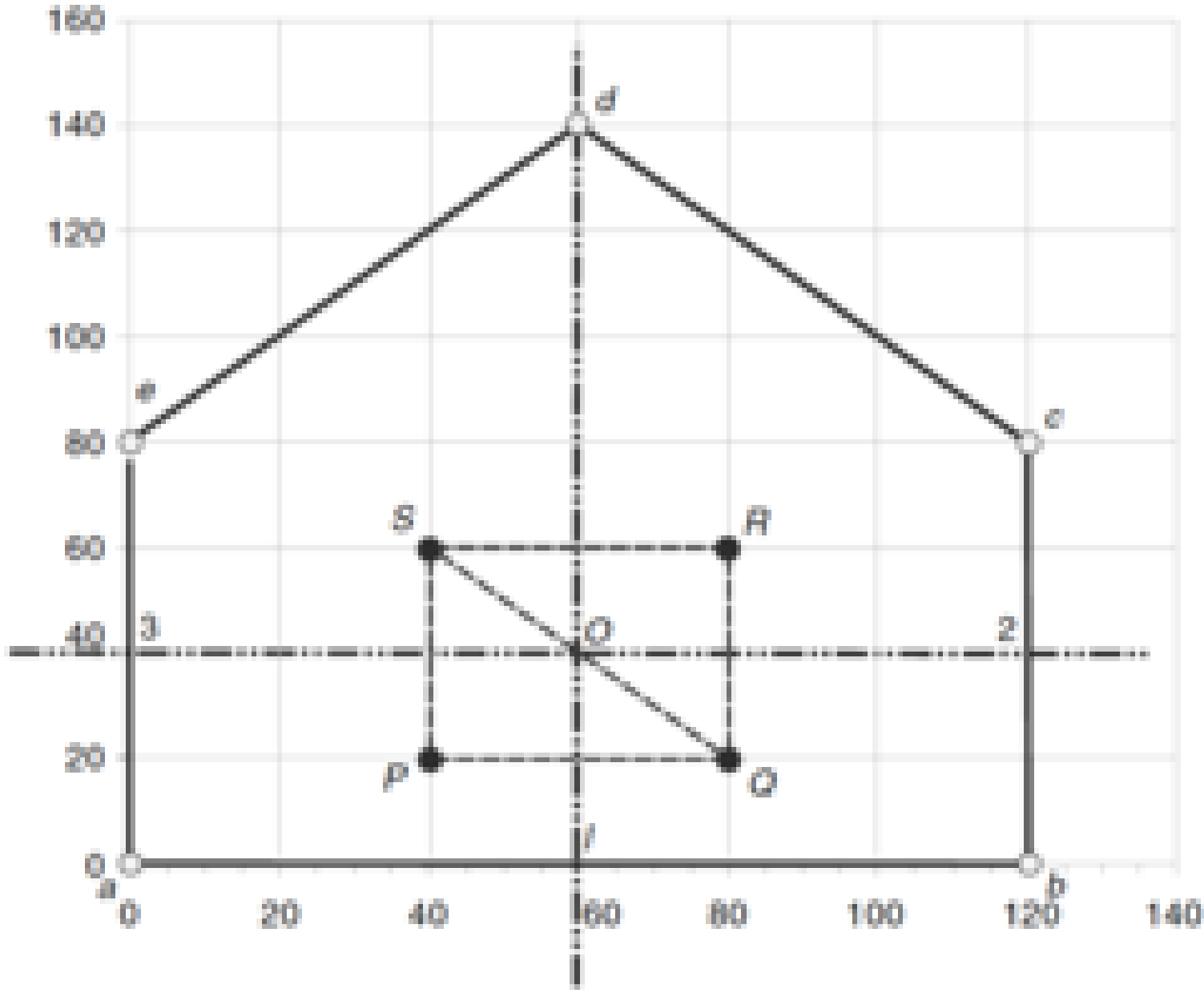

Fig. 2.16 *Thiessen Polygons of Example 2.6*

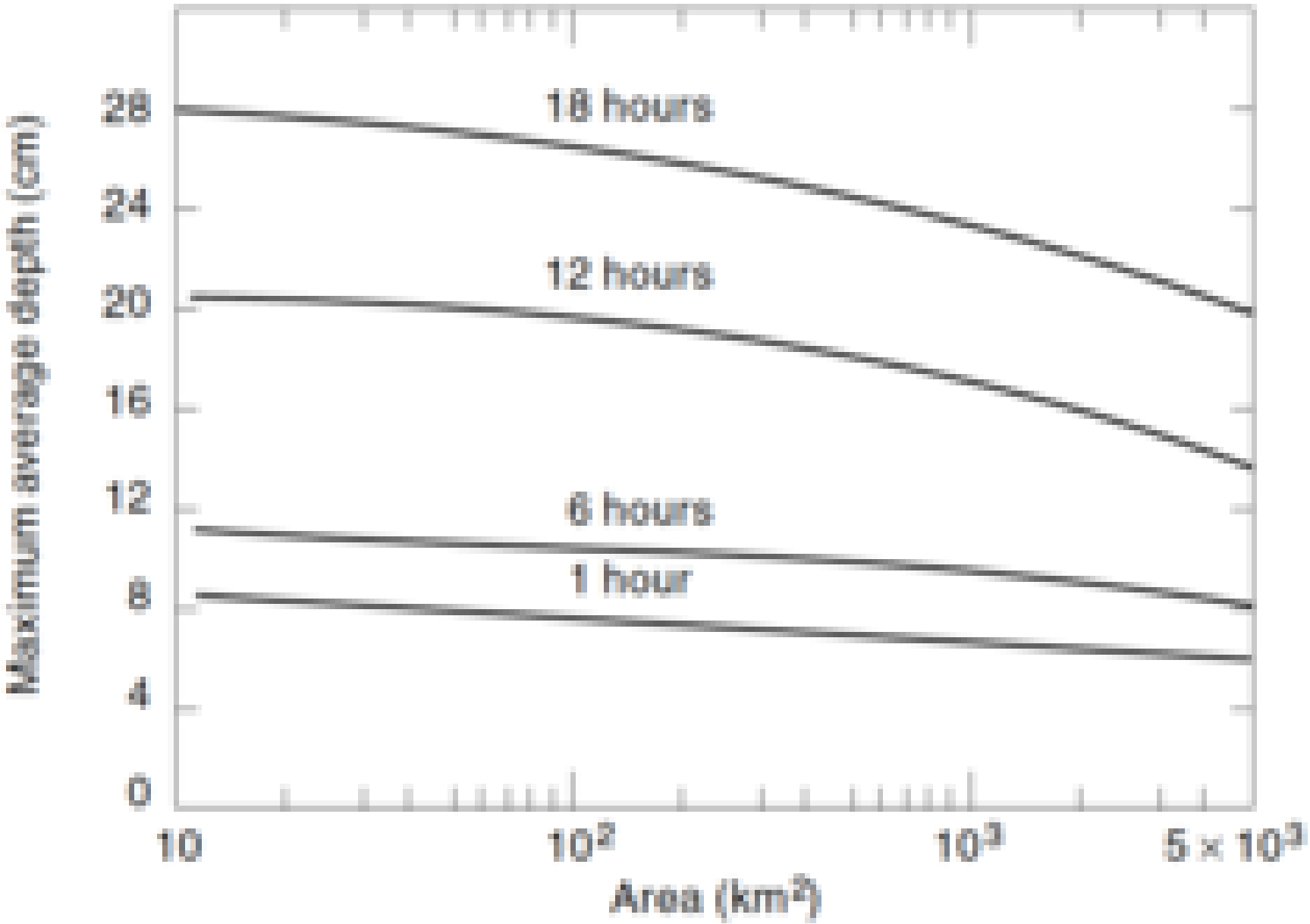

Fig. 2.17 *Typical DAD Curves*

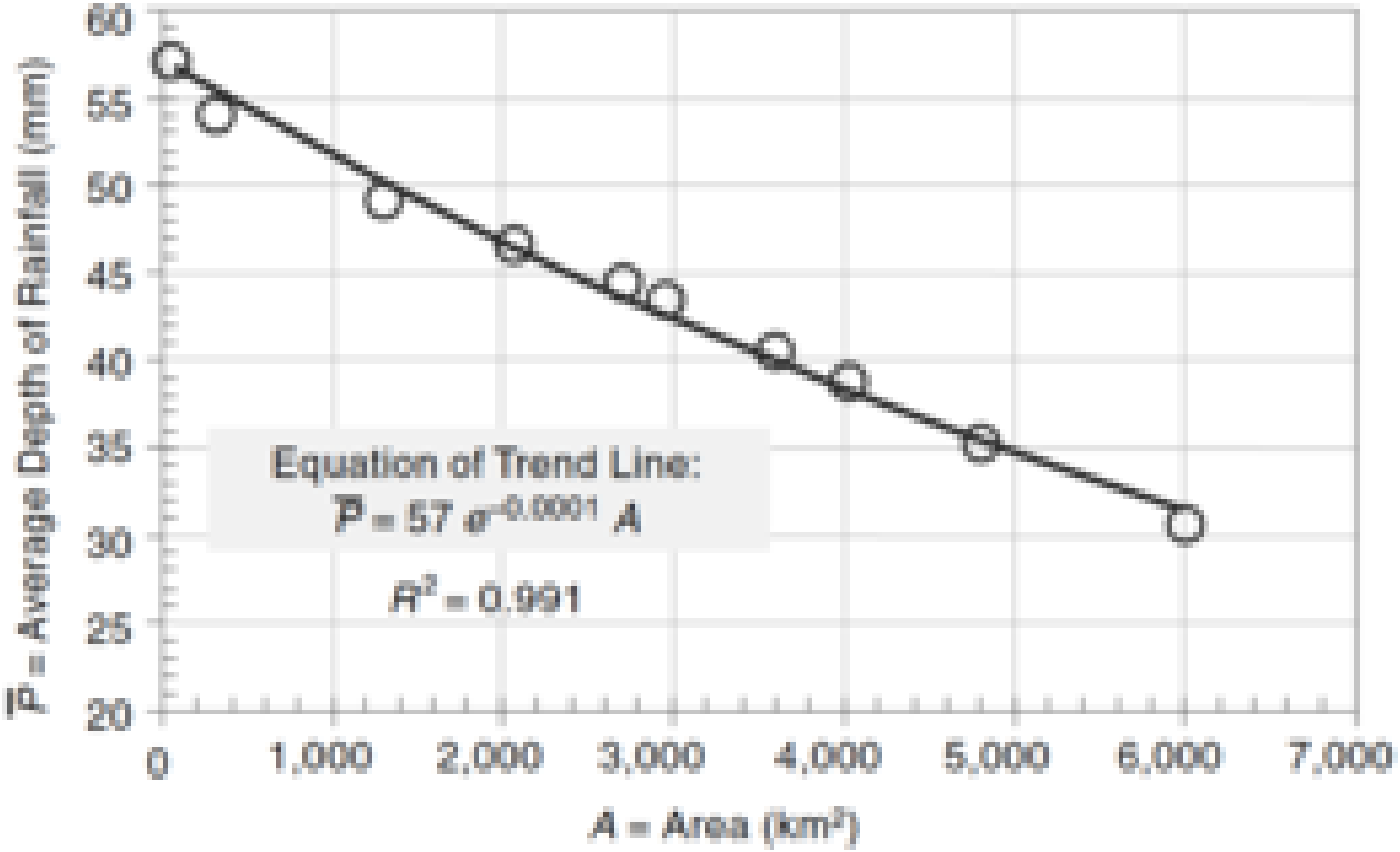

Fig. 2.18 *Depth-Area Curve-Example 2.8*

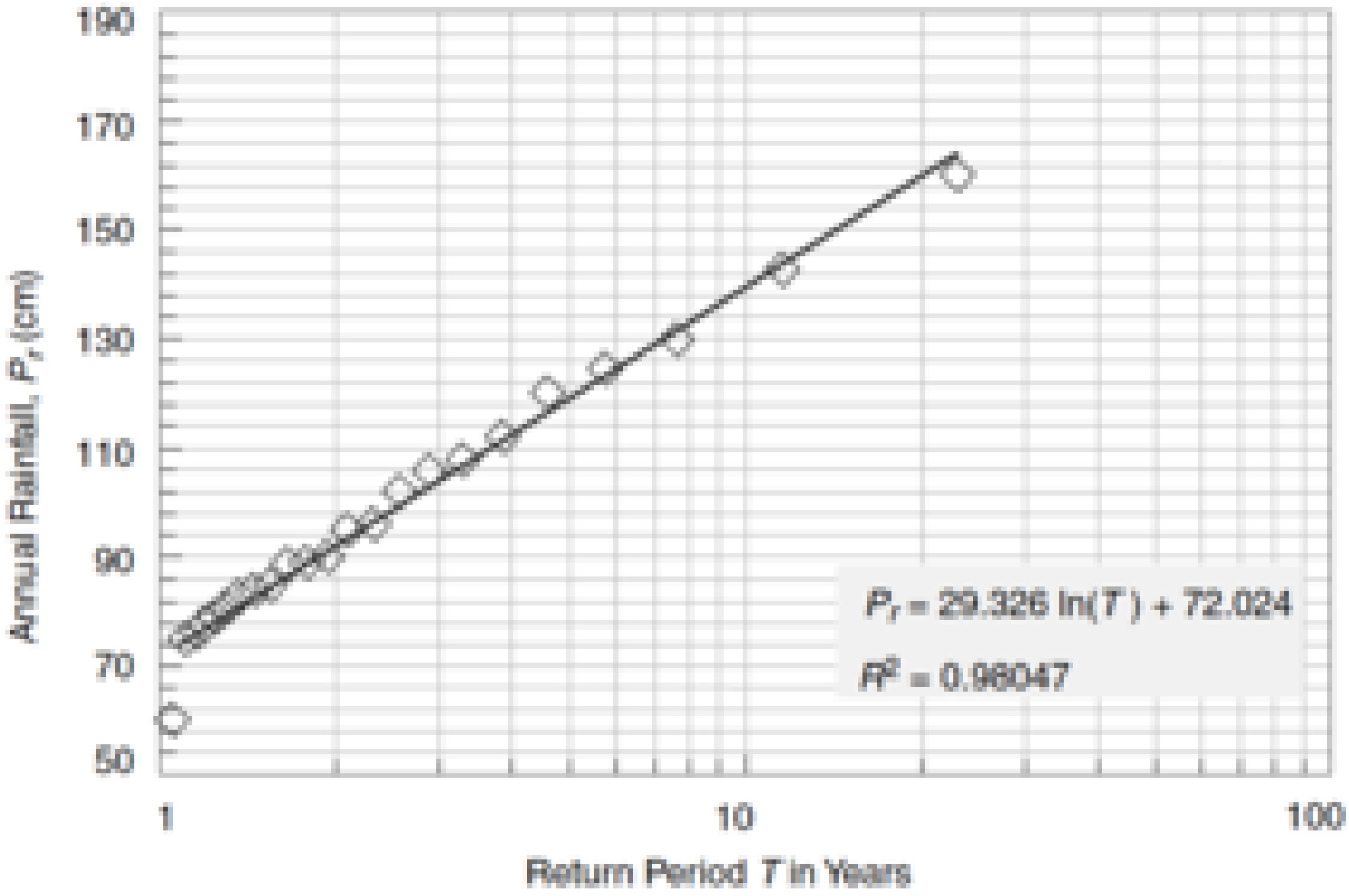

Fig. 2.19 *Return Period of Annual Rainfall at Station—Example 2.10*

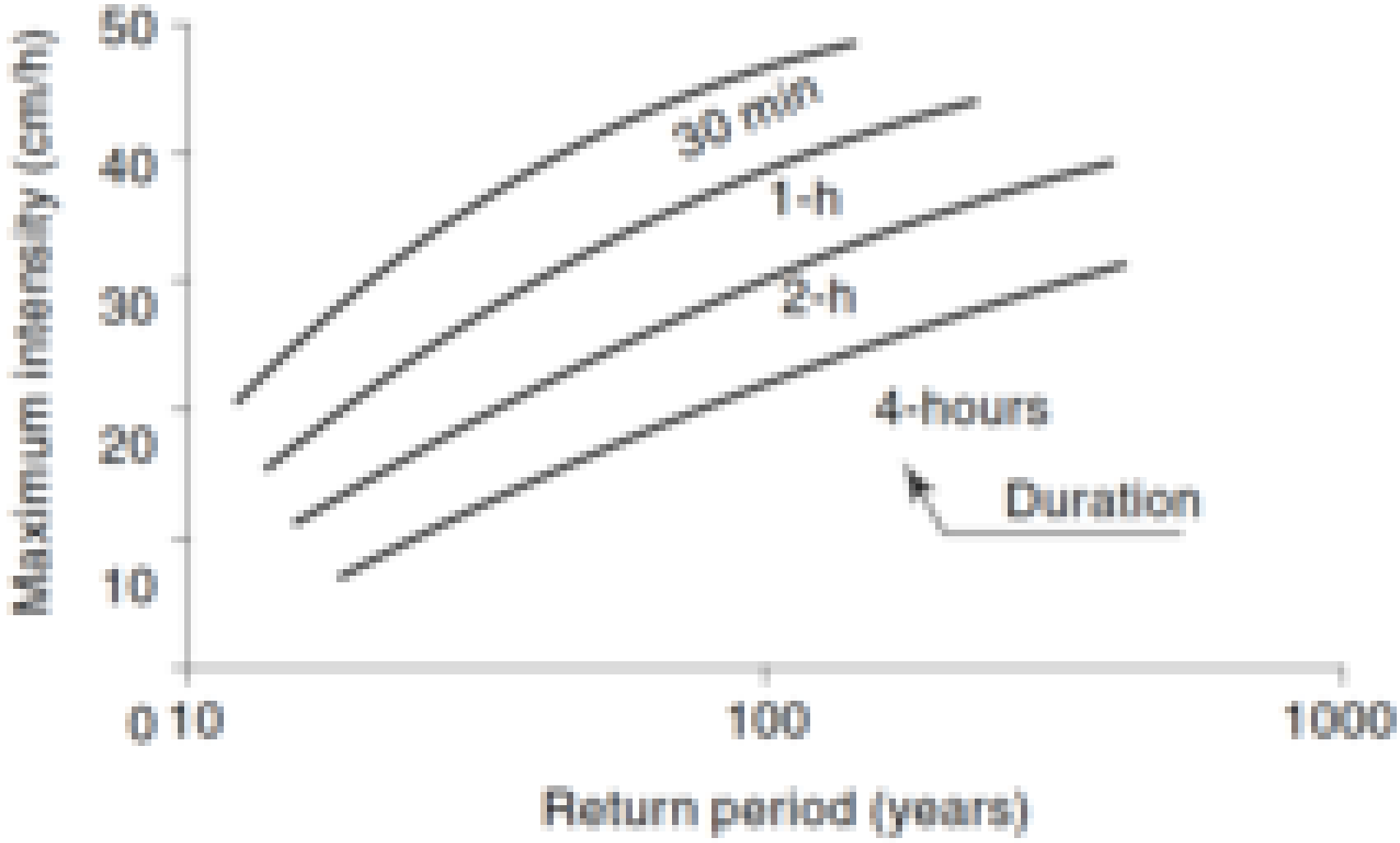

Fig. 2.20 *Maximum Intensity-Return Period-Duration Curves*

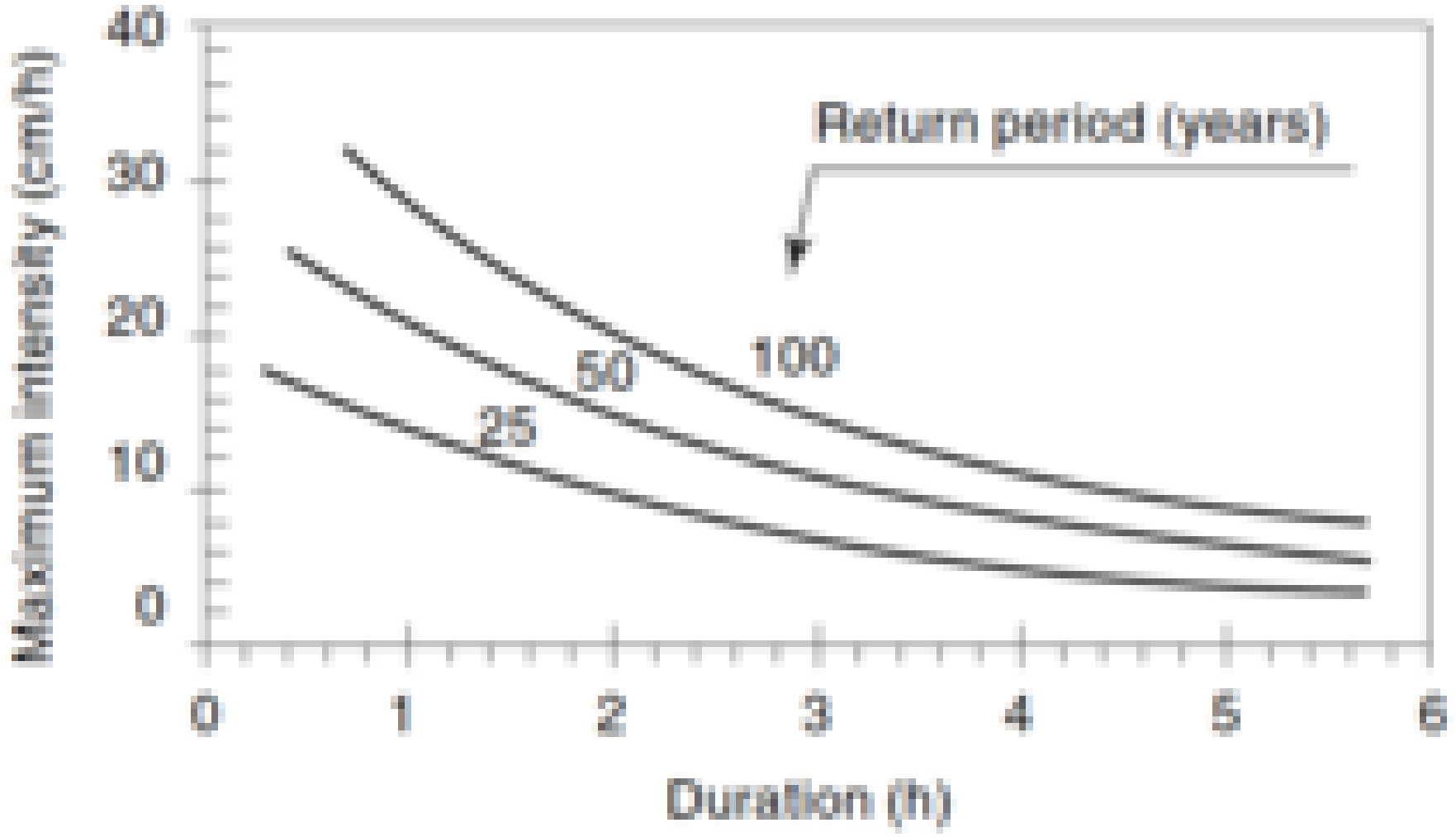

Fig. 2.21 *Maximum Intensity-Duration-Frequency Curves*

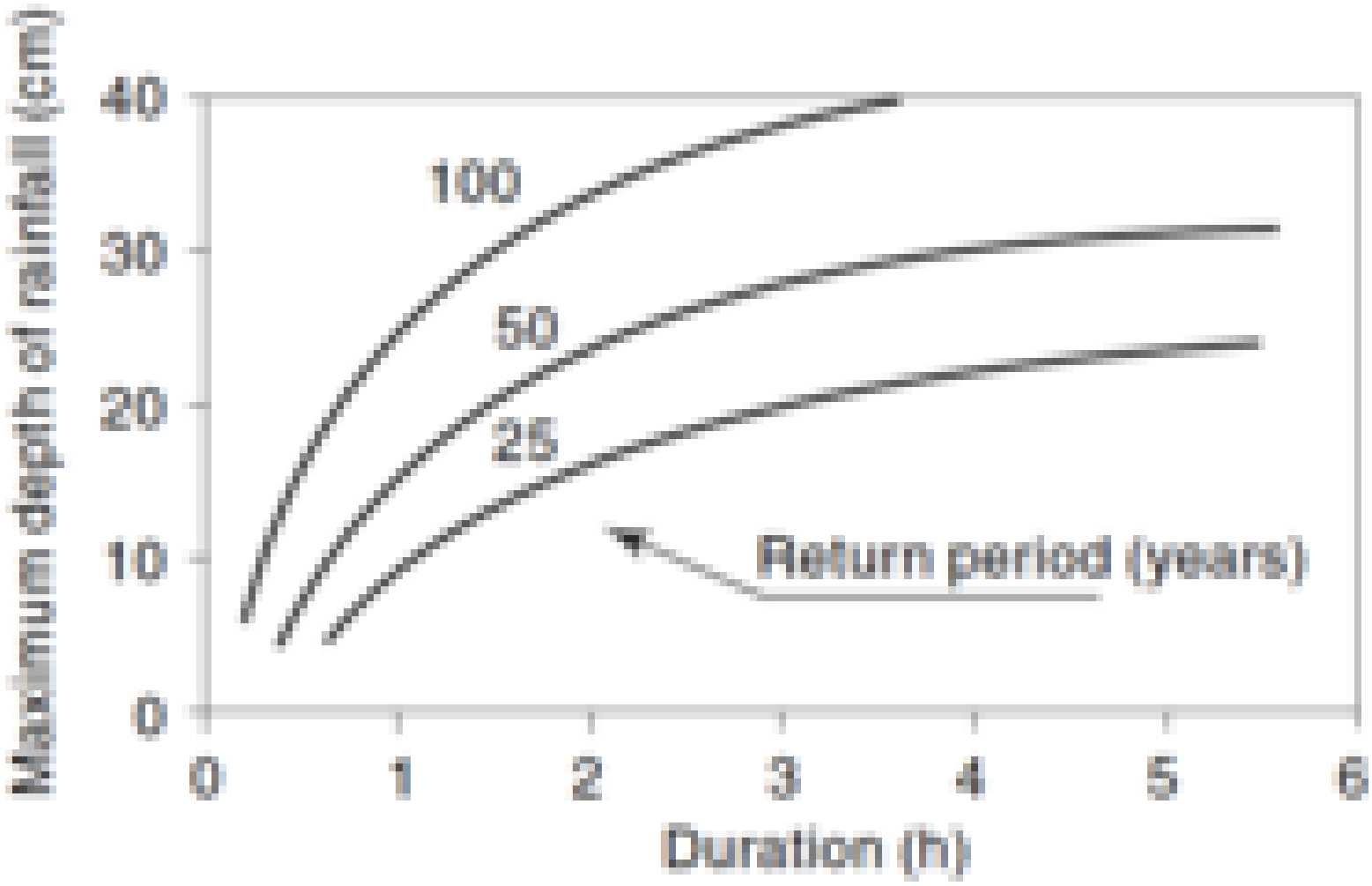

Fig. 2.22 *Maximum Depth-Duration-Frequency Curves*

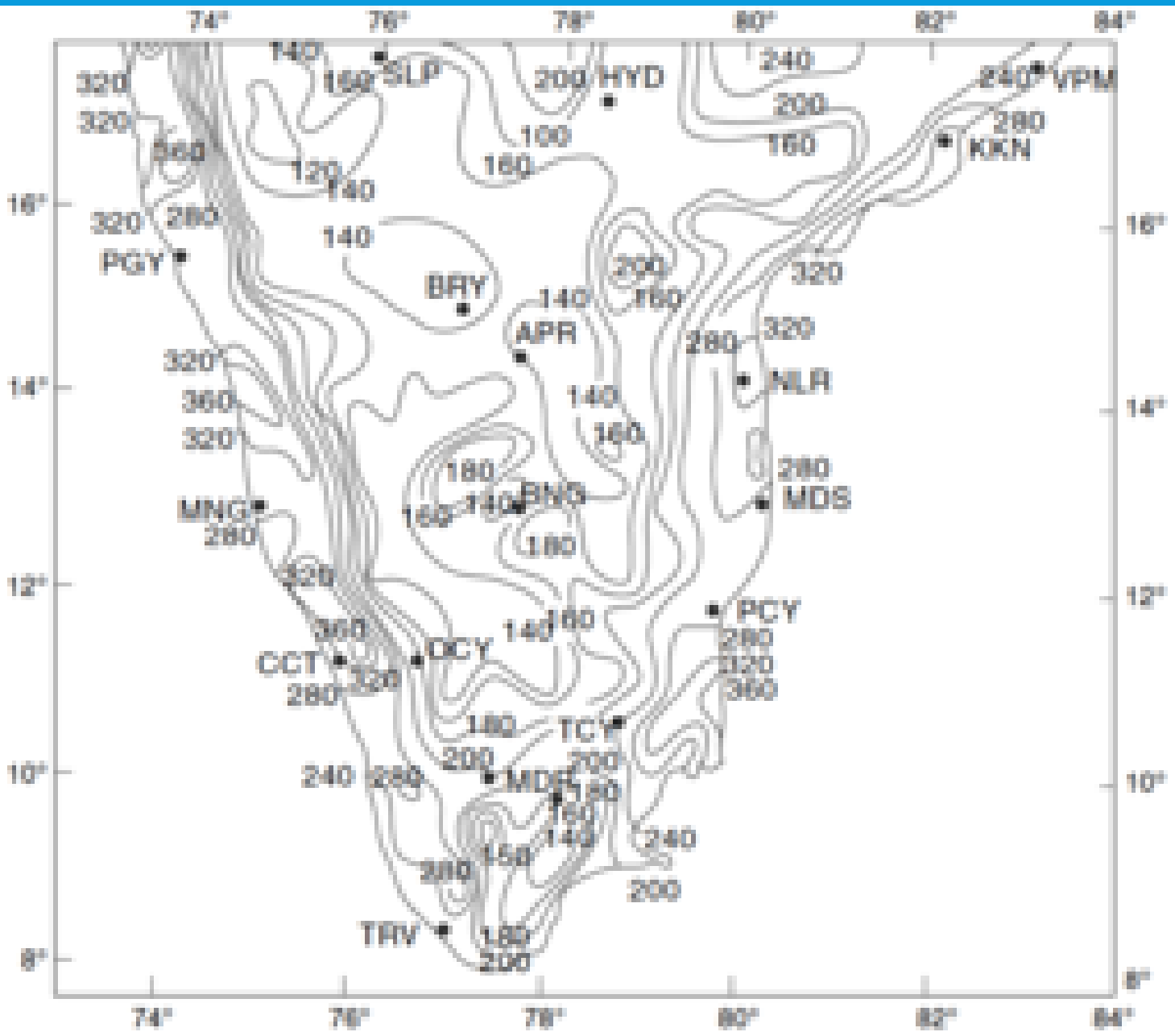

Fig. 2.23 *Isopluvial Map of 50 yr 24 h Maximum Rainfall (mm)*

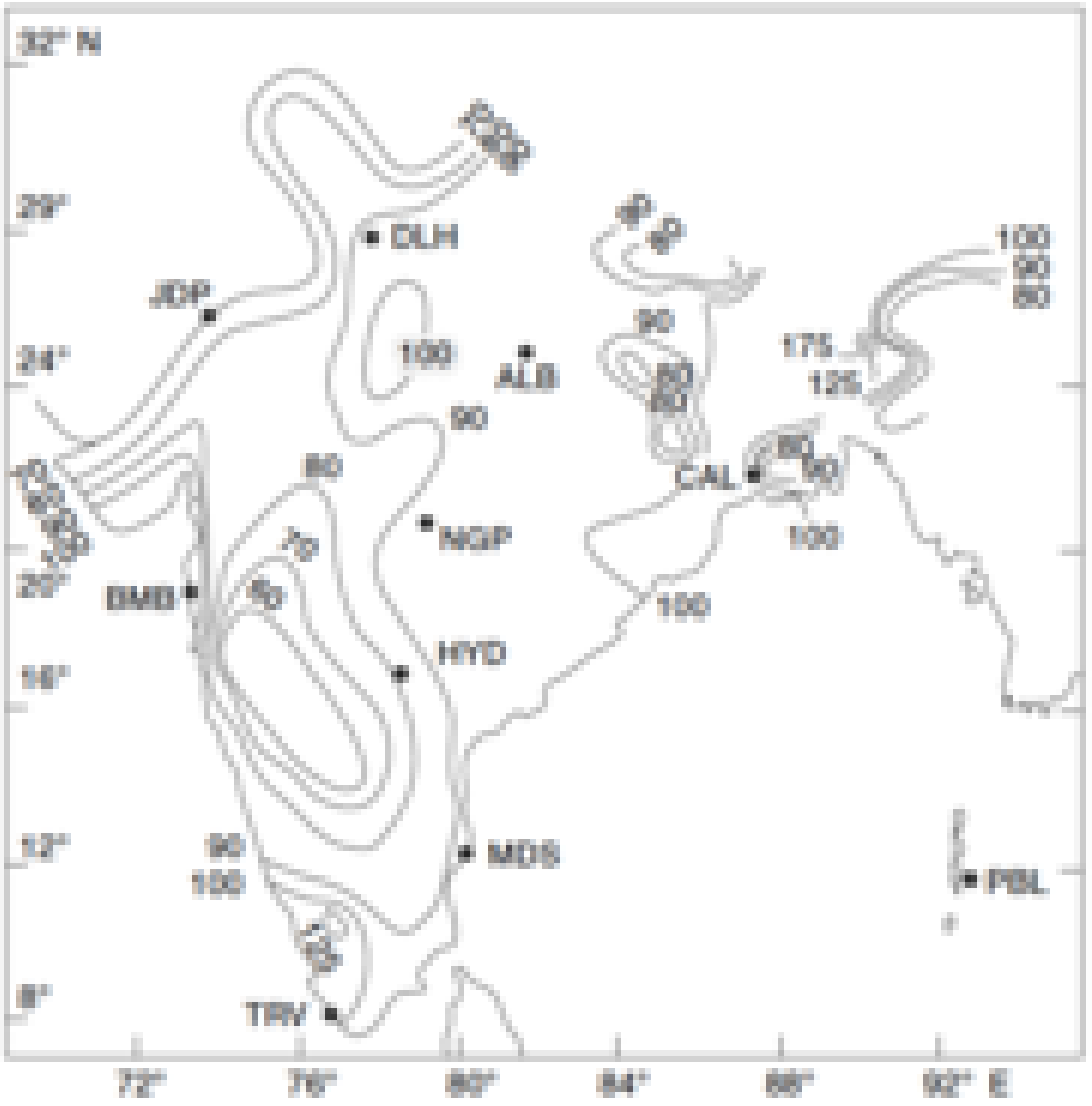

Fig. 2.24 *Isopluvial Map of 50 yr–1 h Maximum Rainfall (mm)*

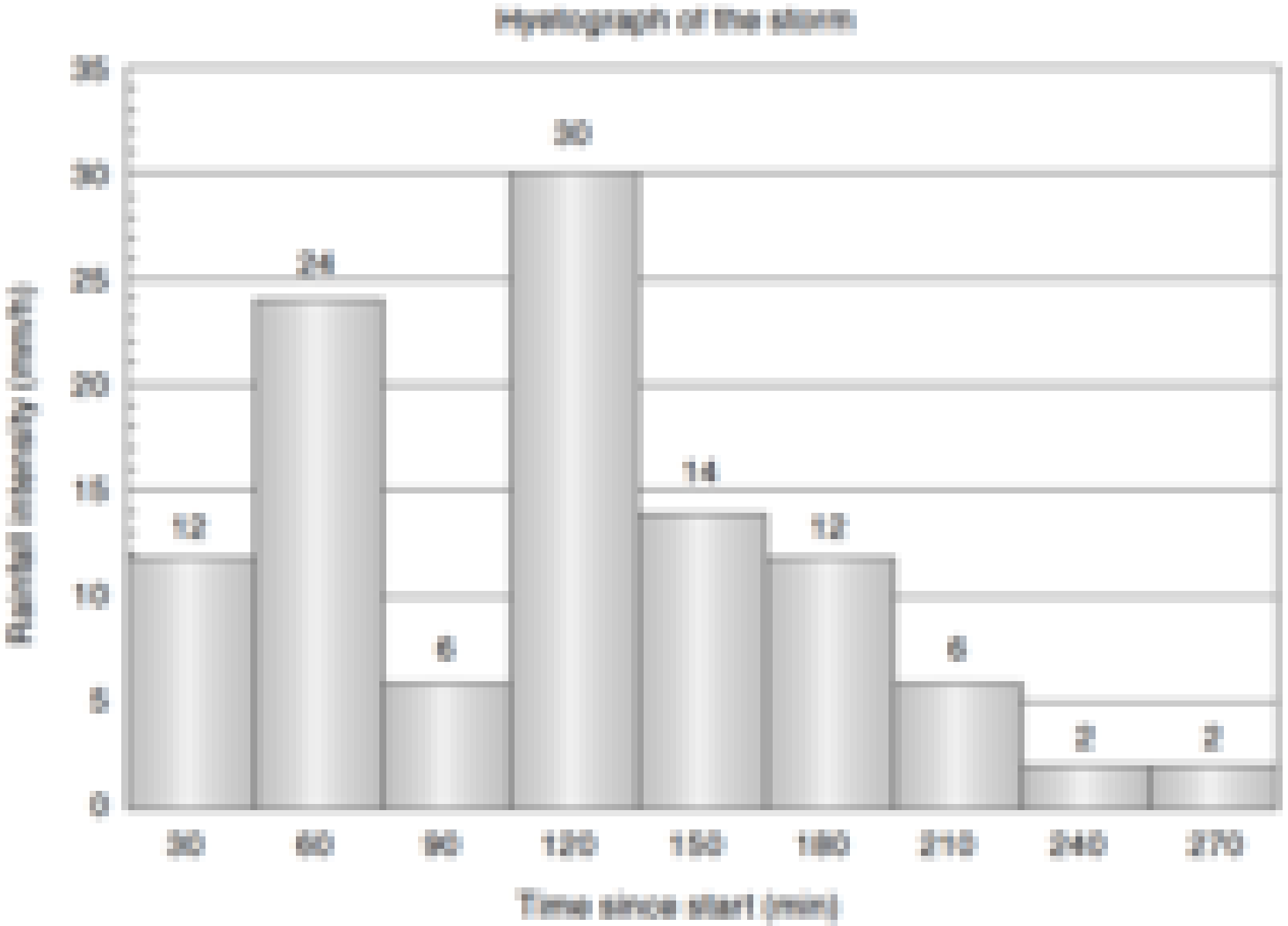

Fig. 2.25 *Hyetograph of the Storm — Example 2.11*

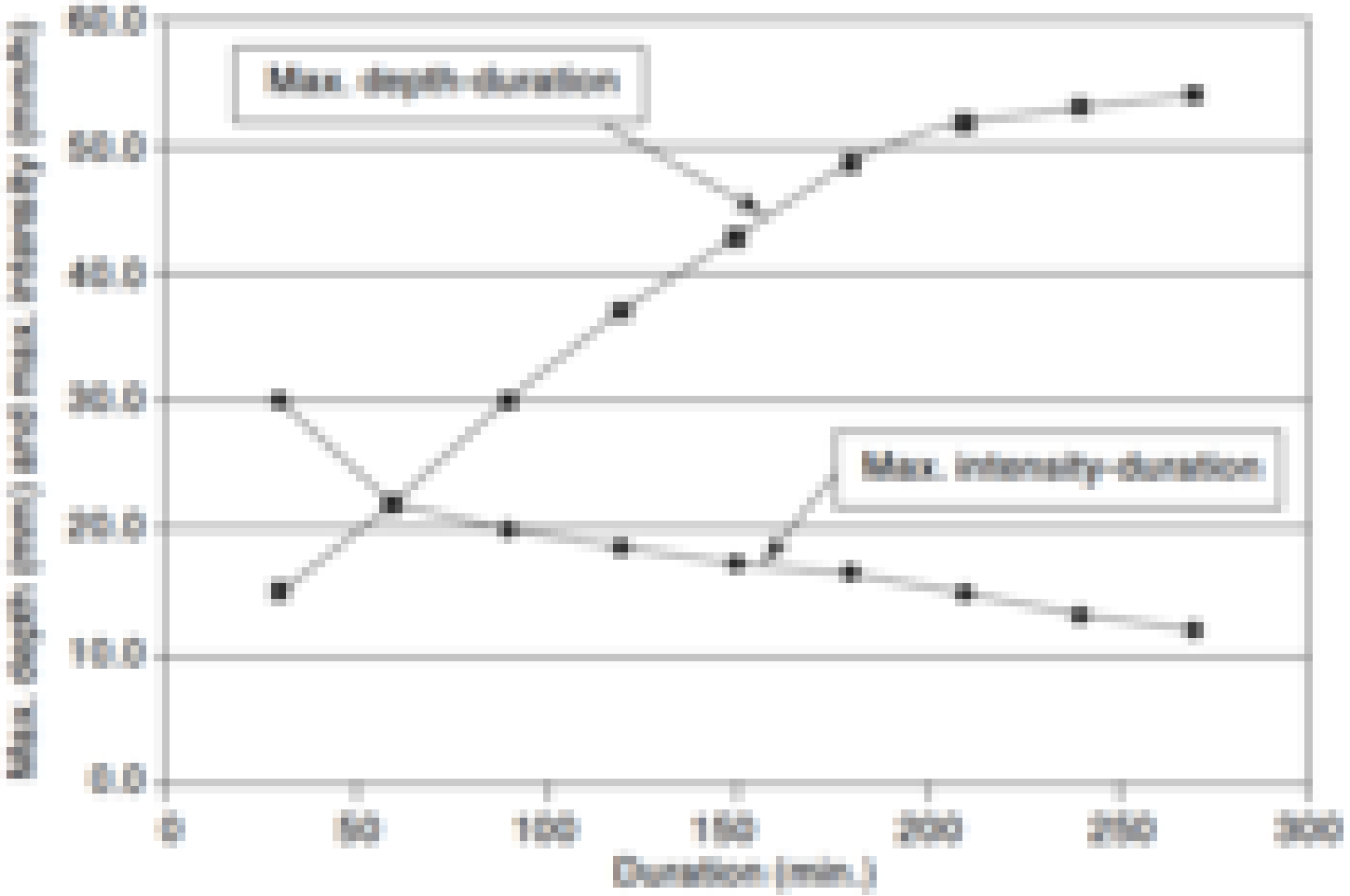

Fig. 2.26 *Maximum Intensity-Duration and Maximum Depth-Duration Curves for the Storm of Example 2.11*

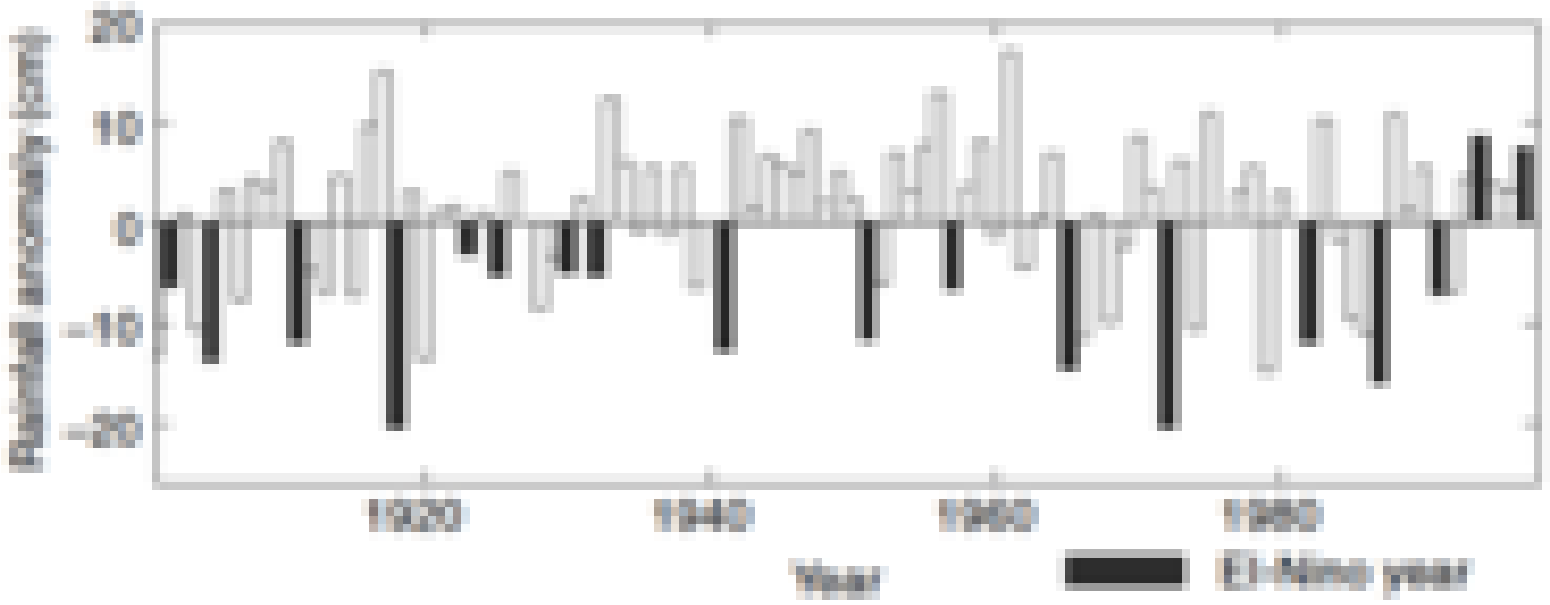

Fig. 2.27 *Inter Annual variation of ISMR Anomaly (Ref.11)*

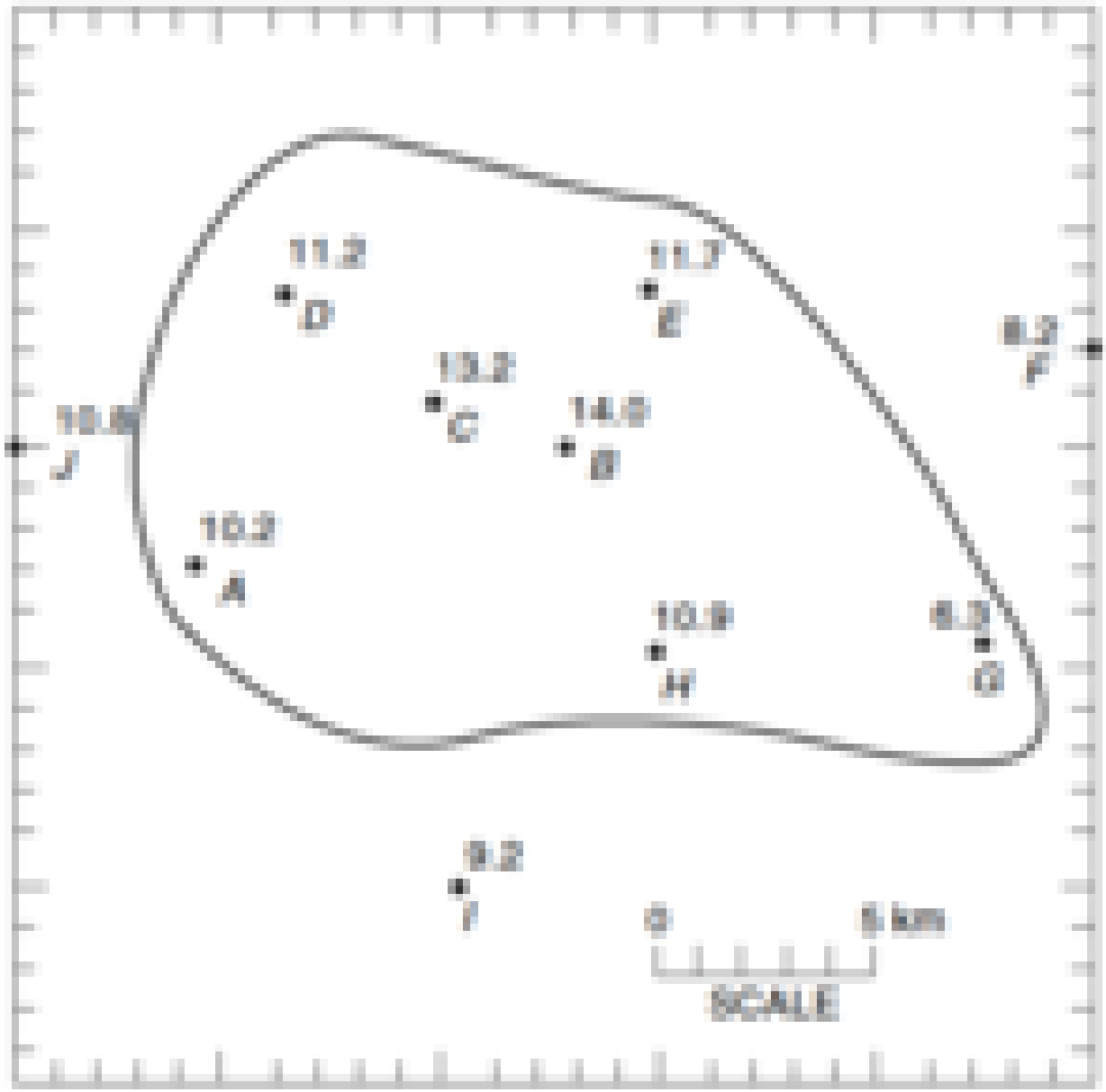

Fig. 2.28 *Problem 2.10*

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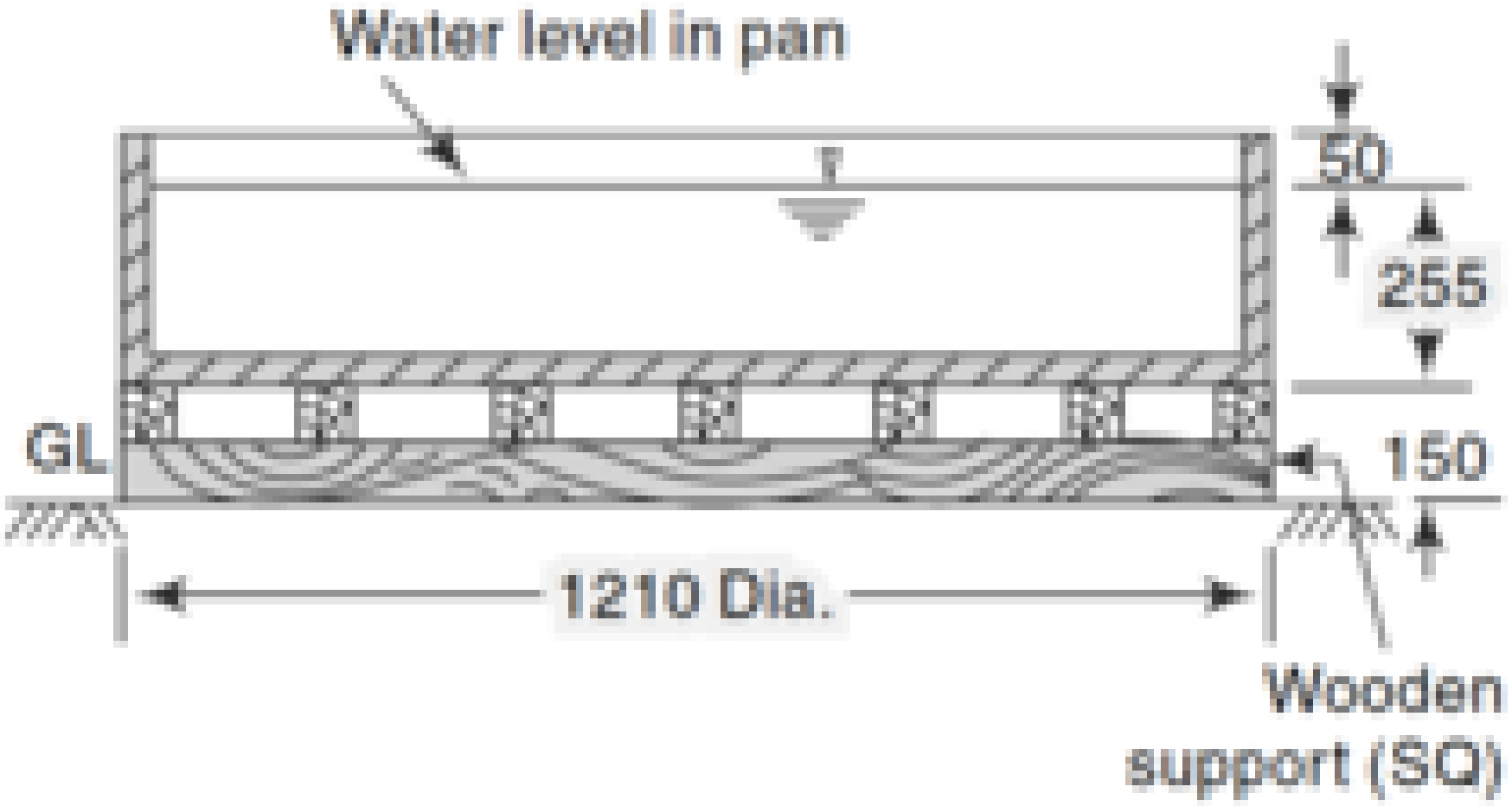

Fig. 3.1 *US Class A Evaporation Pan*

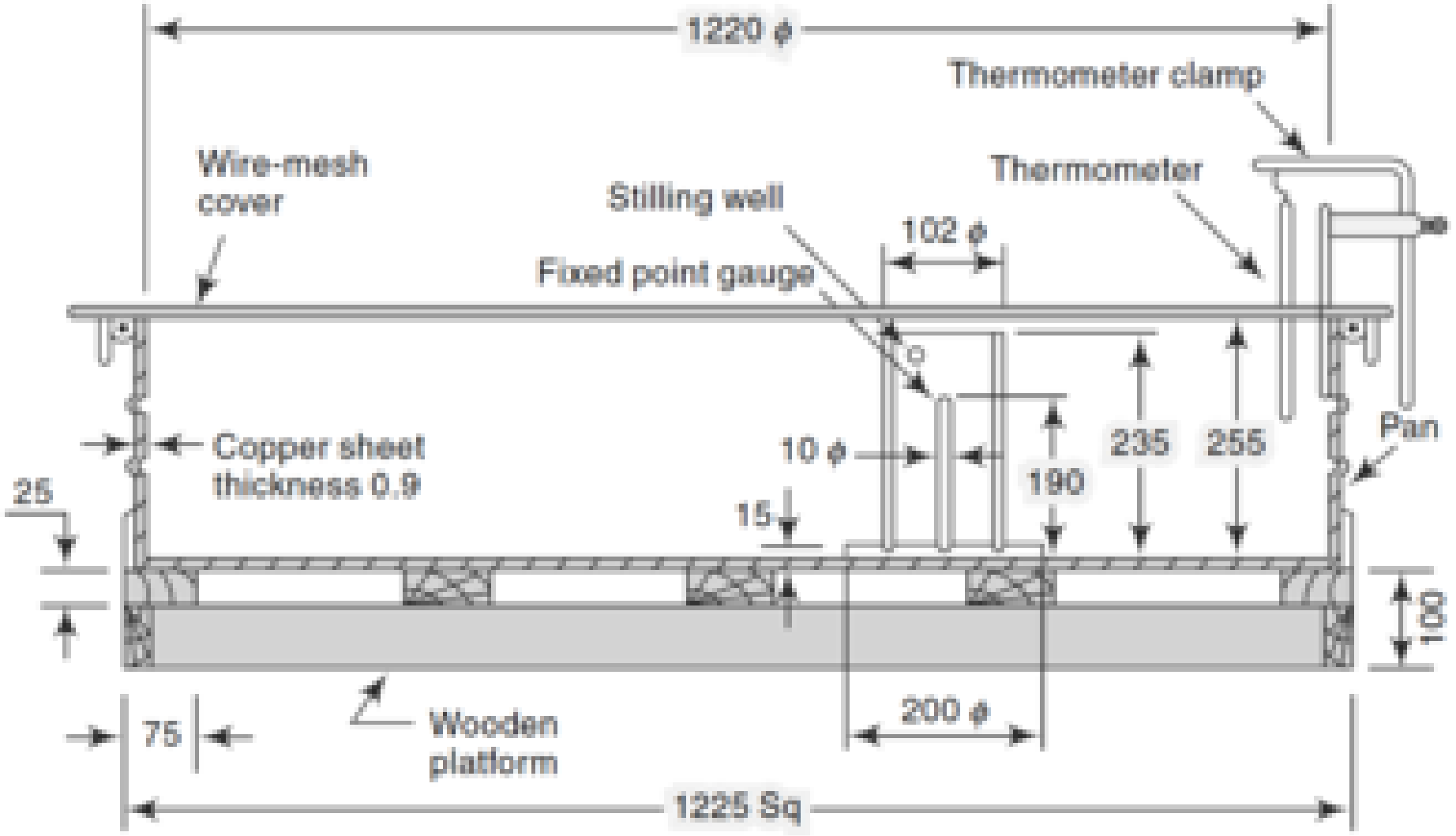

Fig. 3.2 *ISI Standard Evaporation Pan*

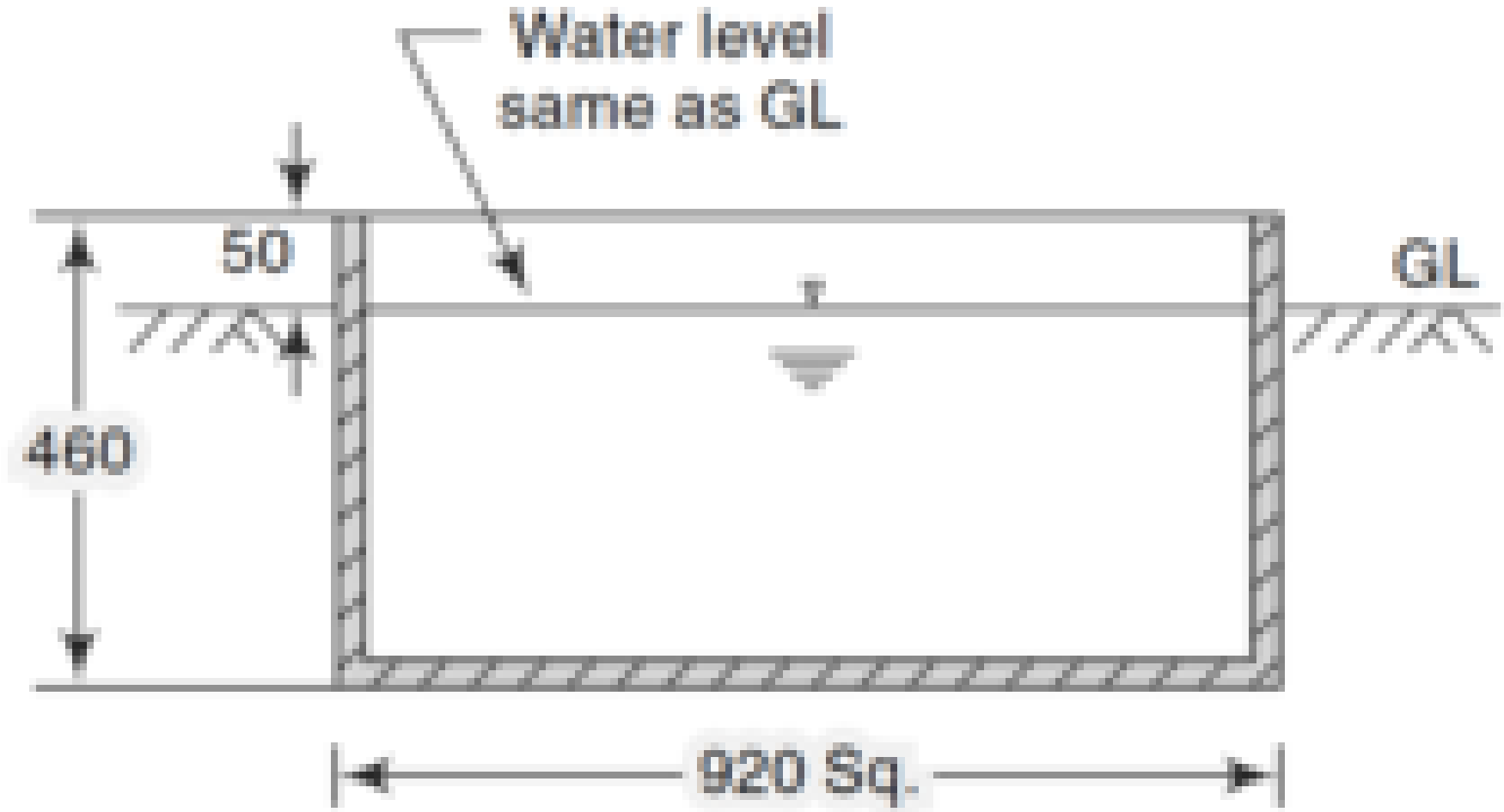

Fig. 3.3 *Colorado Sunken Evaporation Pan*

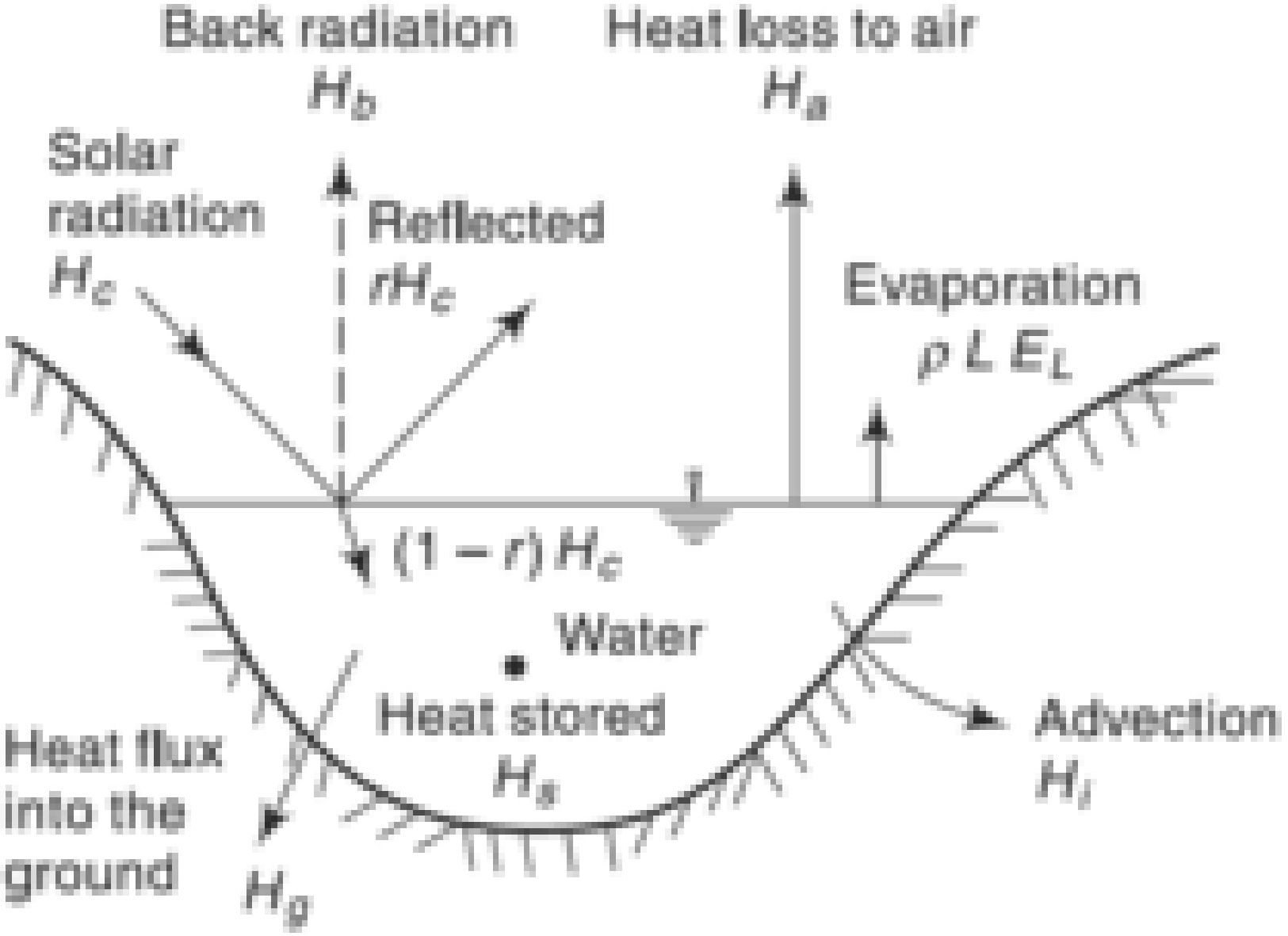

Fig. 3.4 *Energy Balance in a Water Body*

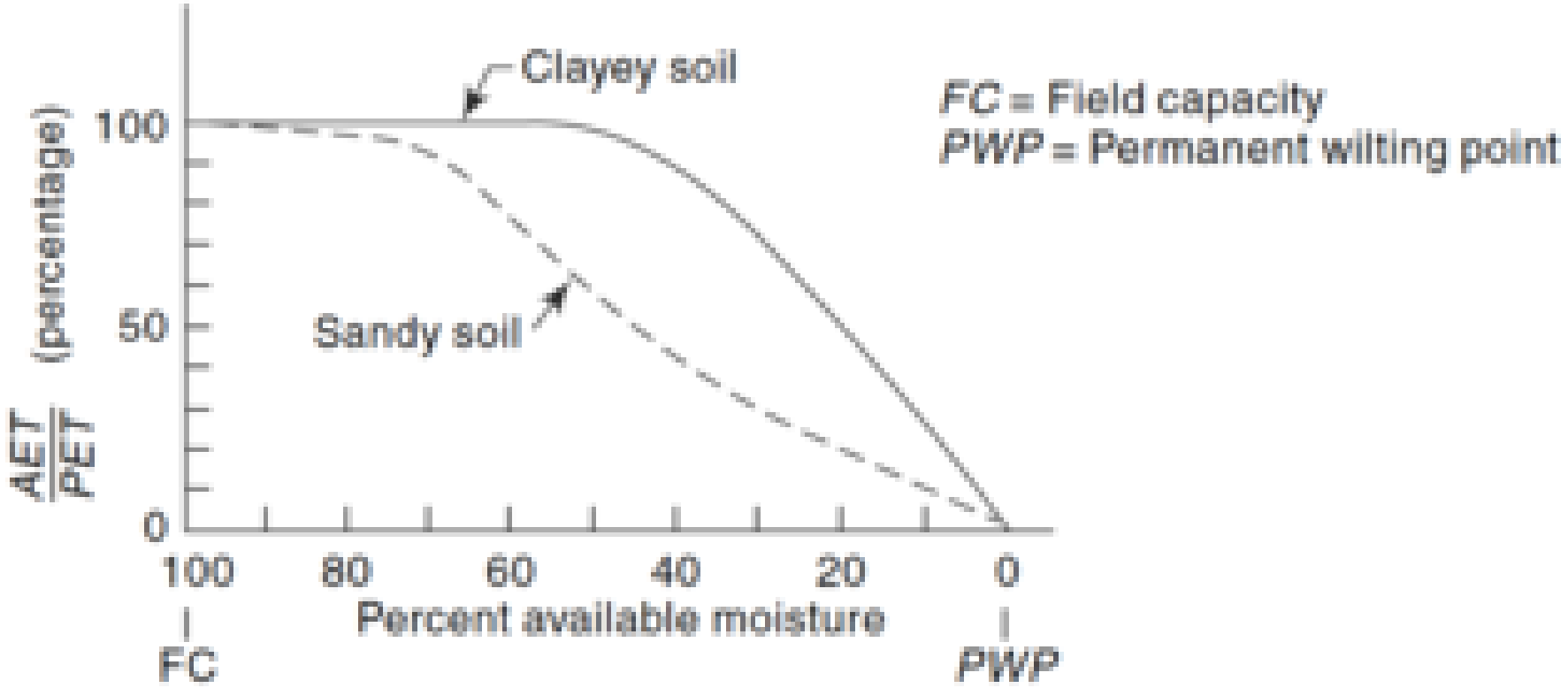

Fig. 3.5 *Variation of AET*

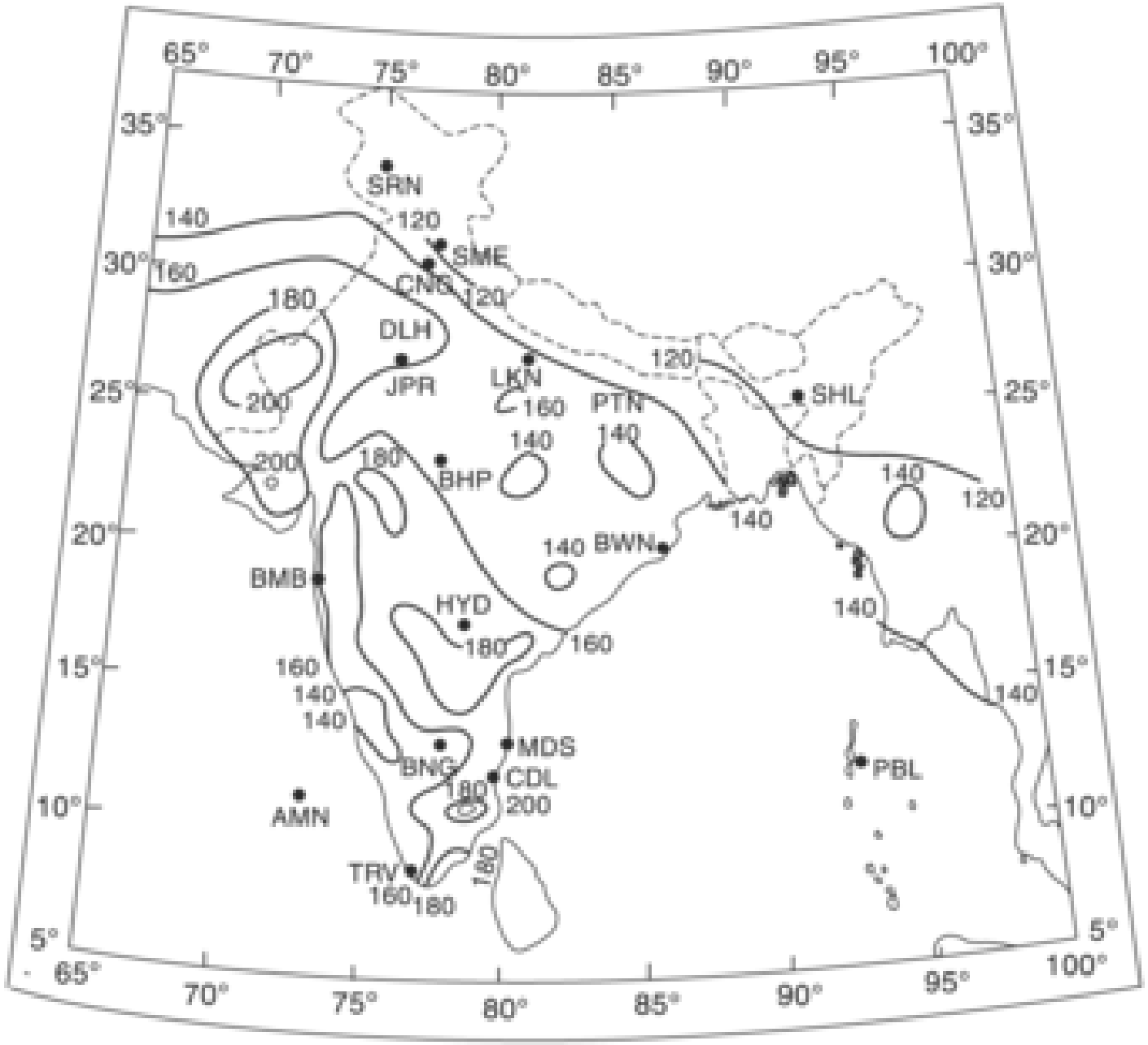

Fig. 3.6(a) *Annual PET (cm) over India*

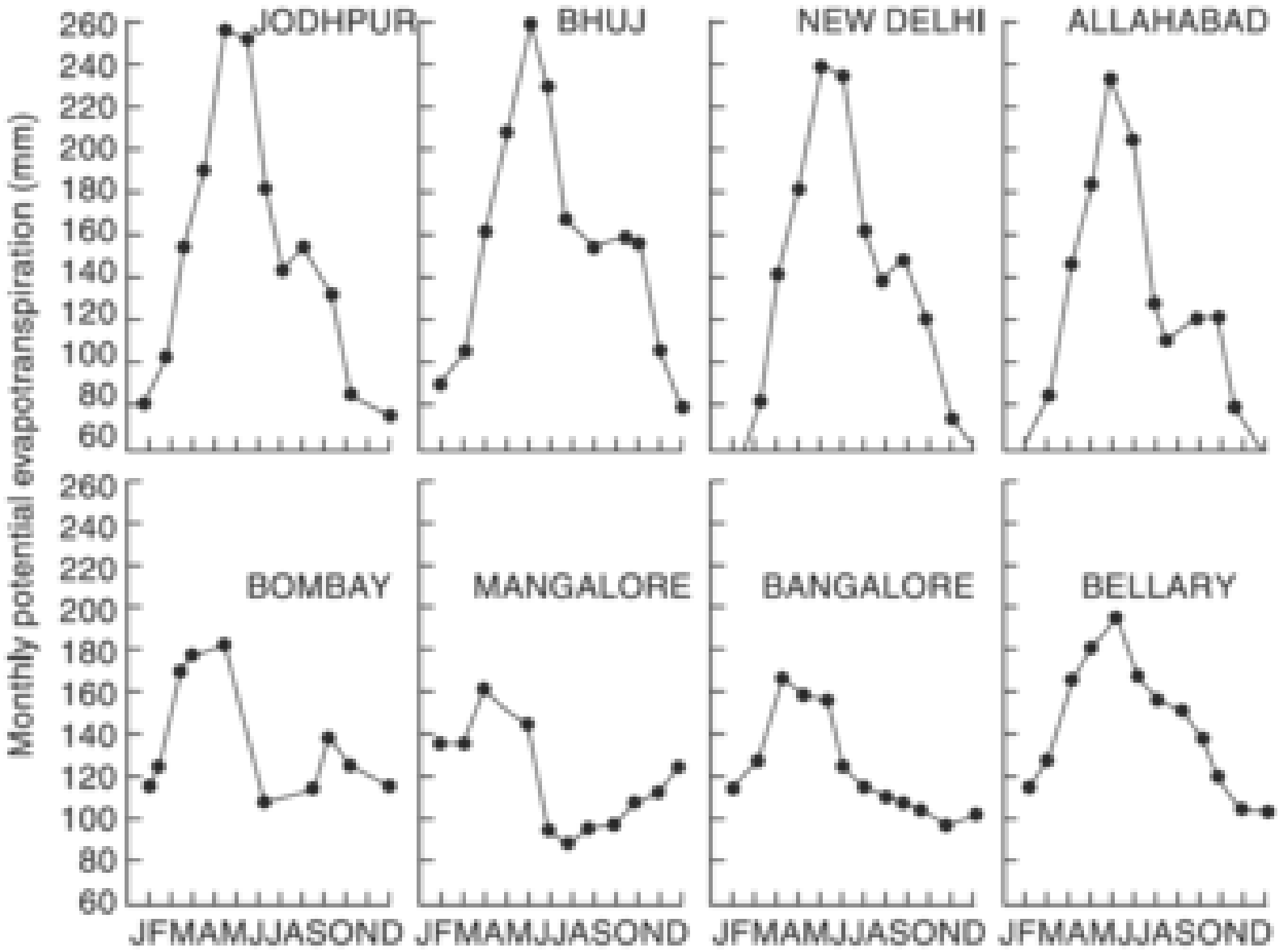

Fig. 3.6(b) ***Monthly Variation of PET (mm)***

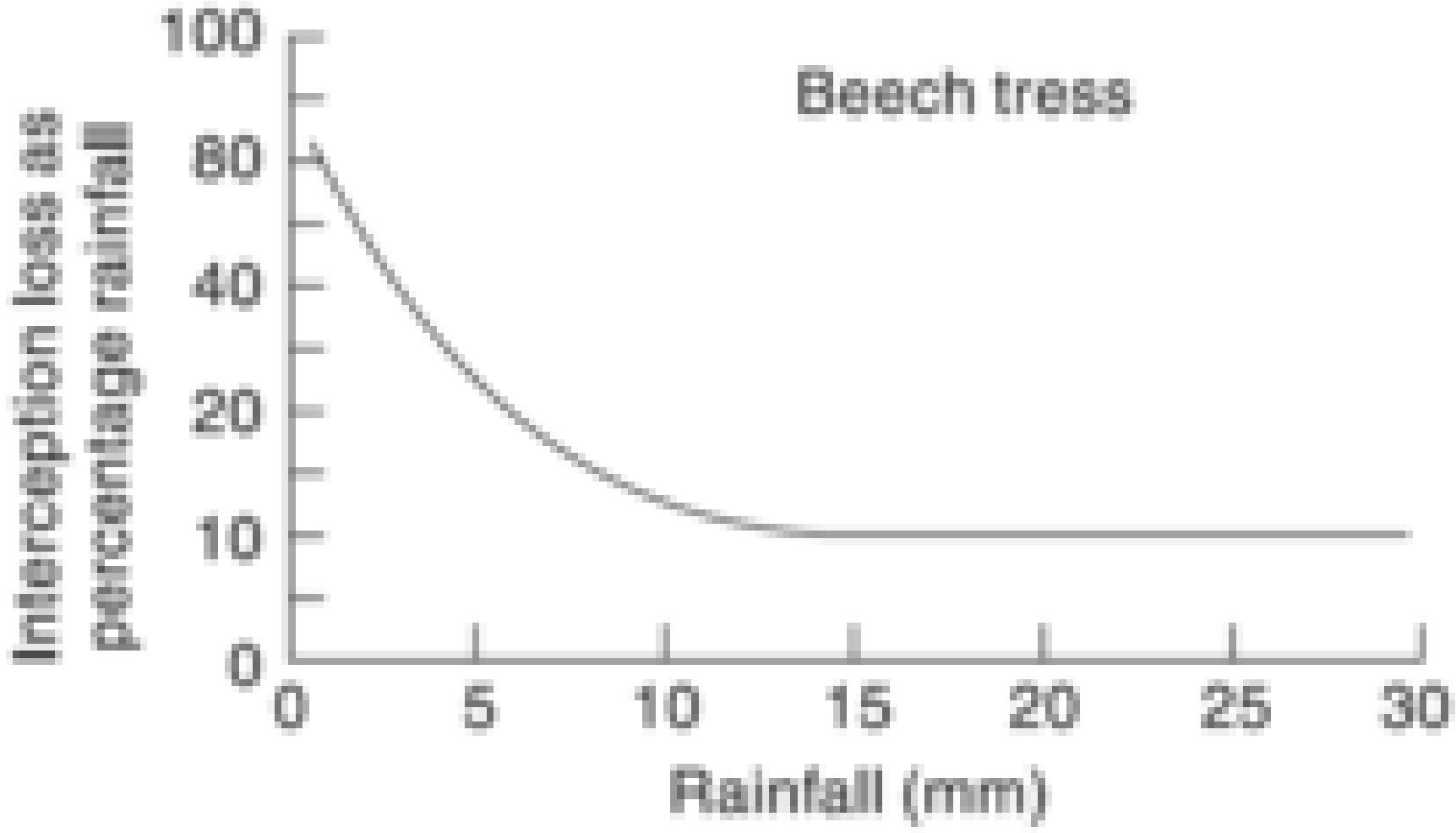

Fig. 3.7 *Typical Interception Loss Curve*

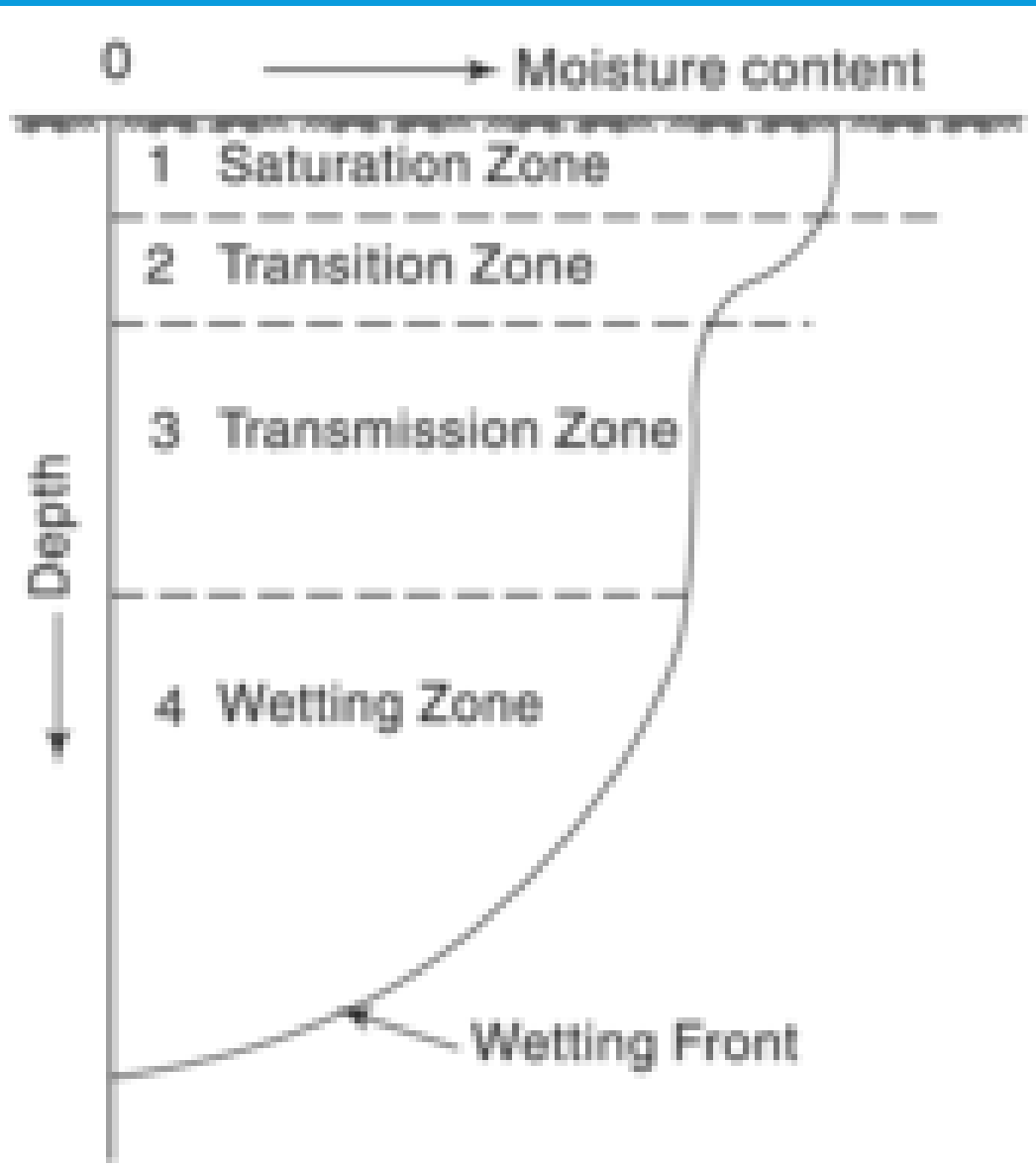

Fig. 3.8 *Distribution of Soil Moisture in the Infiltration Process*

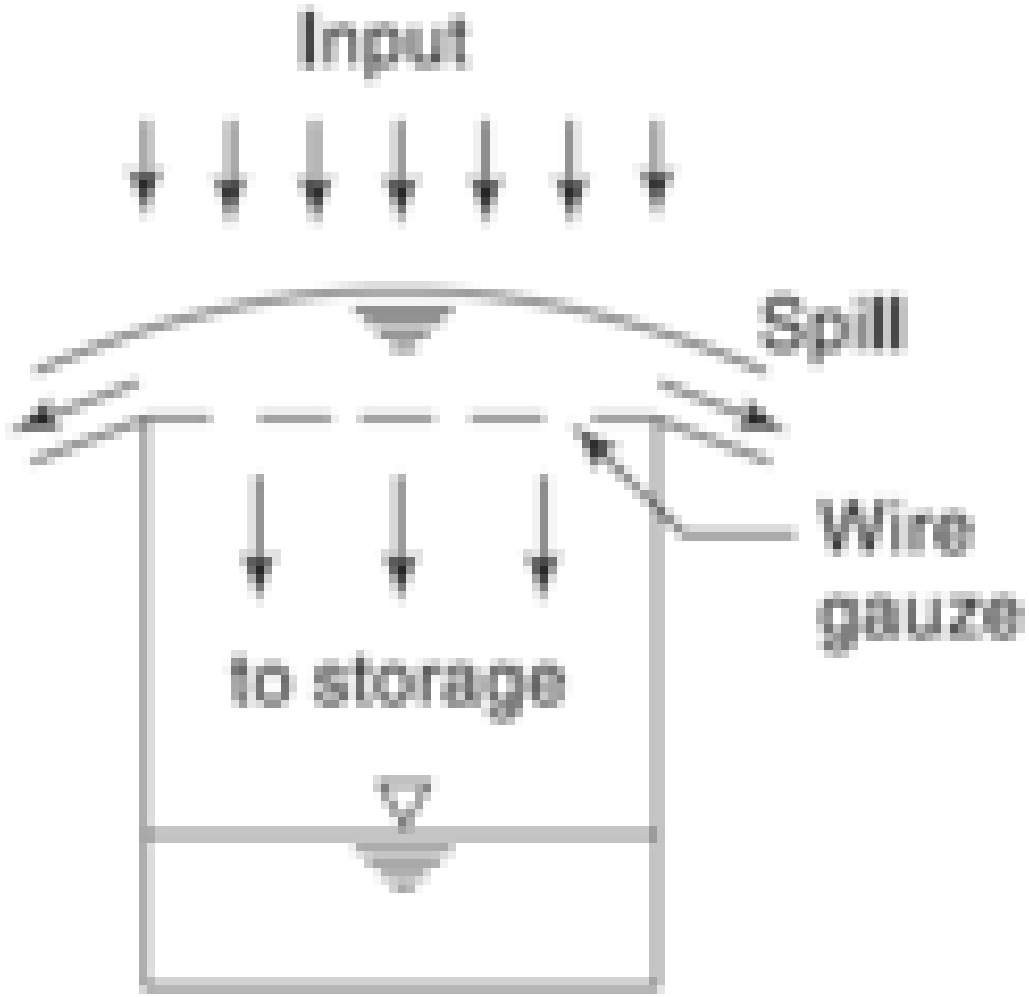

Fig. 3.9 *An Analogy for Infiltration*

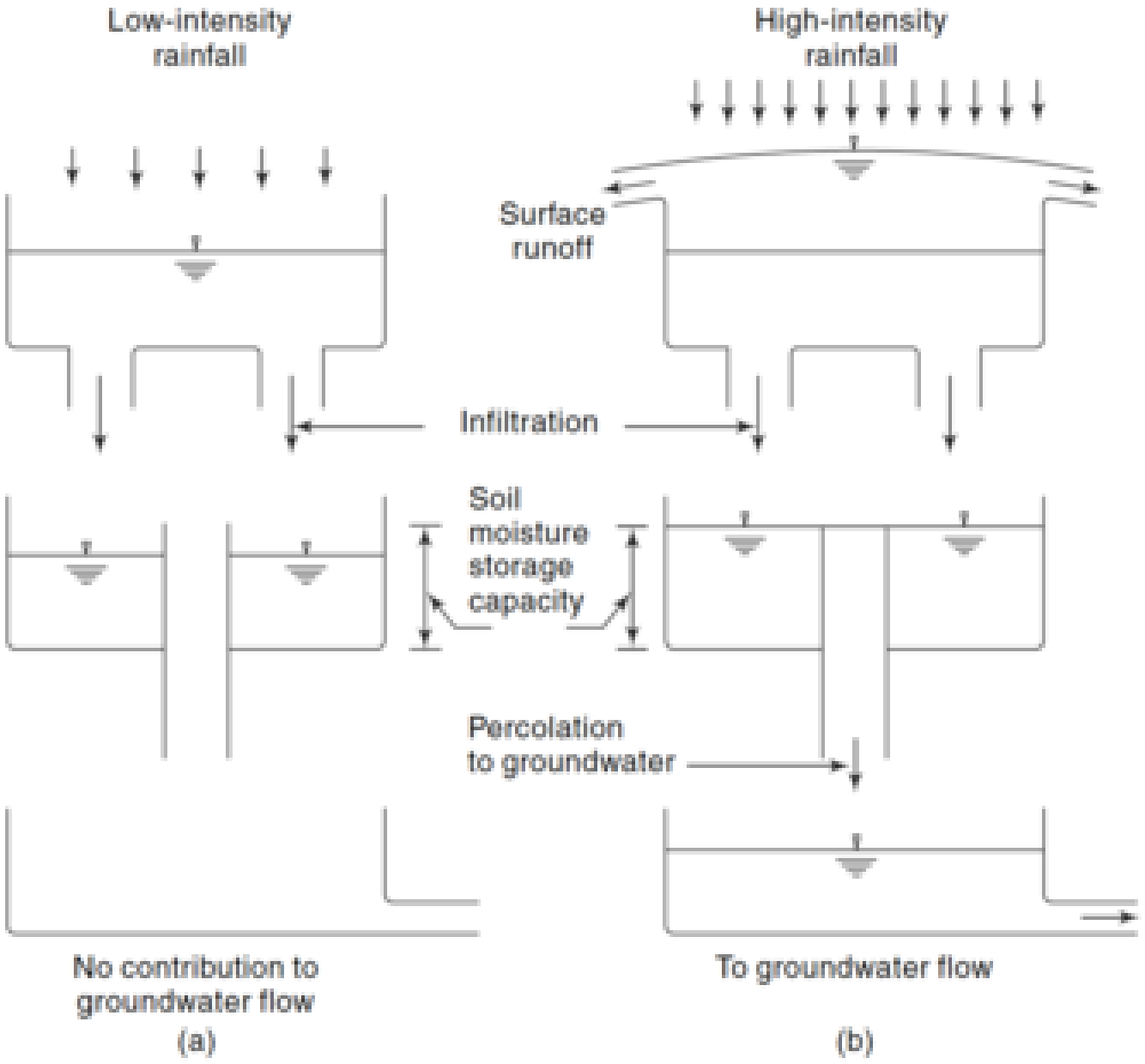

Fig. 3.10 ***An Infiltration Model***

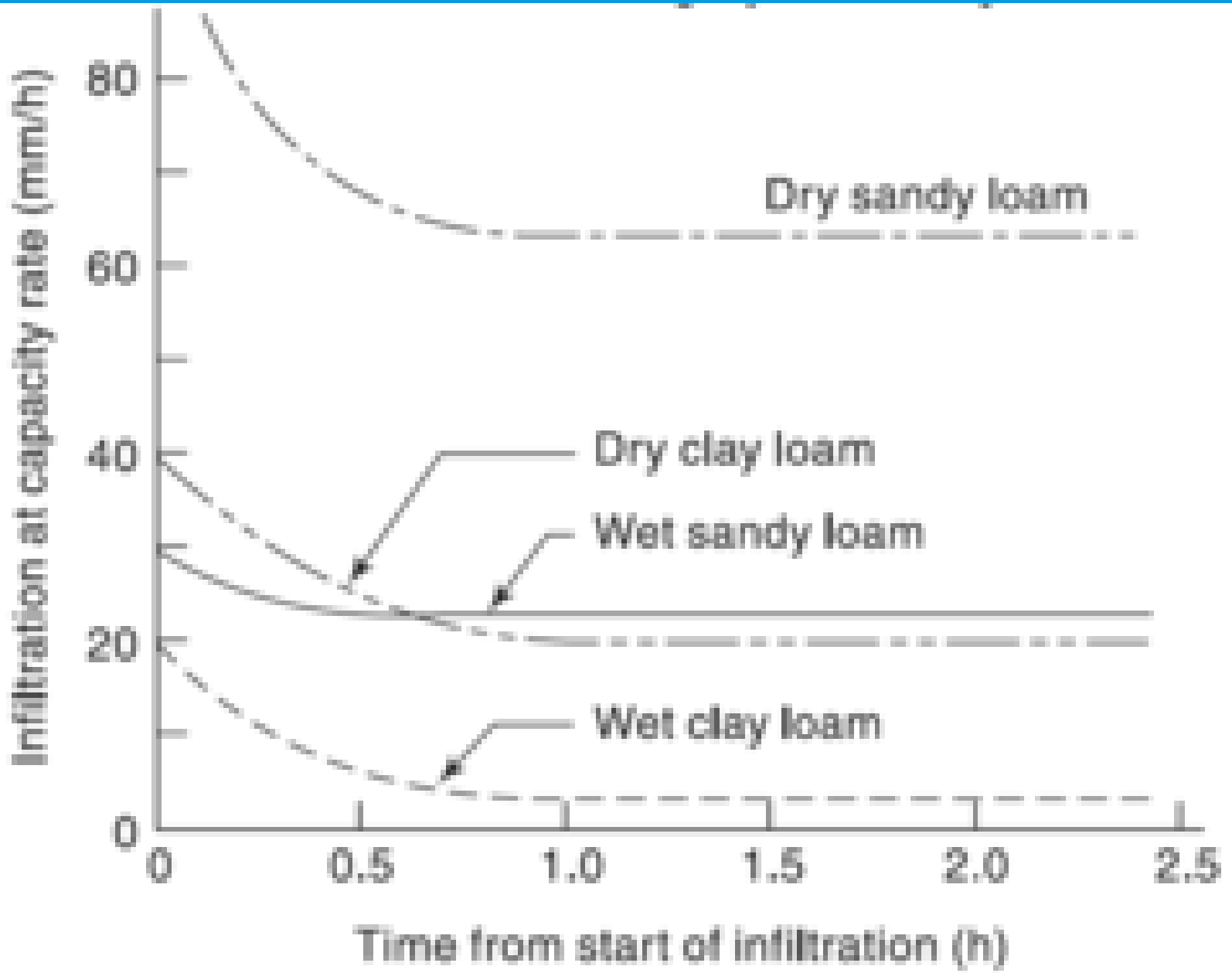

Fig. 3.11 *Variation of Infiltration Capacity*

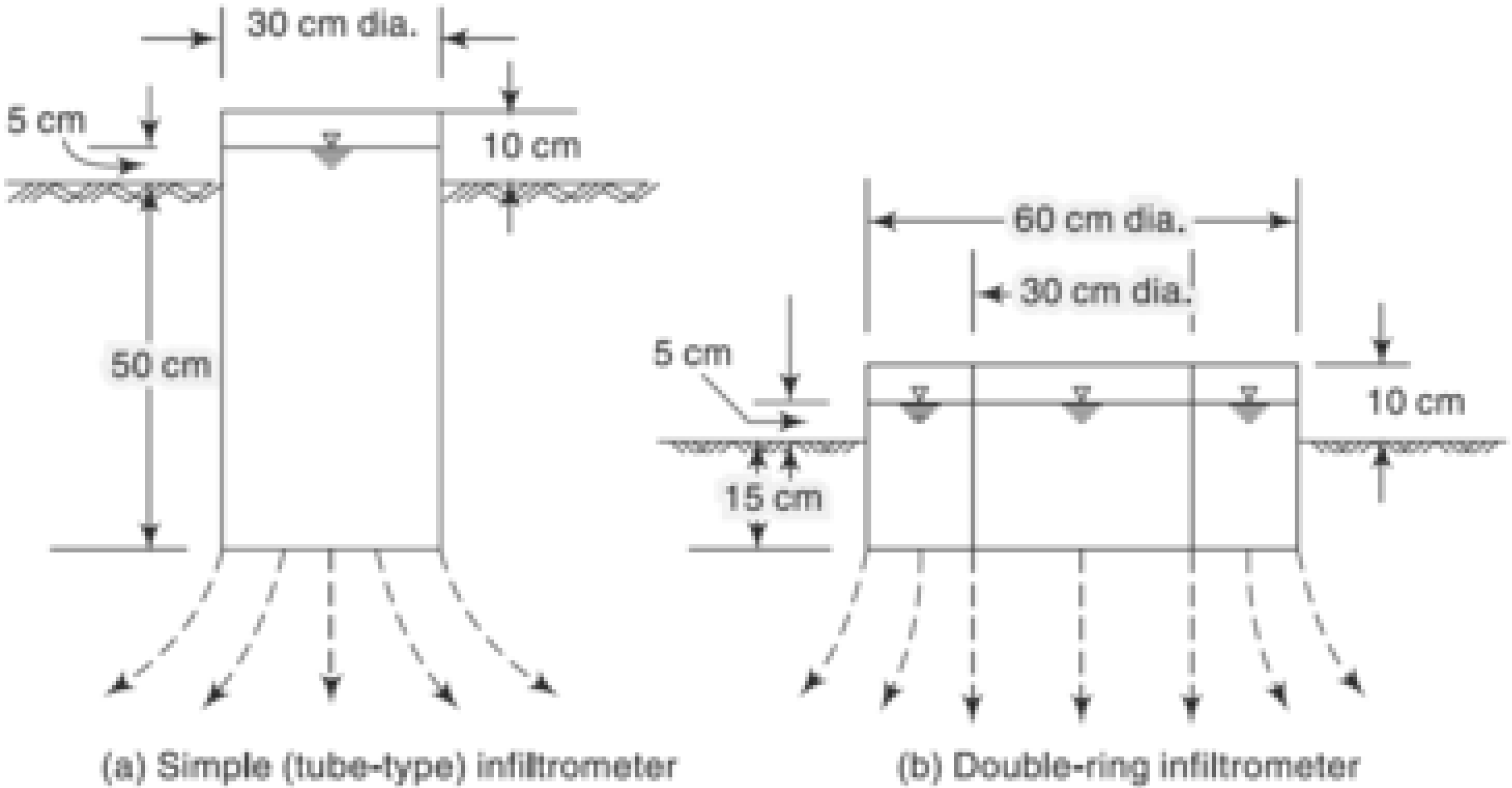

Fig. 3.12 ***Flooding-Type Infiltrometers***

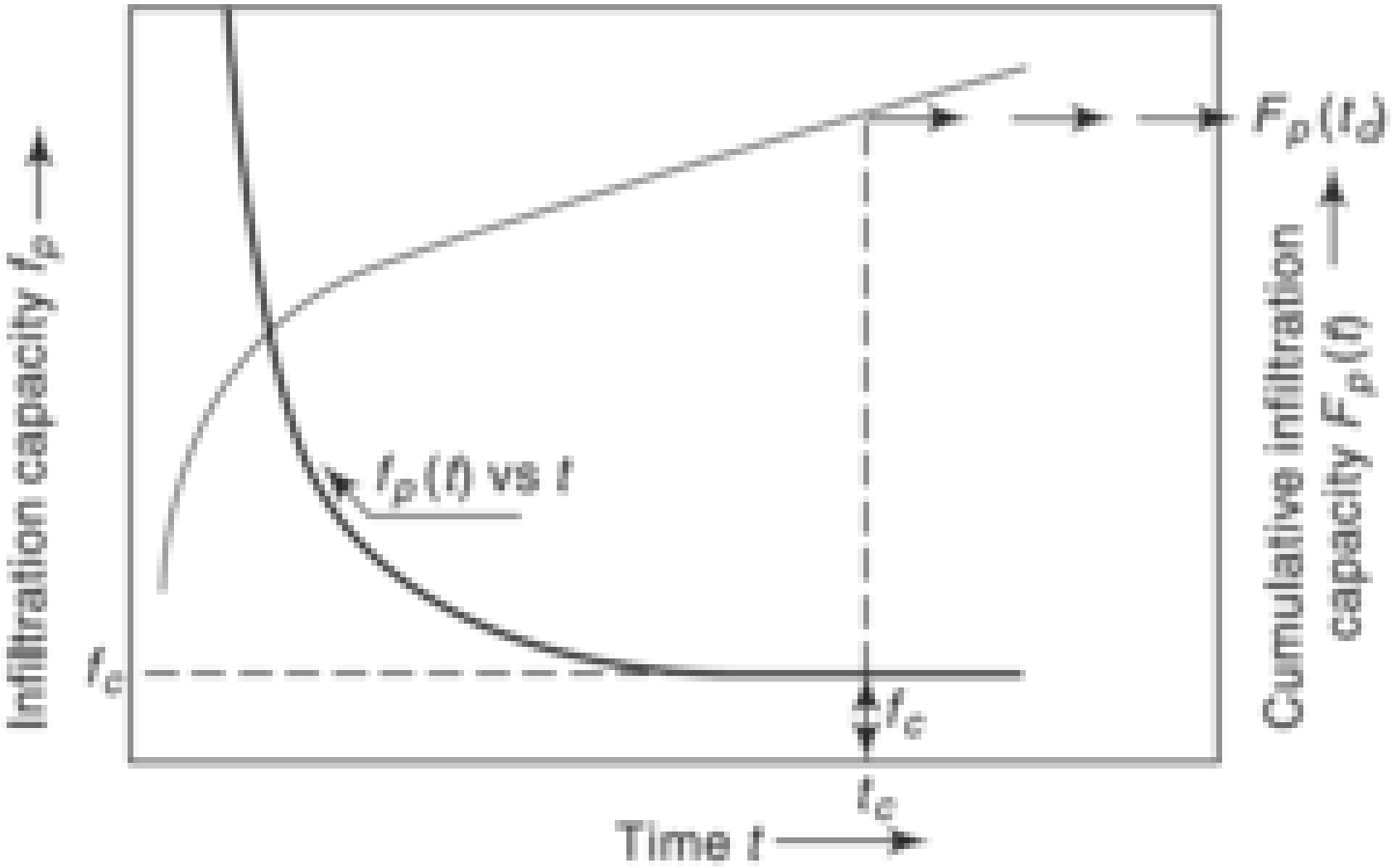

Fig. 3.13 *Curves of Infiltration Capacity and Cumulative Infiltration Capacity*

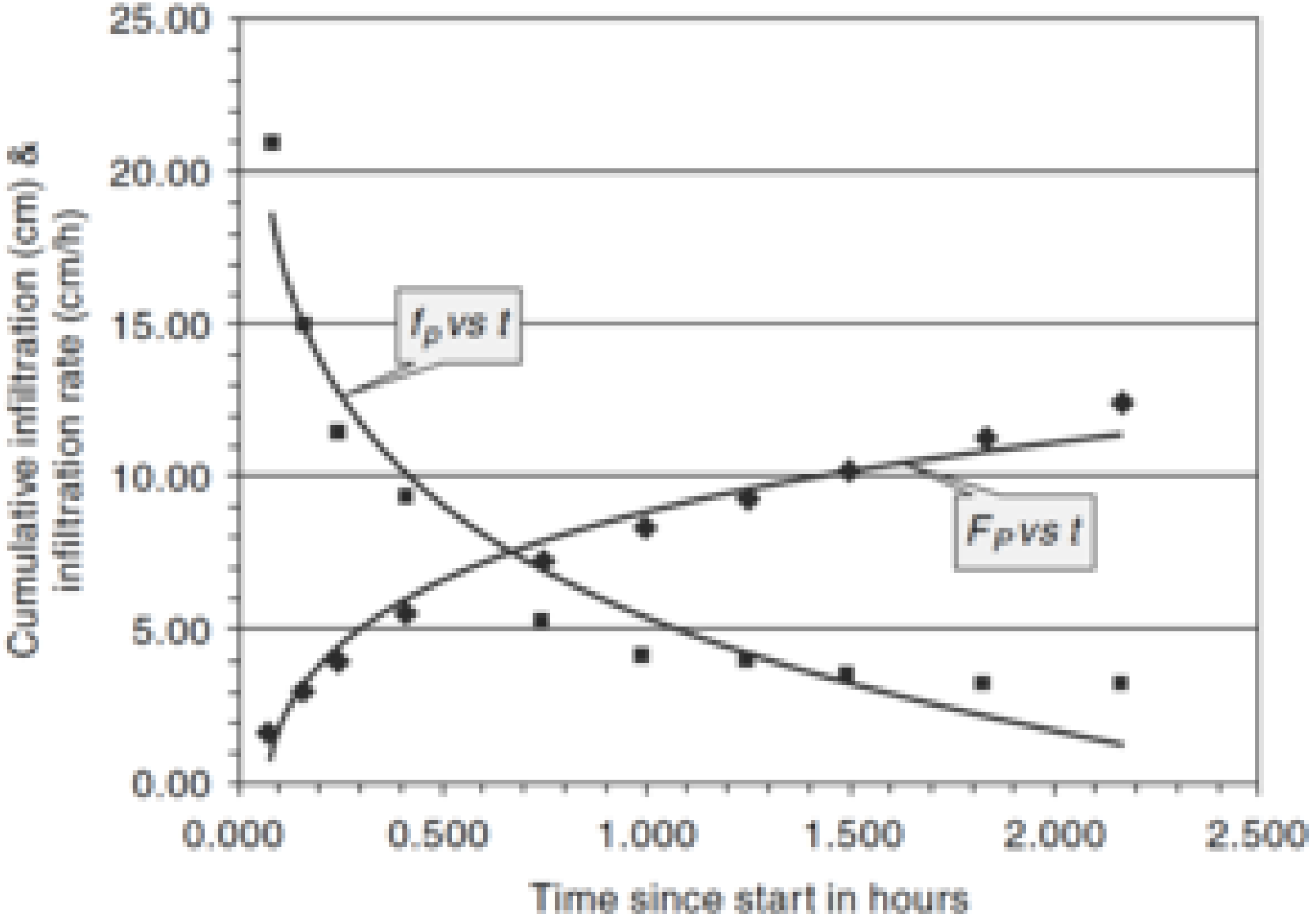

Fig. 3.14 (a) *Plots of F_p vs Time and f_p vs Time*

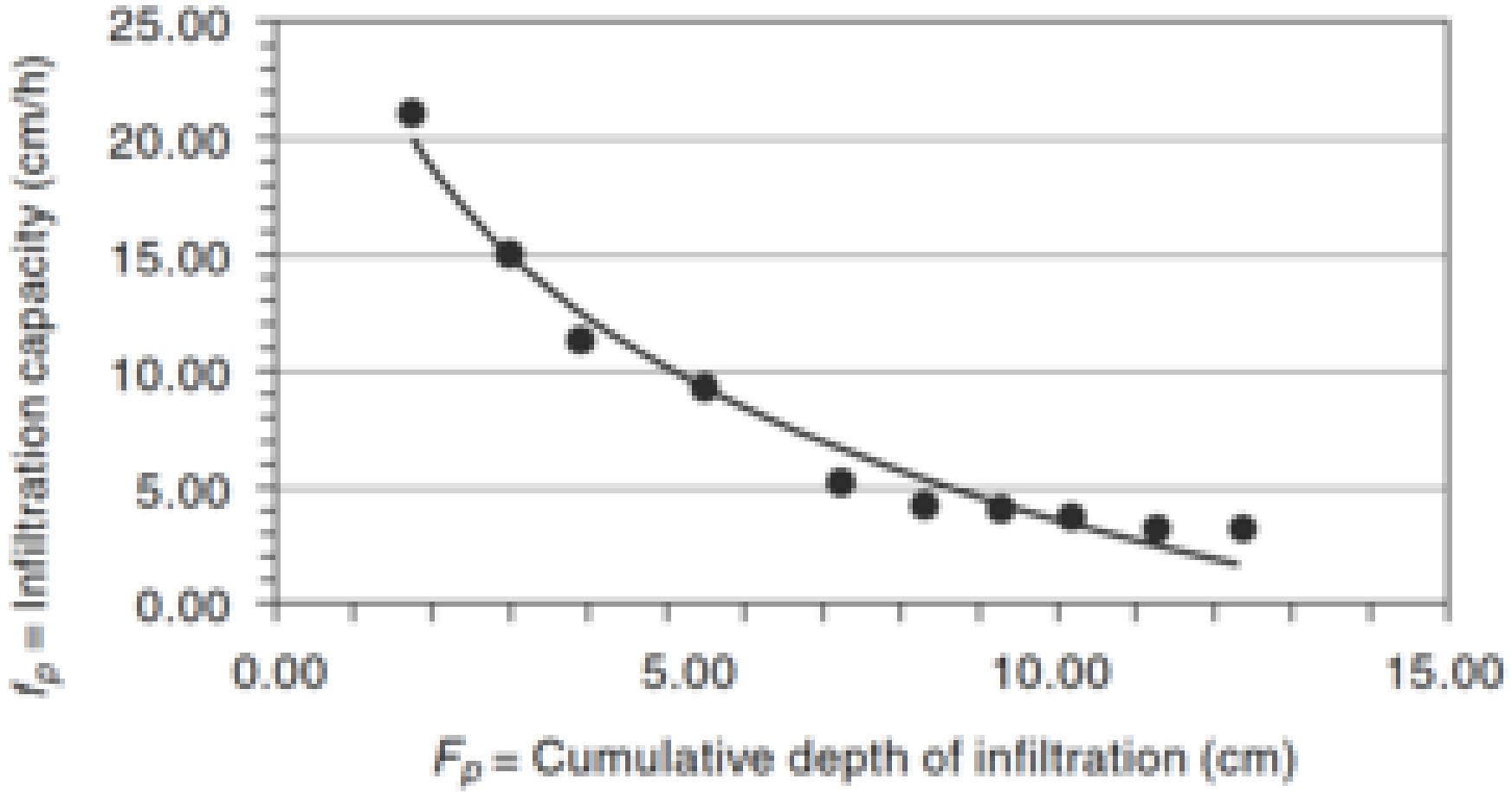

Fig. 3.14 (b) *Plot of f_p vs F_p*

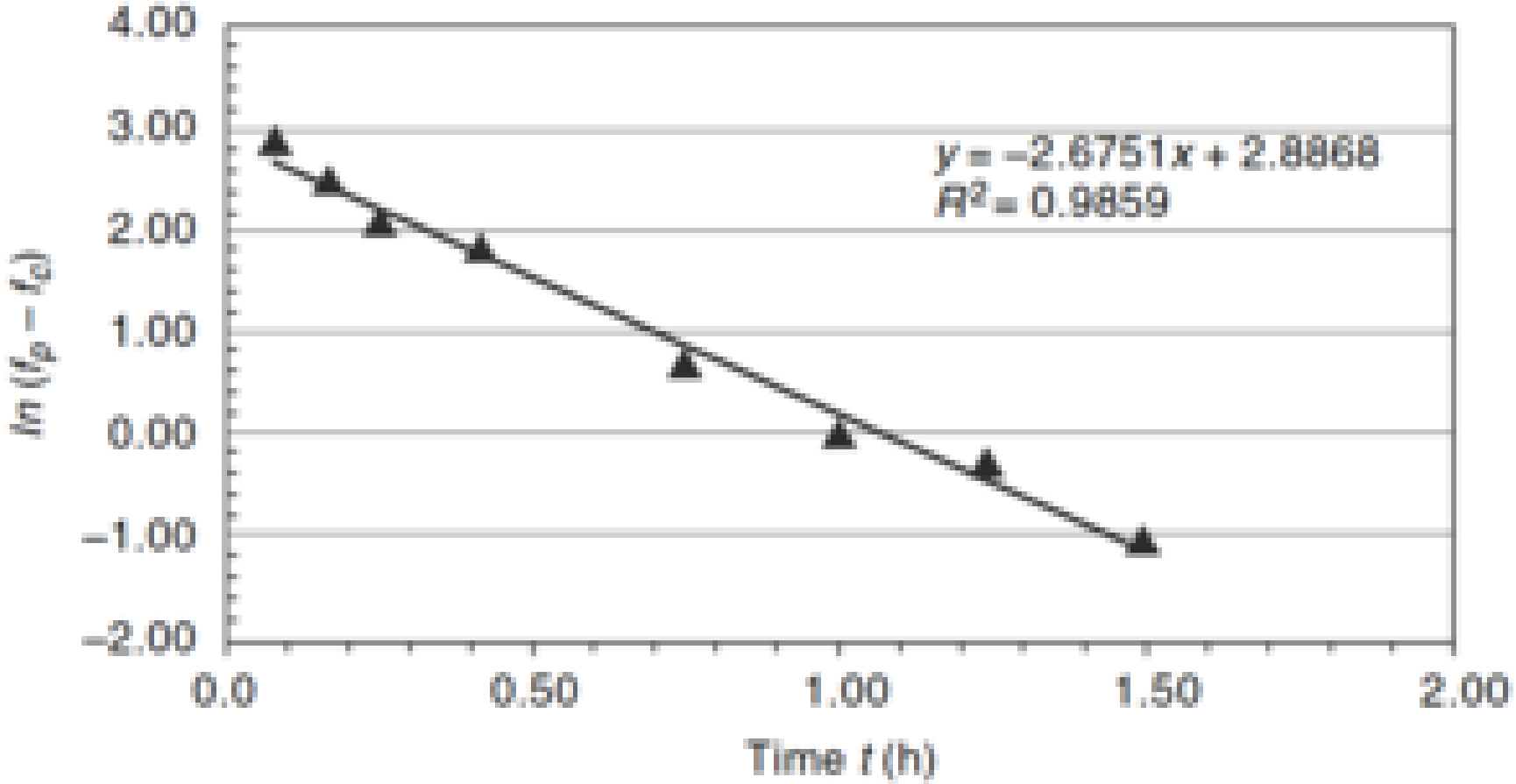

Fig. 3.14 (c) *Horton's Equation. Plot of $\ln(f_p - f_c)$ vs Time*

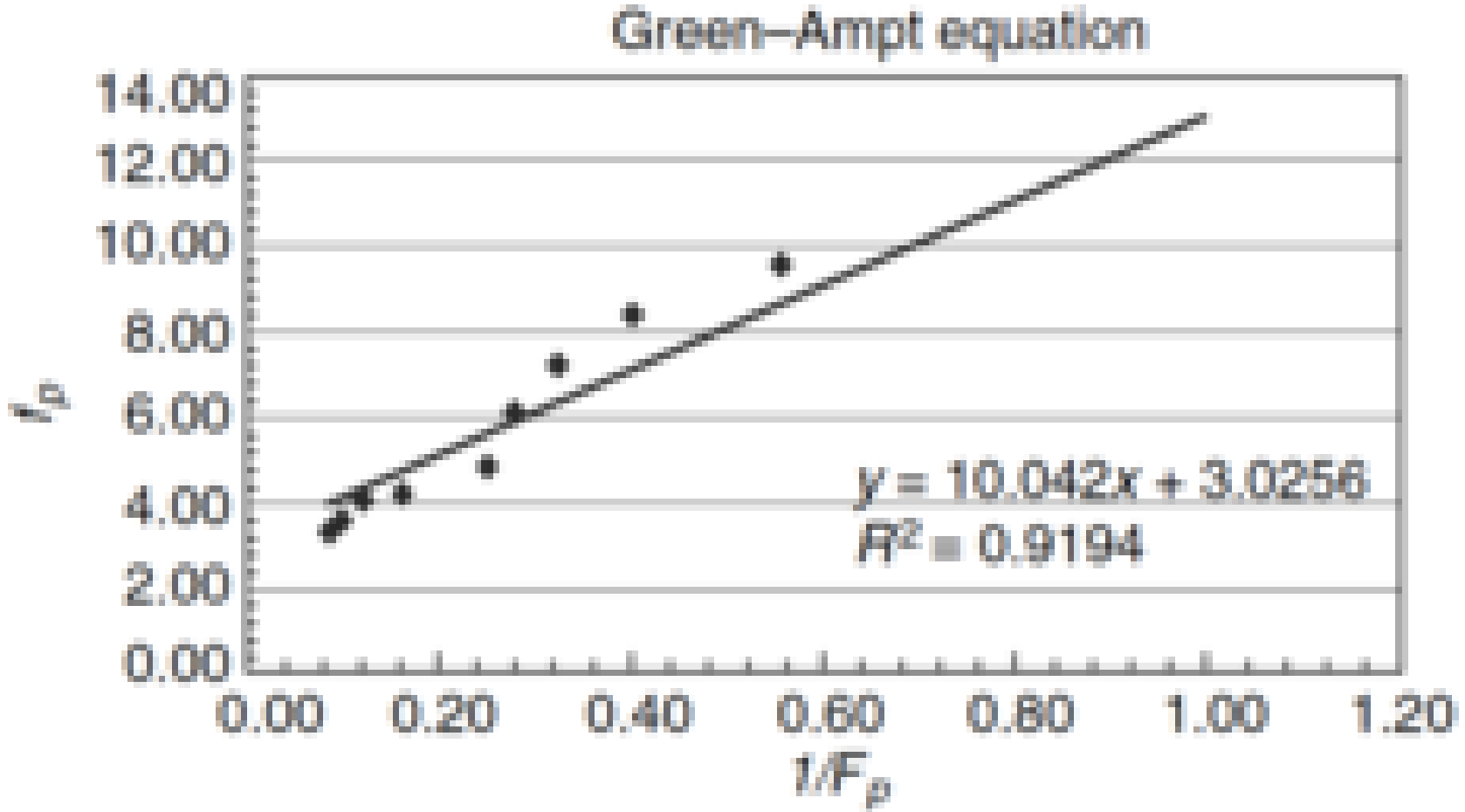

Fig. 3.15 (a) ***Fitting of Green–Ampt Equation***

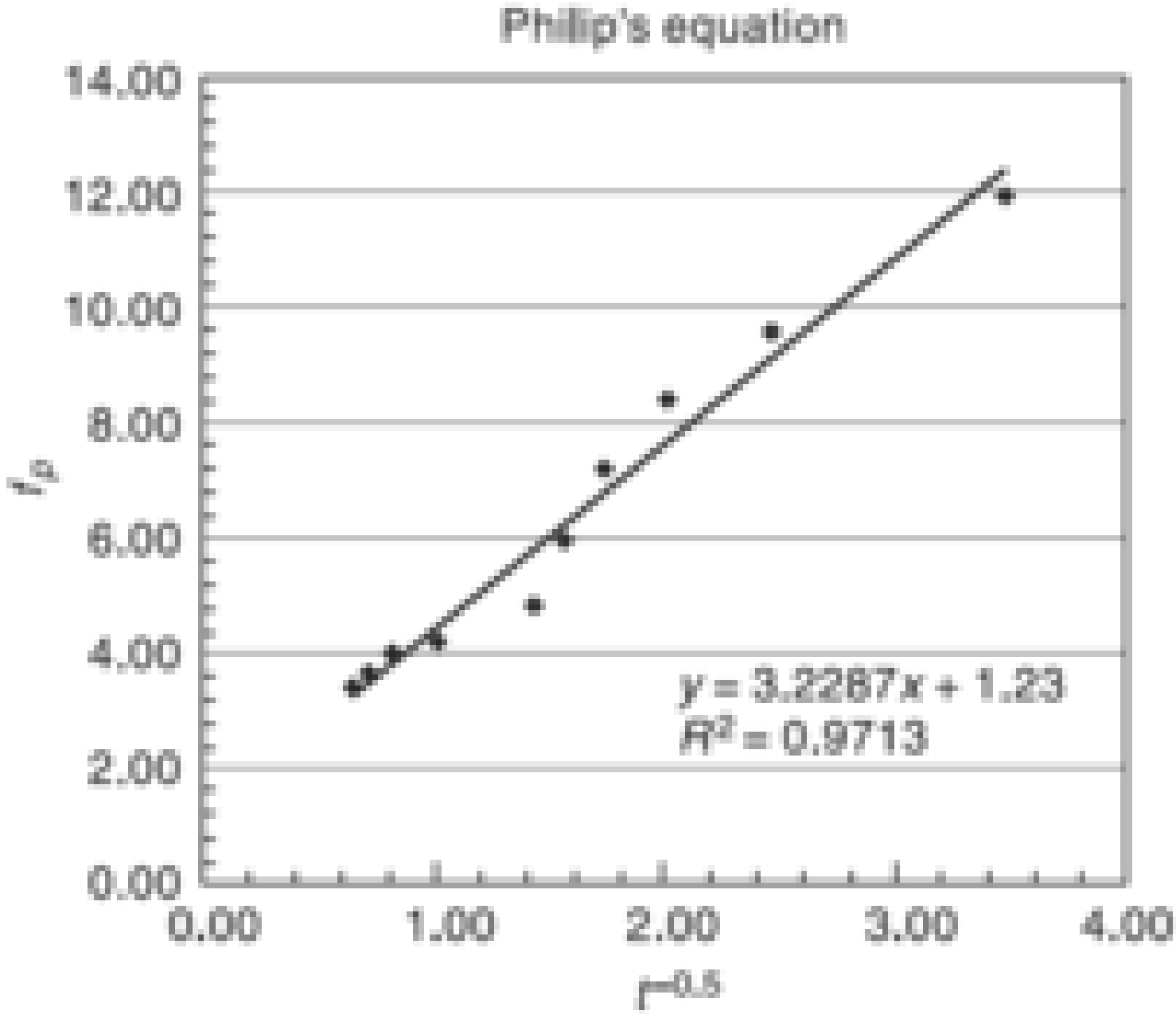

Fig. 3.15 (b) ***Fitting of Philip's Equation***

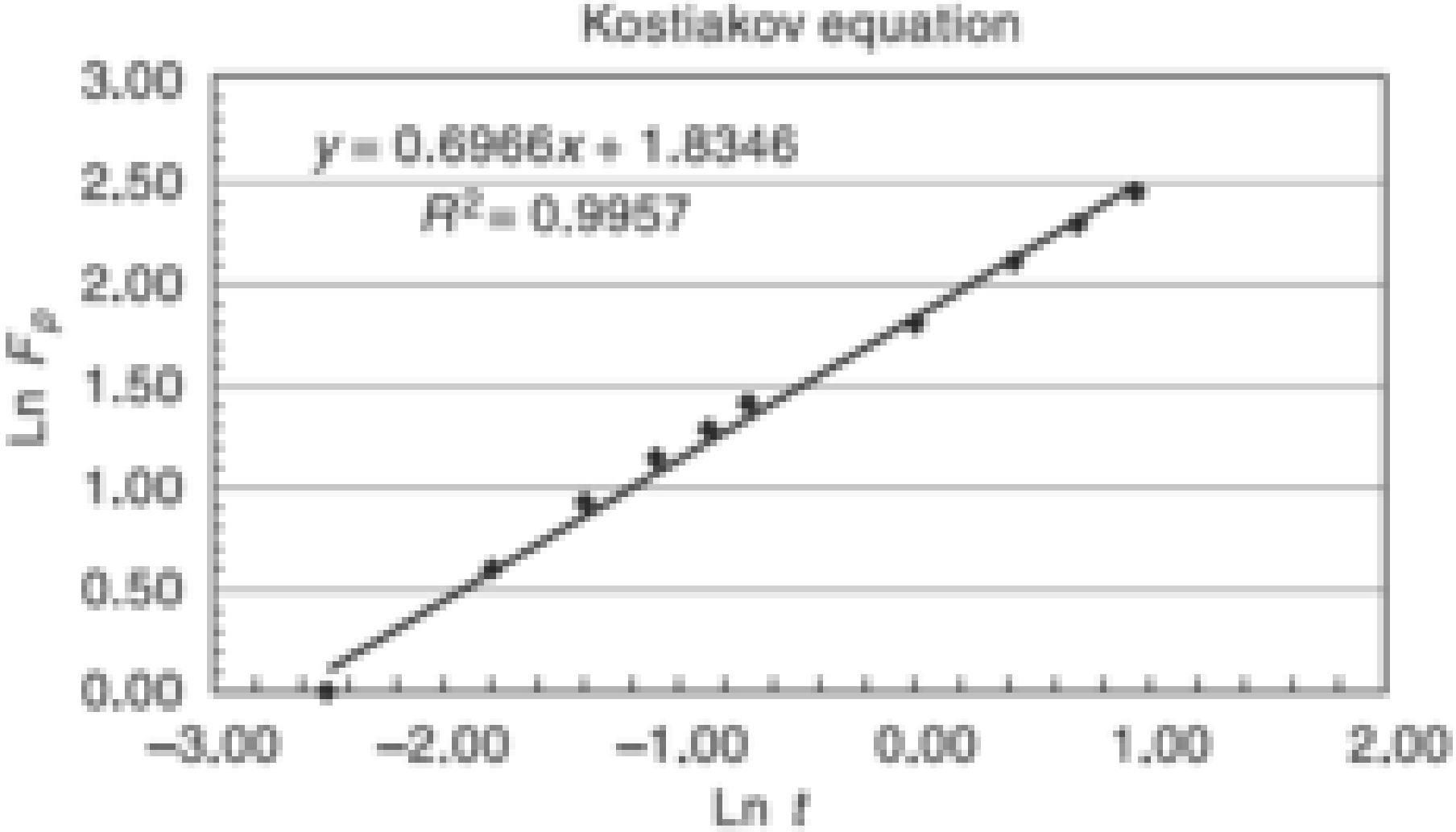

Fig. 3.15 (c) ***Fitting of Kostiakov Equation***

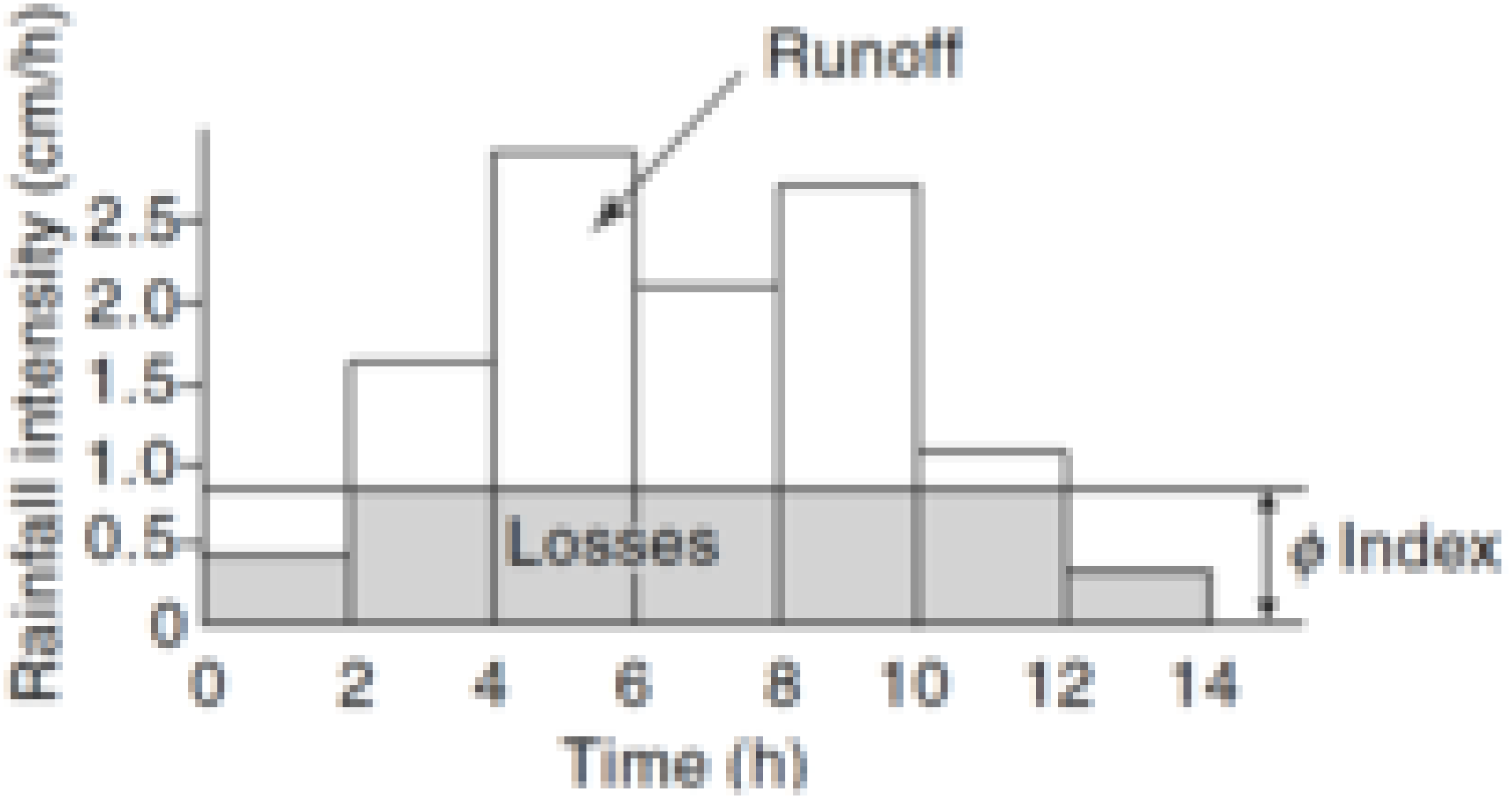

Fig. 3.16 *φ-Index*

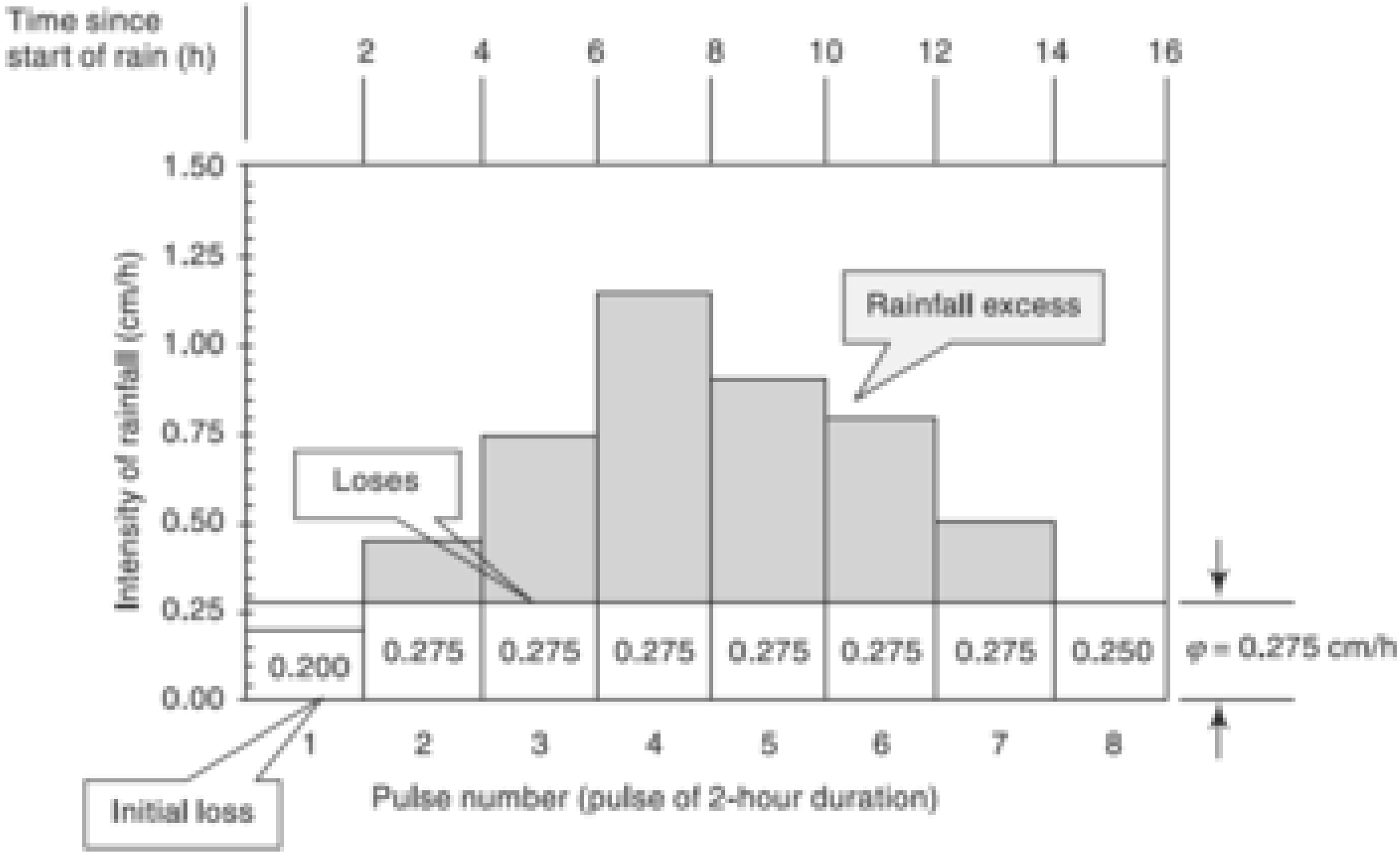

Fig. 3.17 *Hyetograph and Rainfall Excess of the Storm–Example 3.11*

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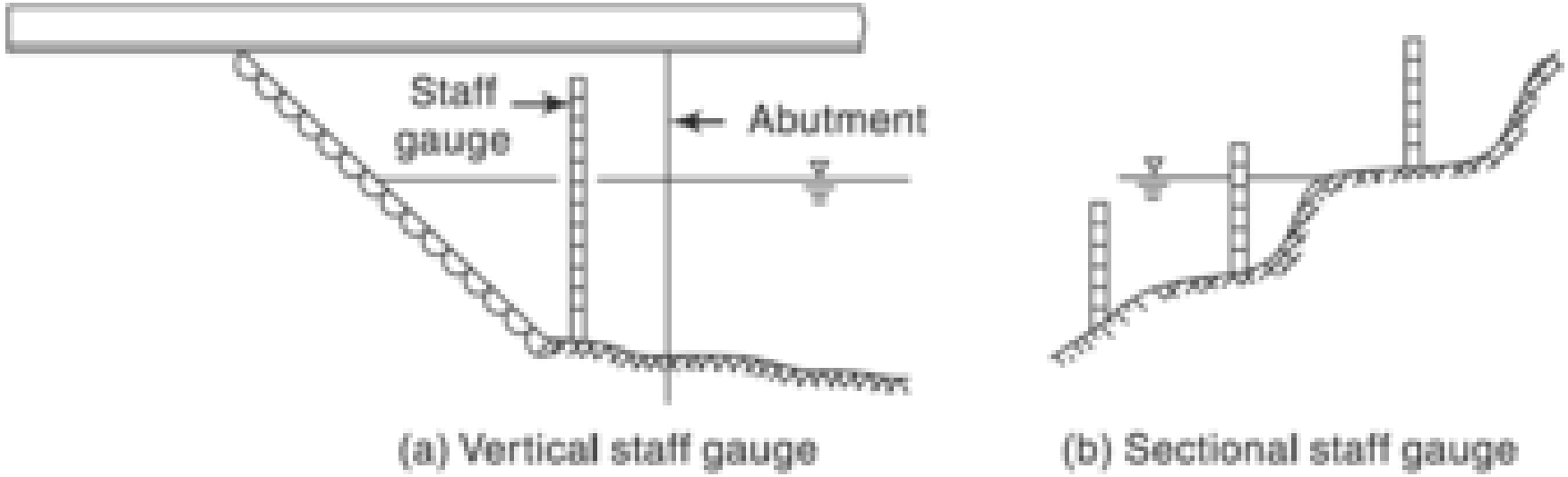

Fig. 4.1 ***Staff Gauge***

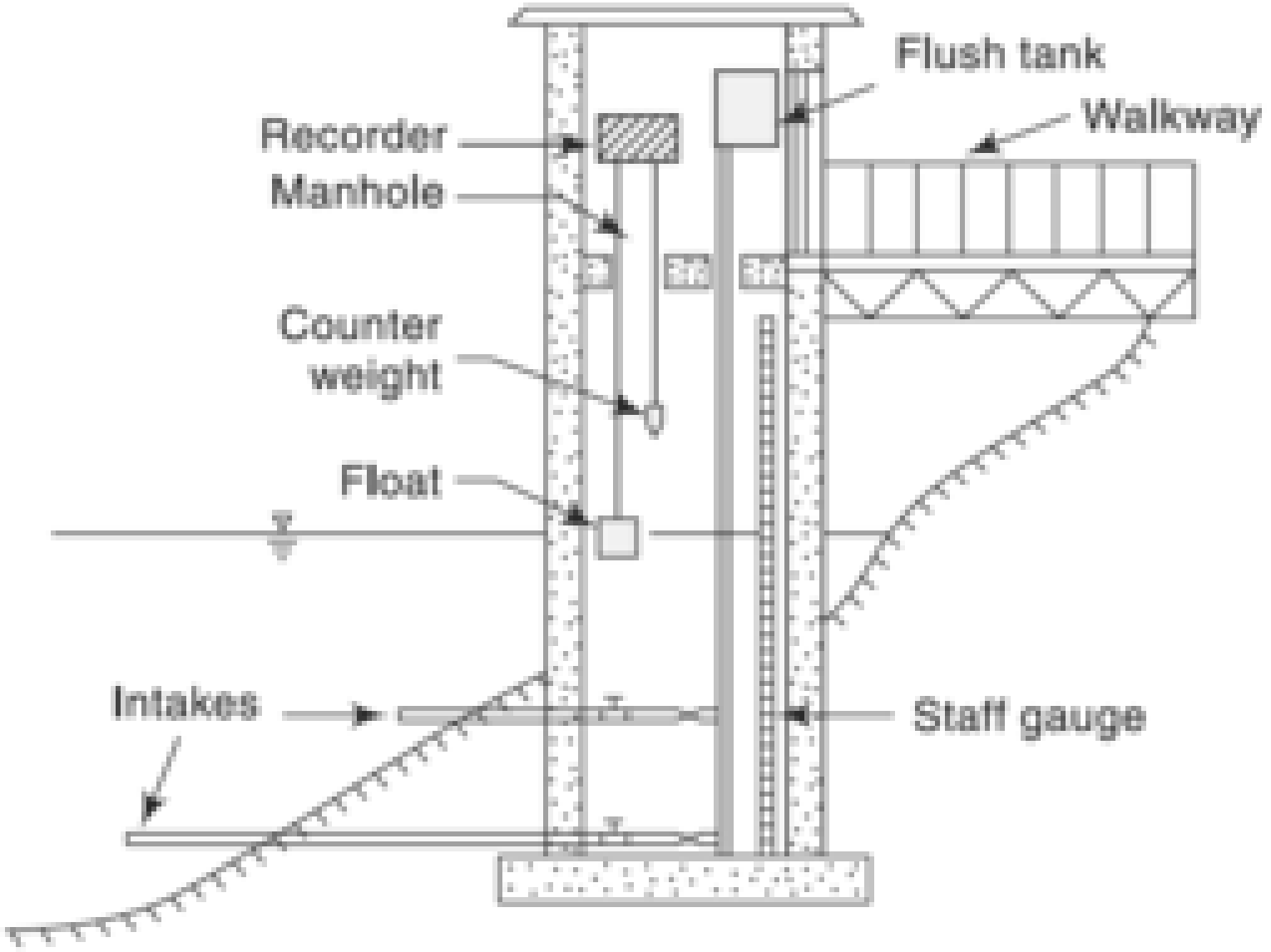

Fig. 4.2 *Stilling well Installation*

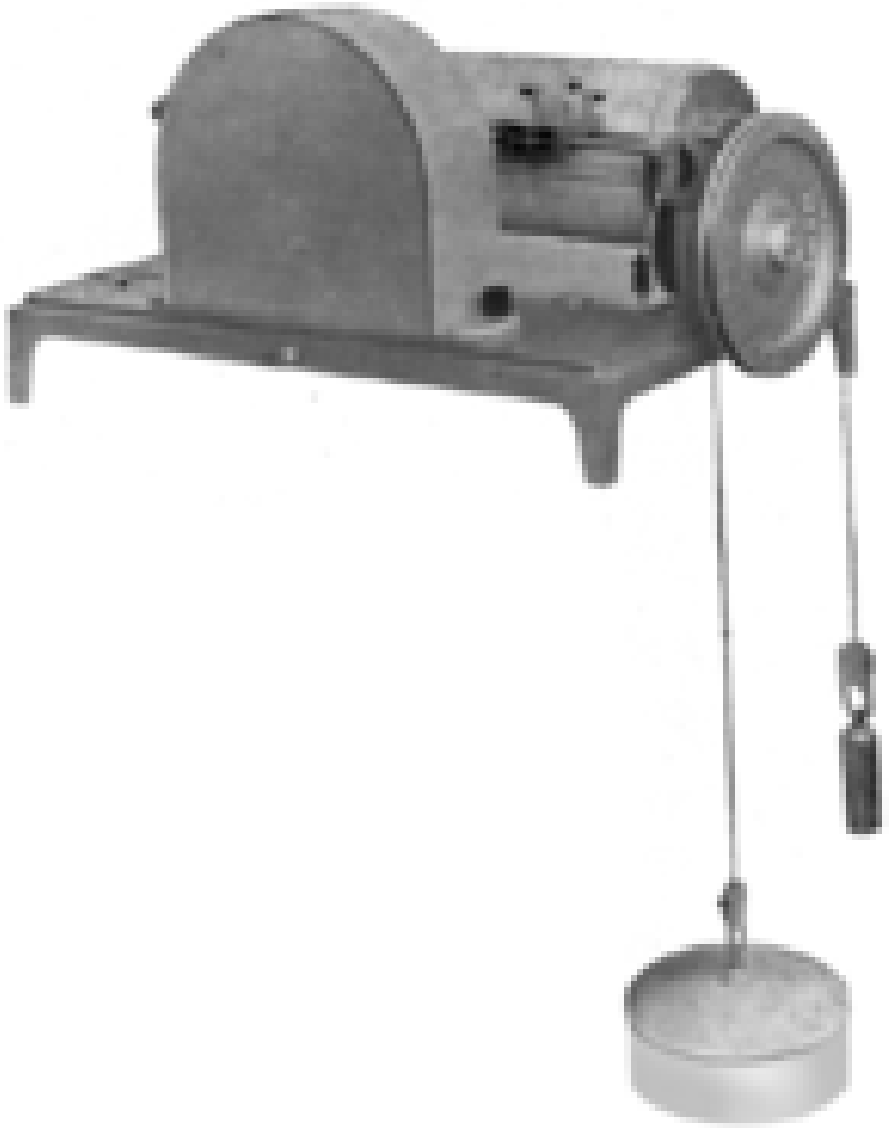

Fig. 4.3 *Water-depth recorder—Stevens Type F recorder*
(Courtesy: Leupold and Stevens, Inc. Beaverton, Oregon, USA)

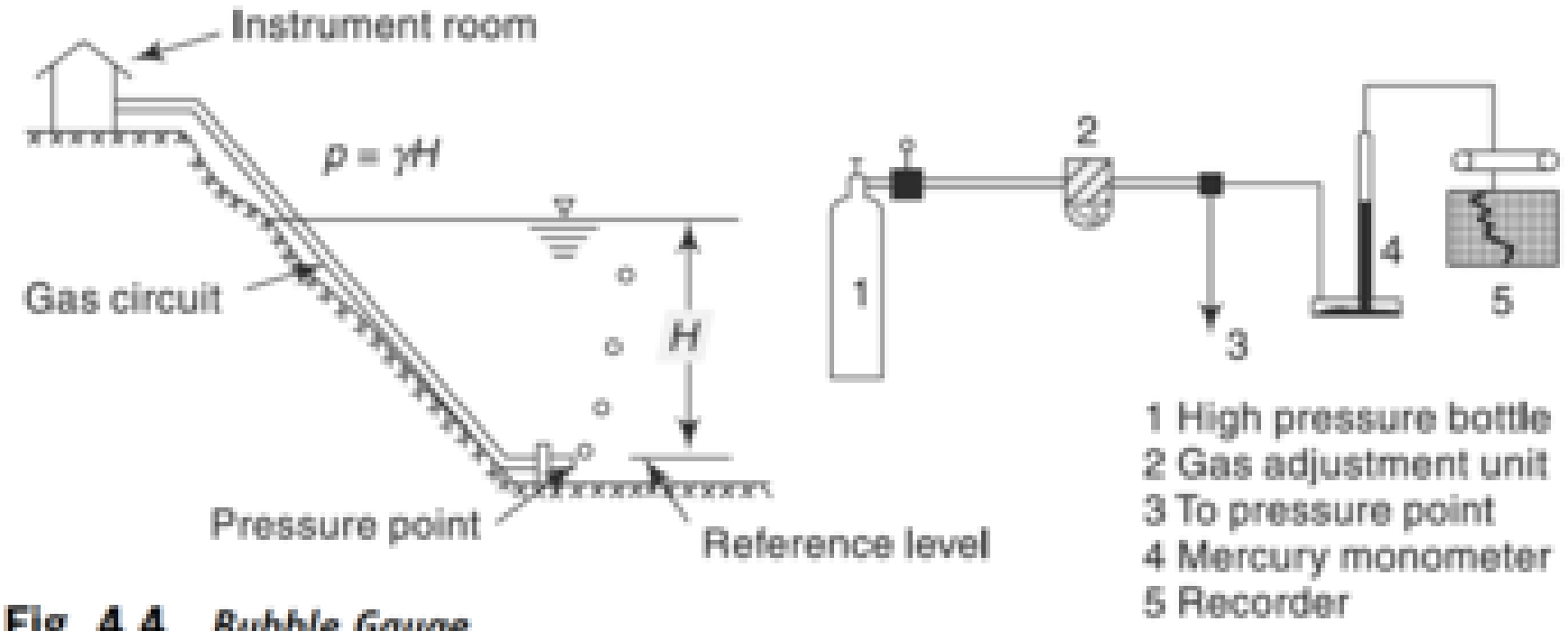

Fig. 4.4 *Bubble Gauge*

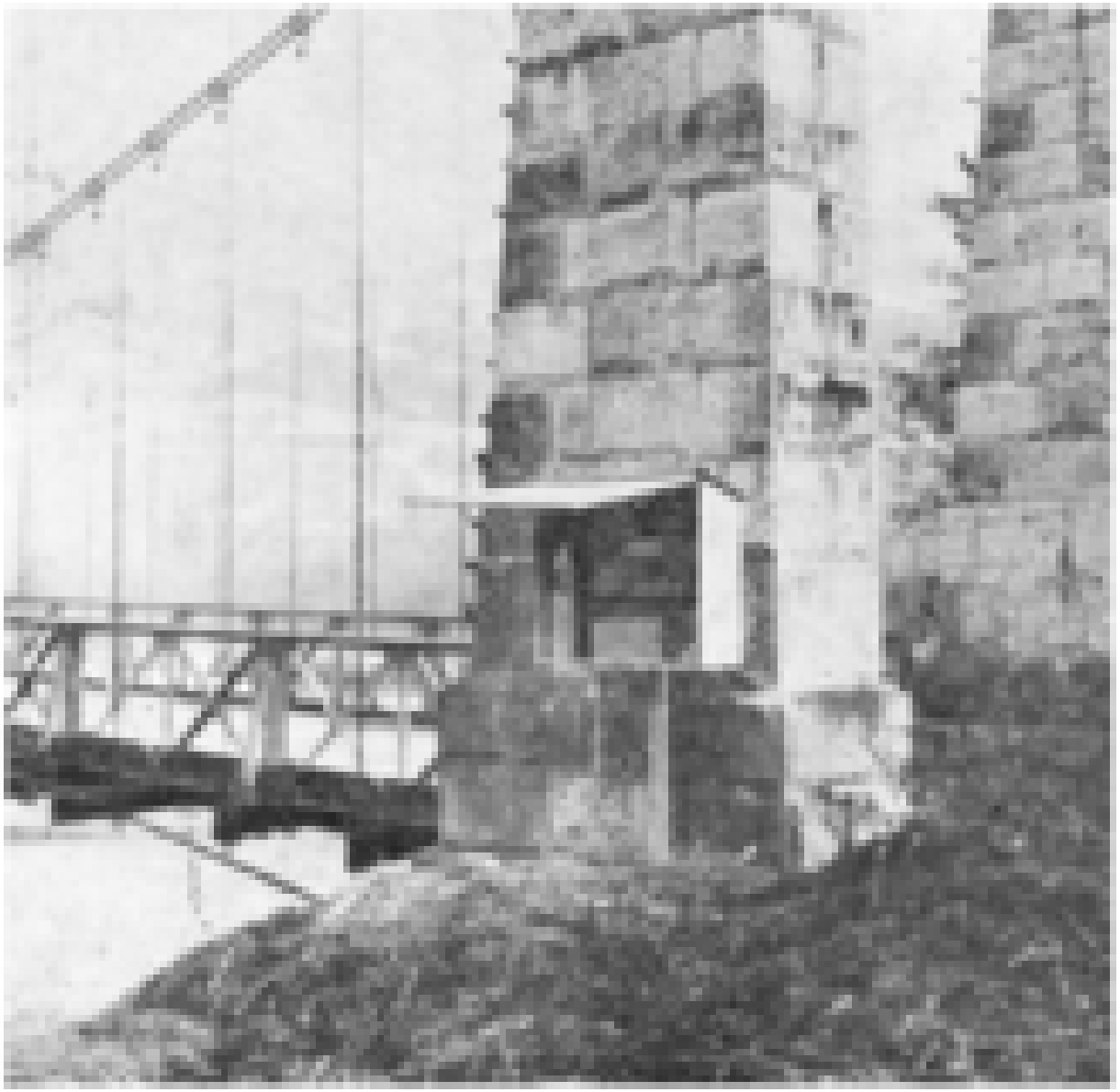

Fig. 4.5 *Bubble Gauge Installation—Telemnip*
(Courtesy: Neyrtec, Grenoble, France)

Fig. 4.6 ***Bubble Gauge—Stevens Manometer Servo***
(Courtesy: Leupold and Stevens, Inc. Beaverton, Oregon, USA)

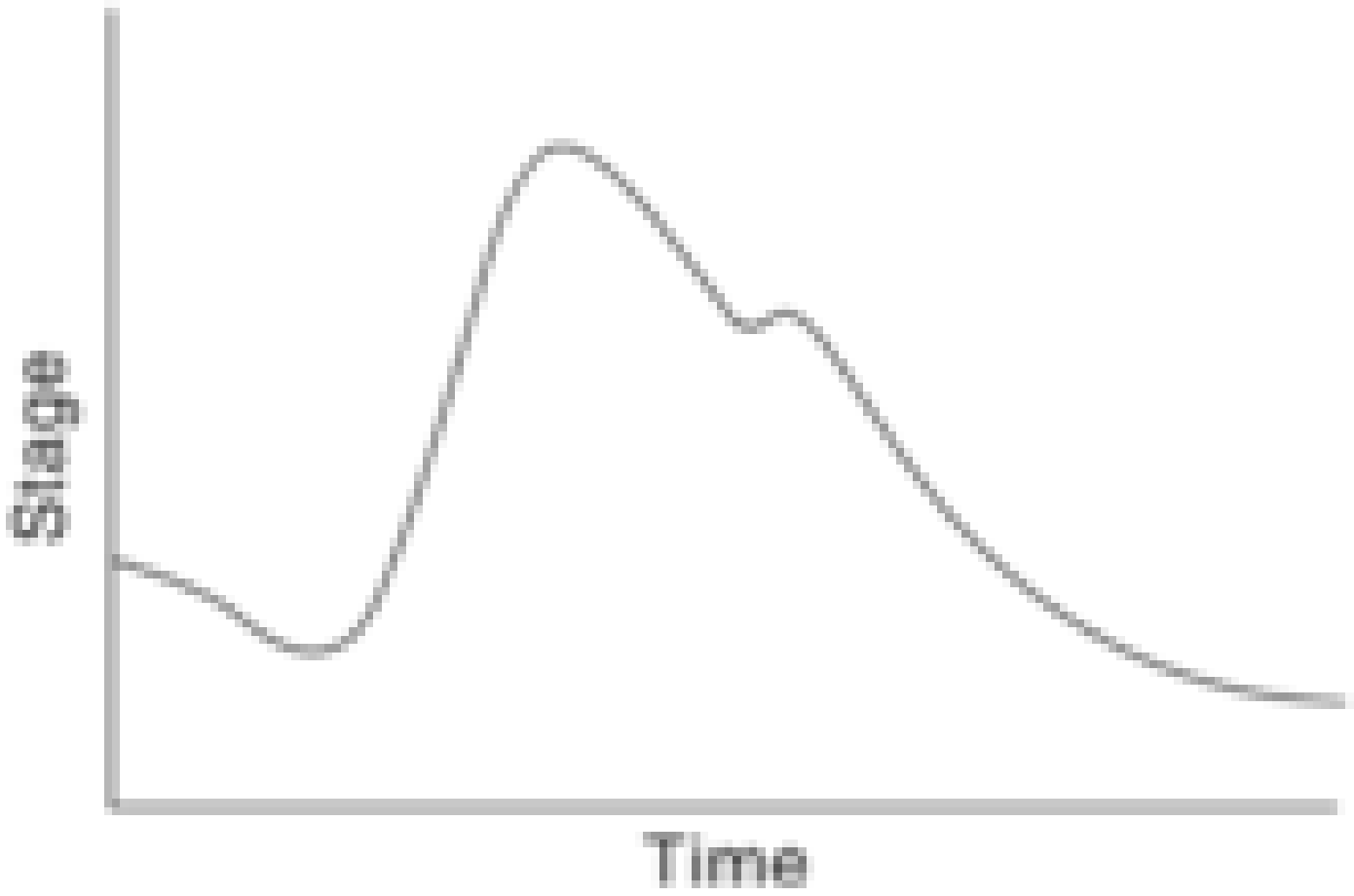

Fig. 4.7 ***Stage Hydrograph***

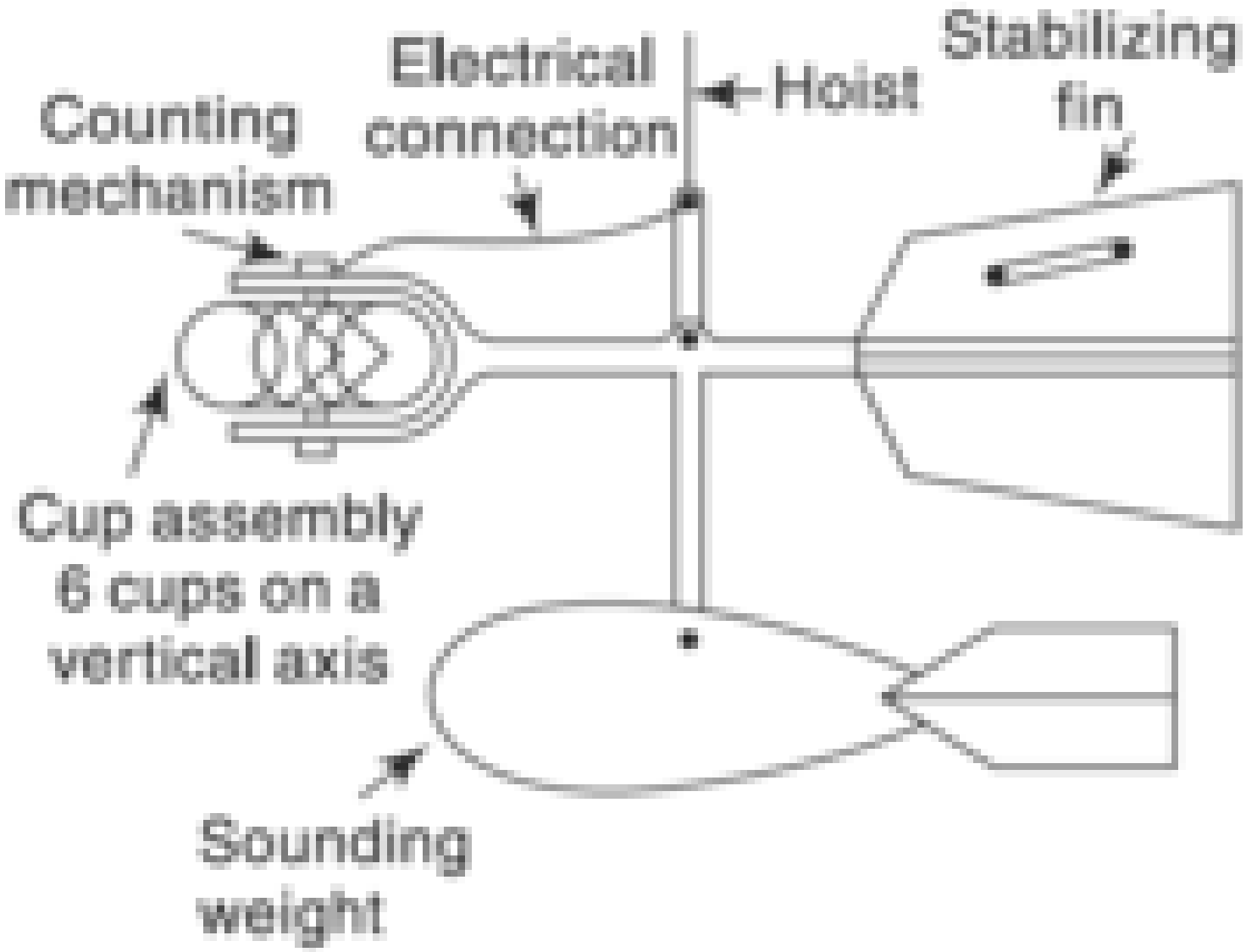

Fig. 4.8 *Vertical-axis Current Meter*

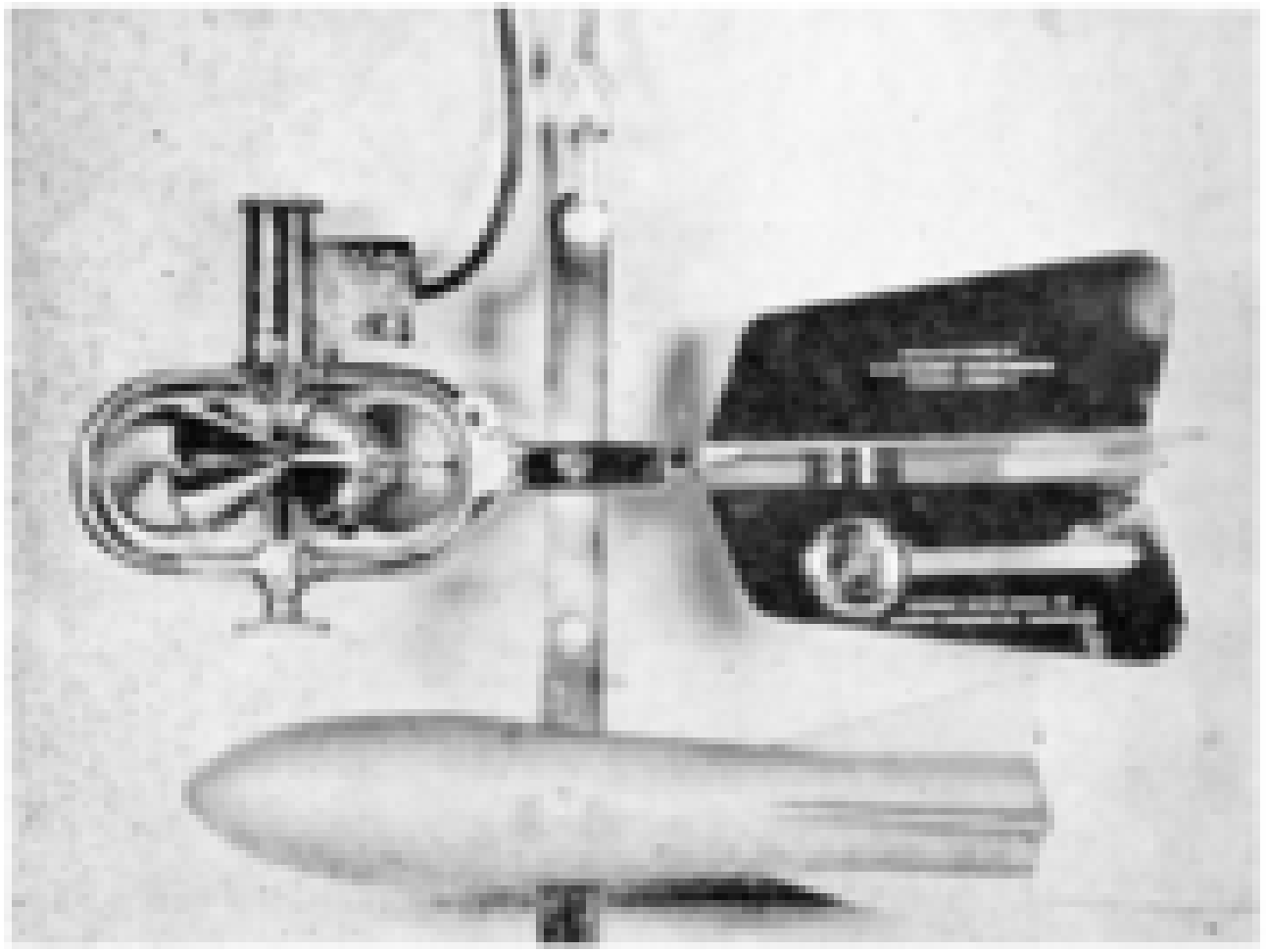

Fig. 4.9 ***Cup-type Current Meter with Sounding Weight—'Lynx' Type***

(Courtesy: Lawrence and Mayo (India) New Delhi)

Fig. 4.10 *Propeller-type Current Meter—Neyrtec Type with Sounding Weight*

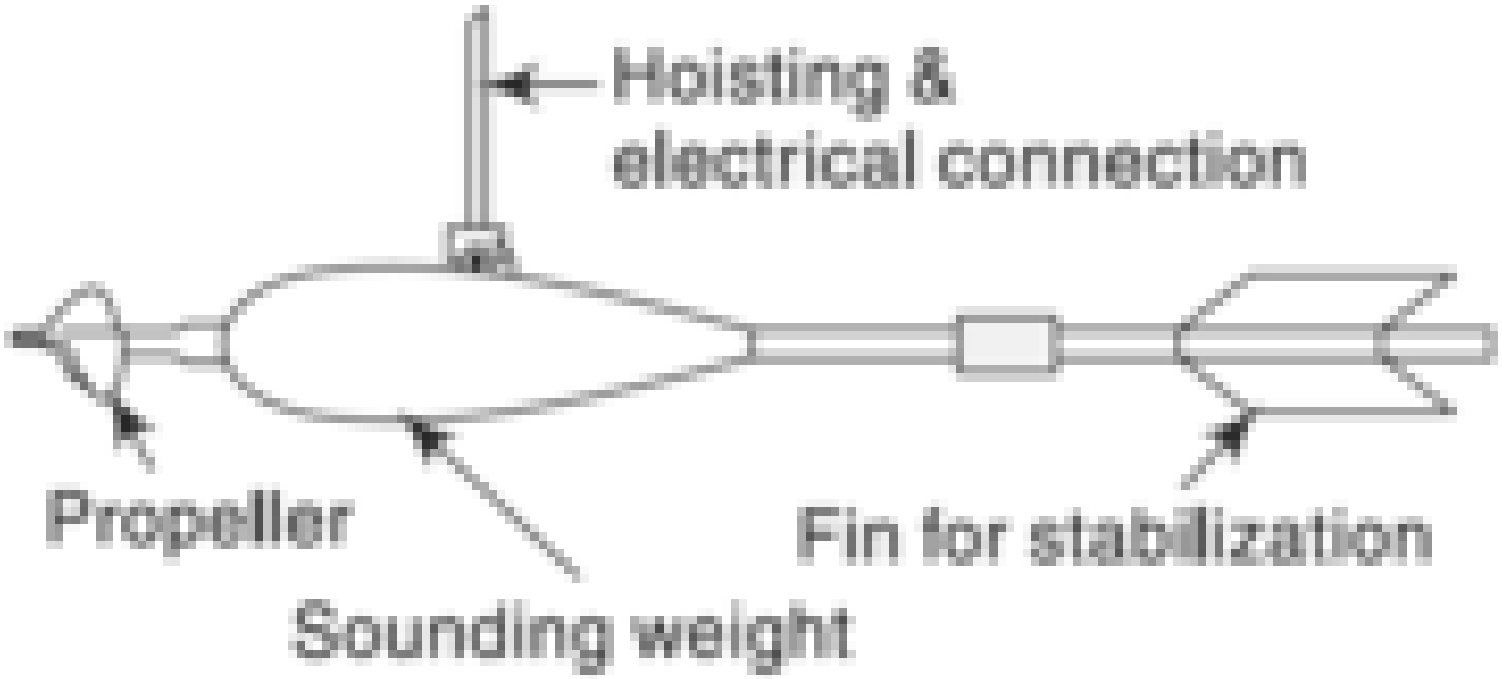

Fig. 4.11 *Horizontal-axis Current Meter*

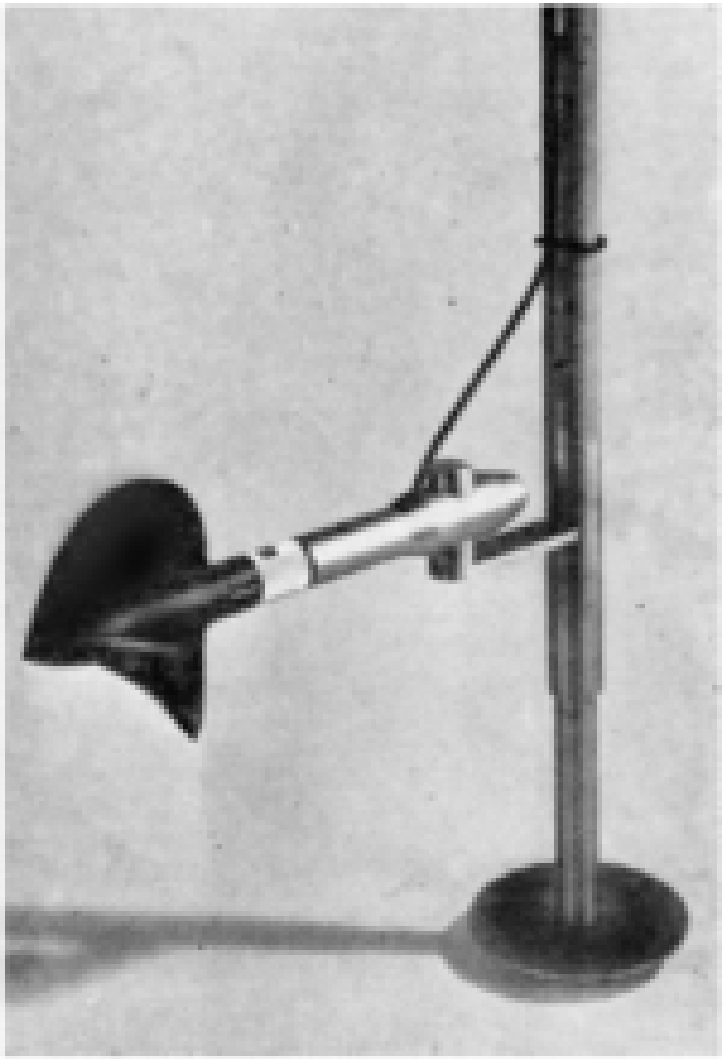

Fig. 4.12(a) ***Neyrtec Type Current Meter for use in Wading***

(Courtesy: Neyrtec, Grenoble, France)

Fig. 4.12(b) ***Neyrtec Type Meter in a Cableway***

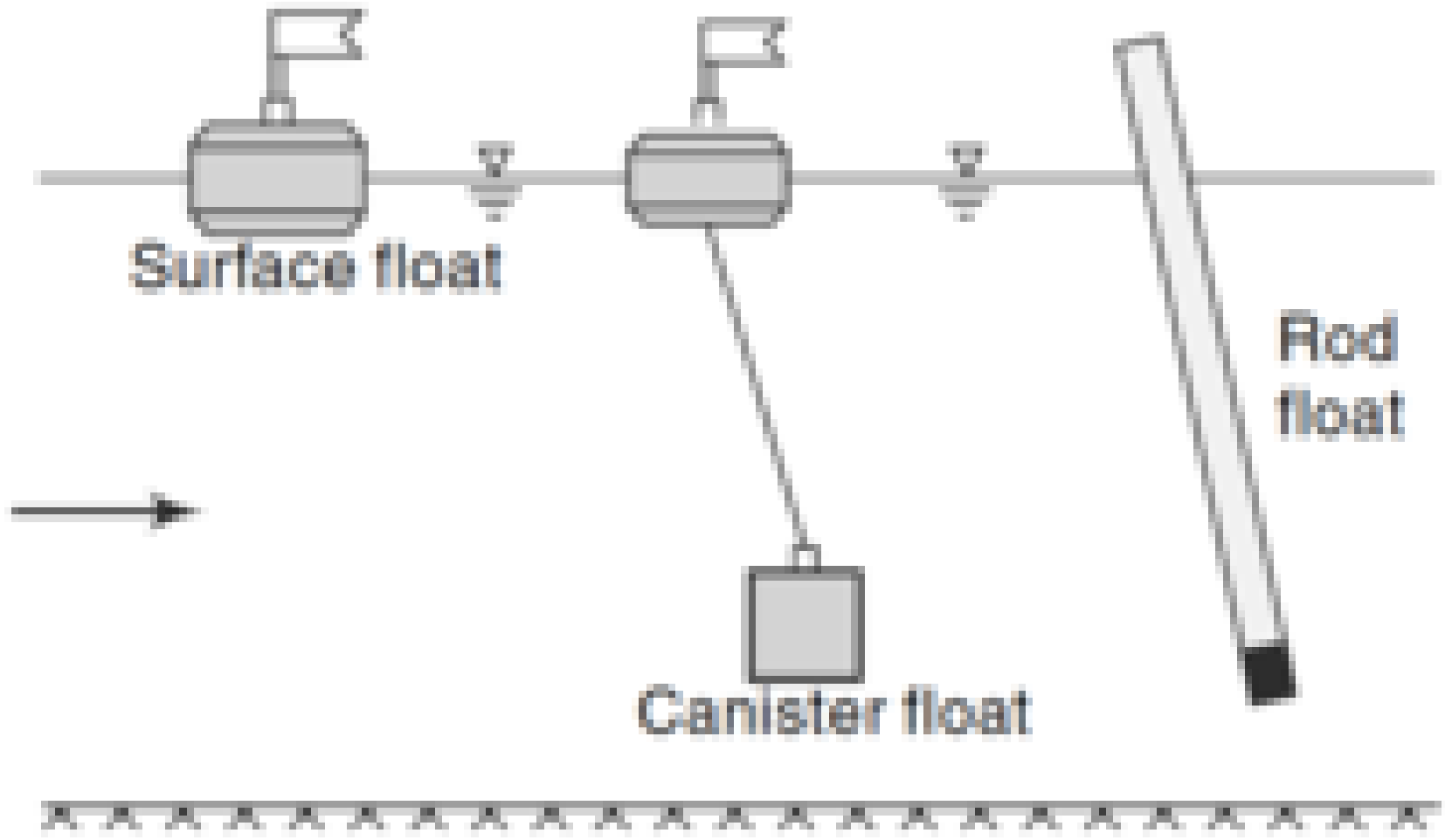

Fig. 4.13 *Floats*

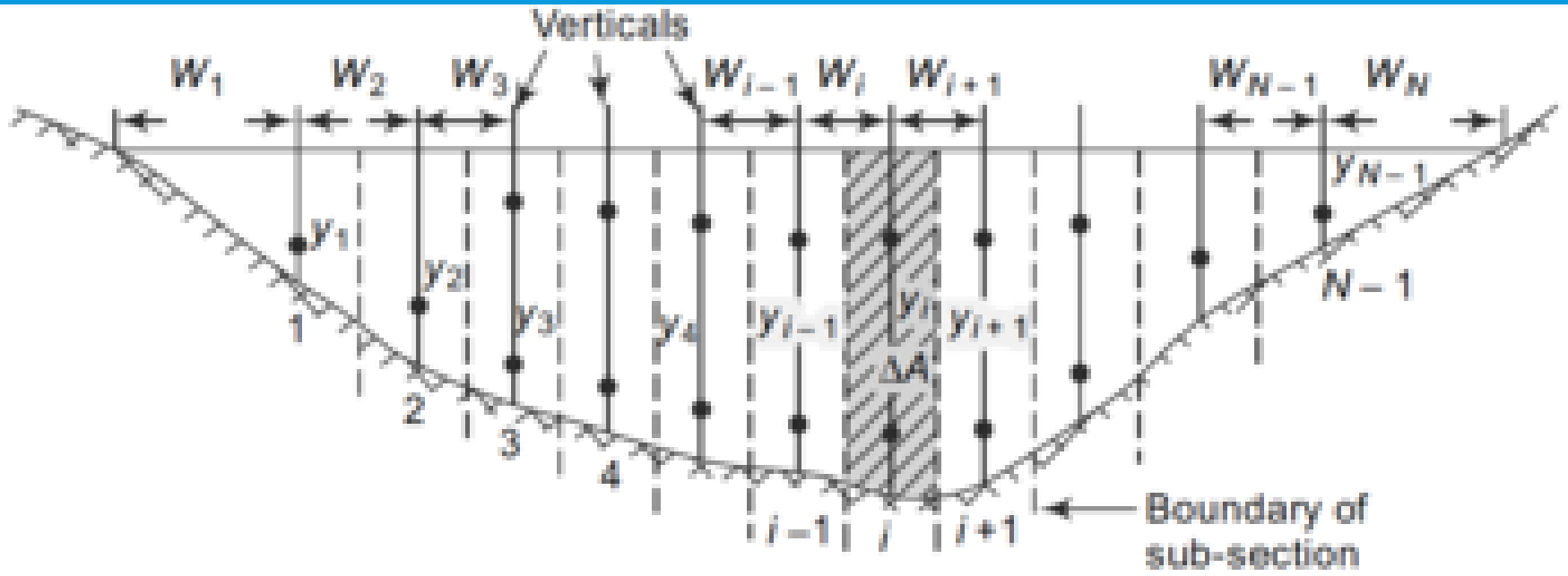

Fig. 4.14 *Stream Section for Area-velocity Method*

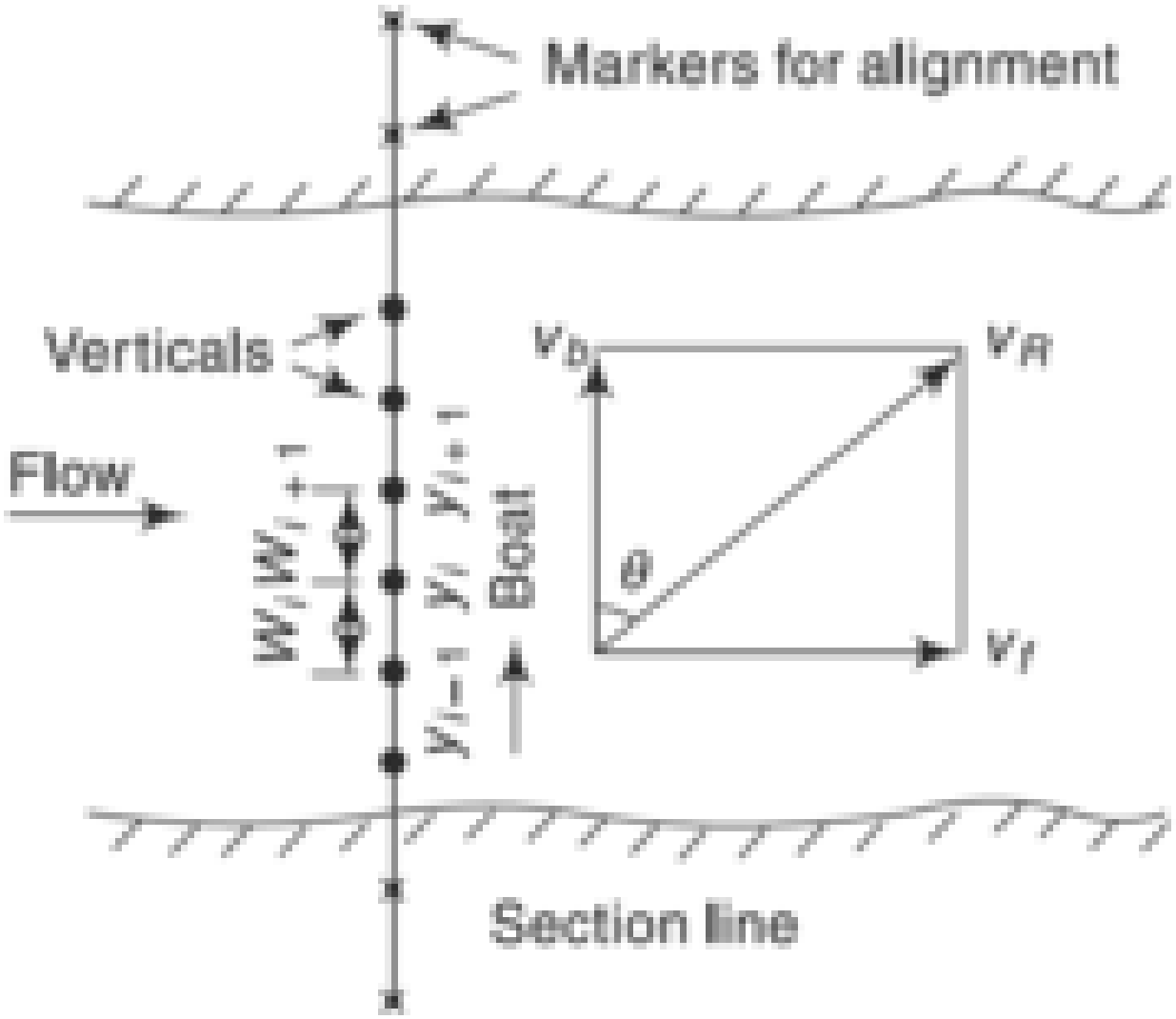

Fig. 4.15 *Moving-boat Method*

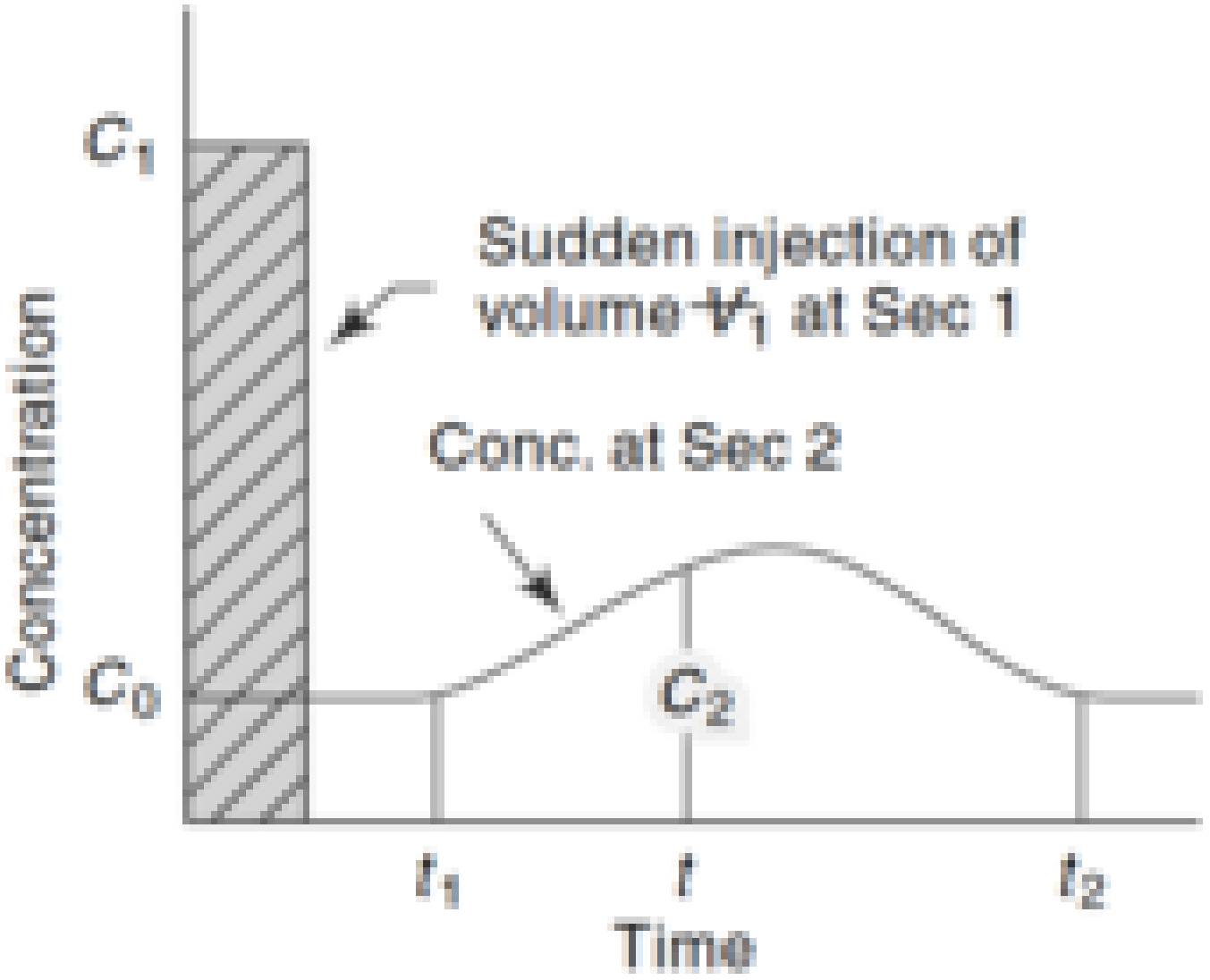

Fig. 4.16 *Sudden-injection Method*

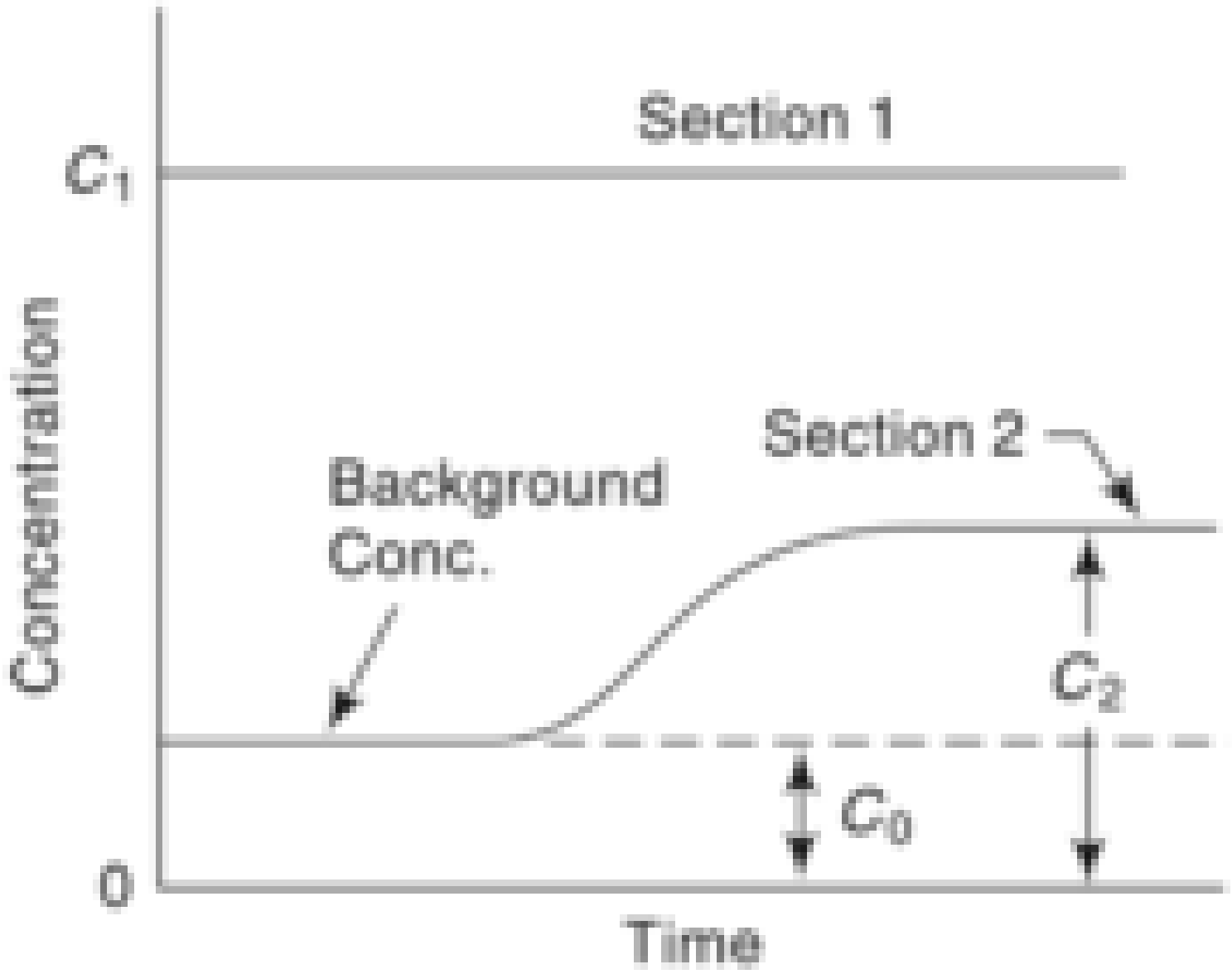

Fig. 4.17 *Constant-Rate Injection Method*

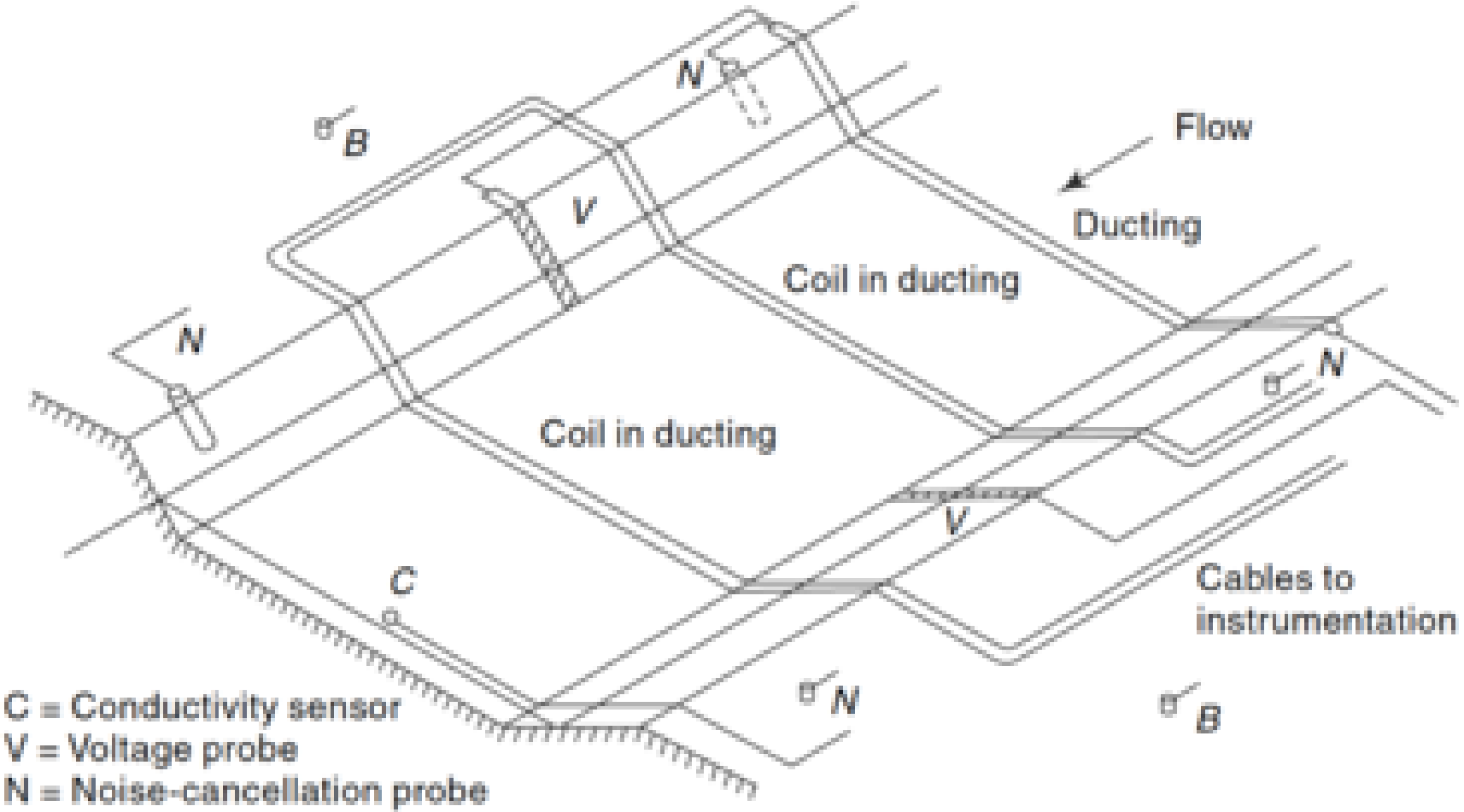

Fig. 4.18 *Electromagnetic Method*

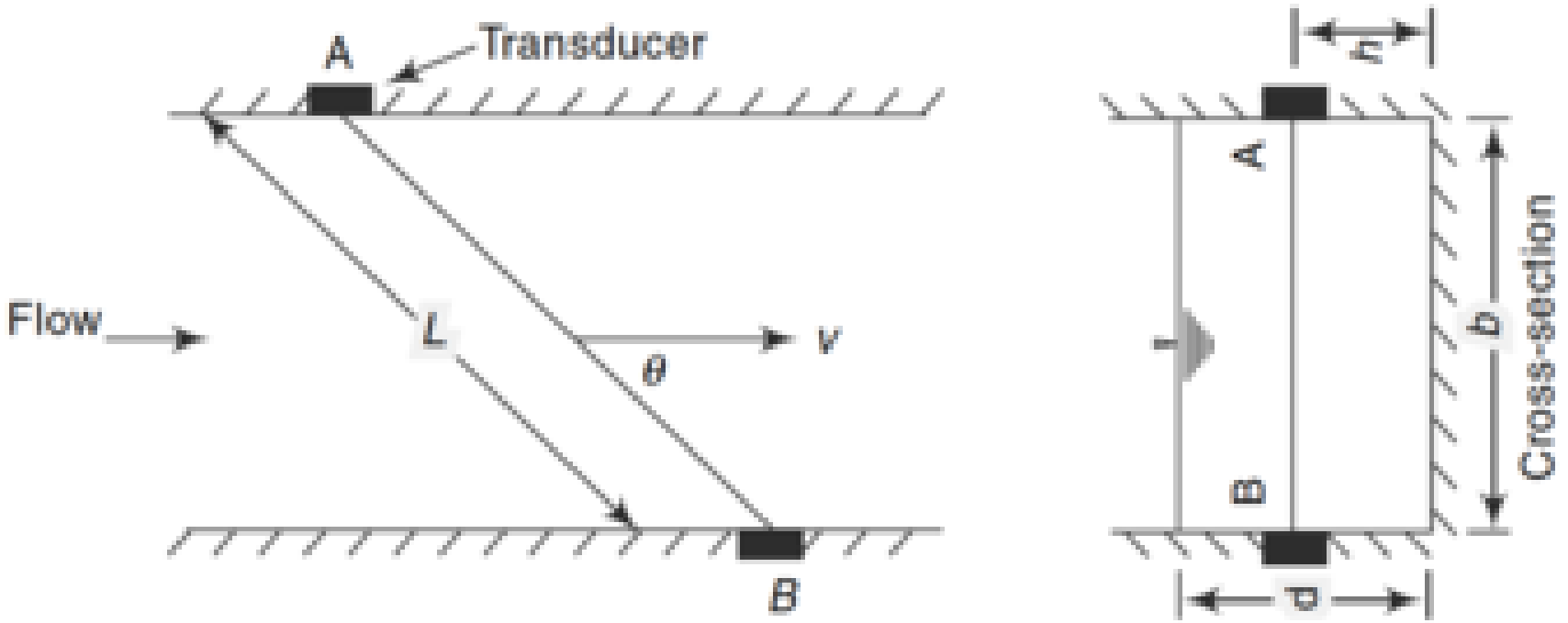

Fig. 4.19 *Ultrasonic Method*

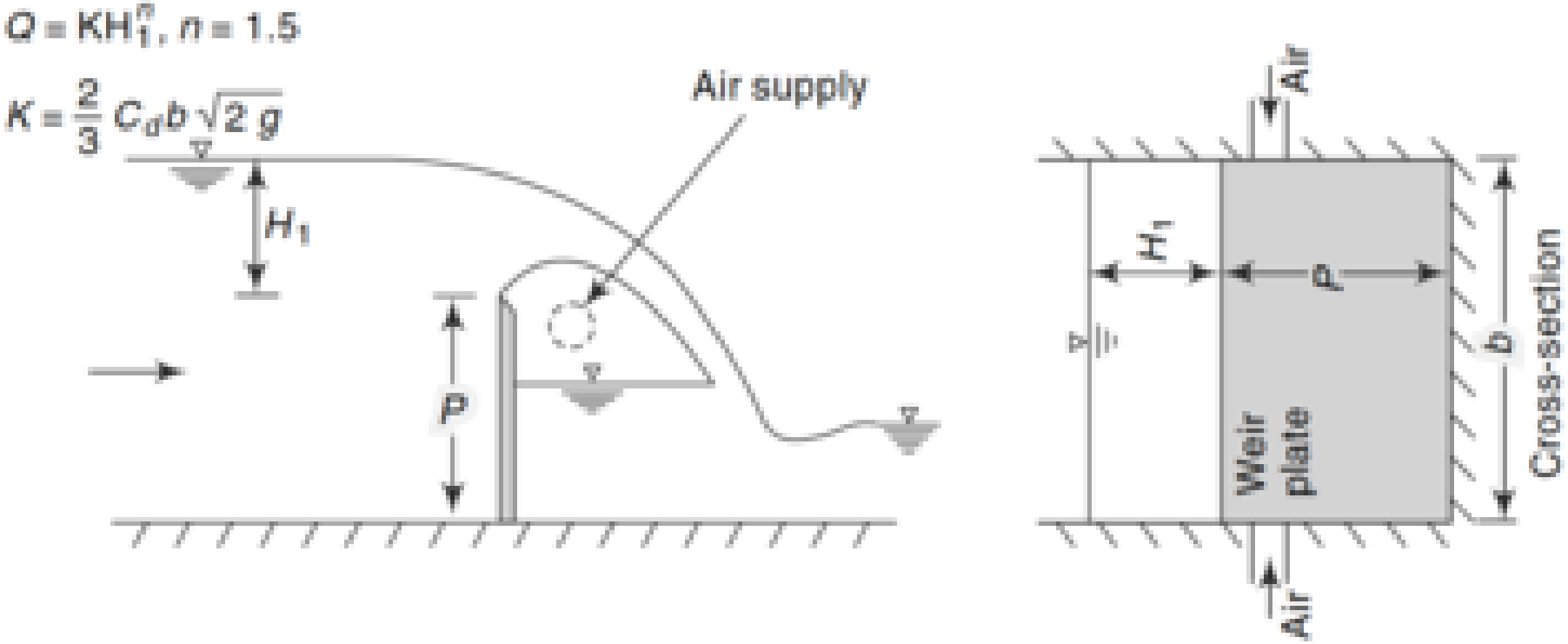

Fig. 4.20(a) *Flow over a Weir: (a) Free Flow*

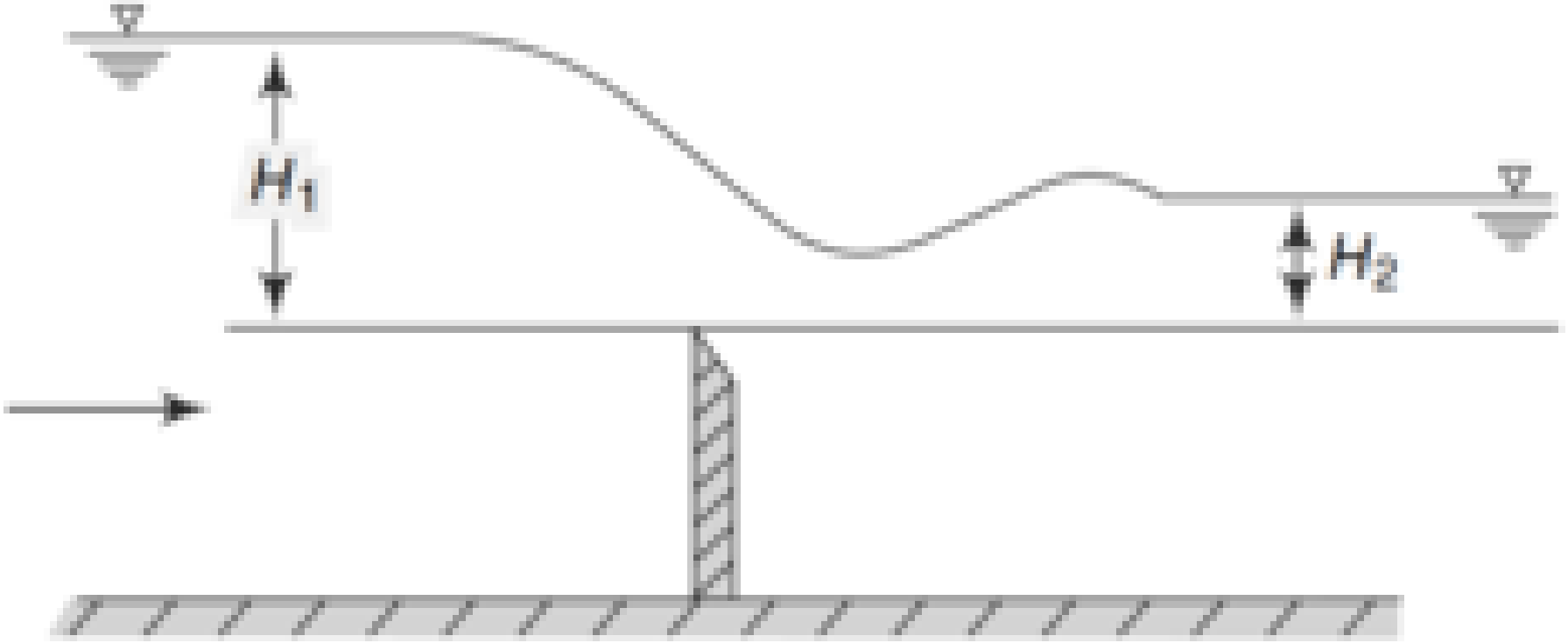

Fig. 4.20(b) *Submerged Flow*

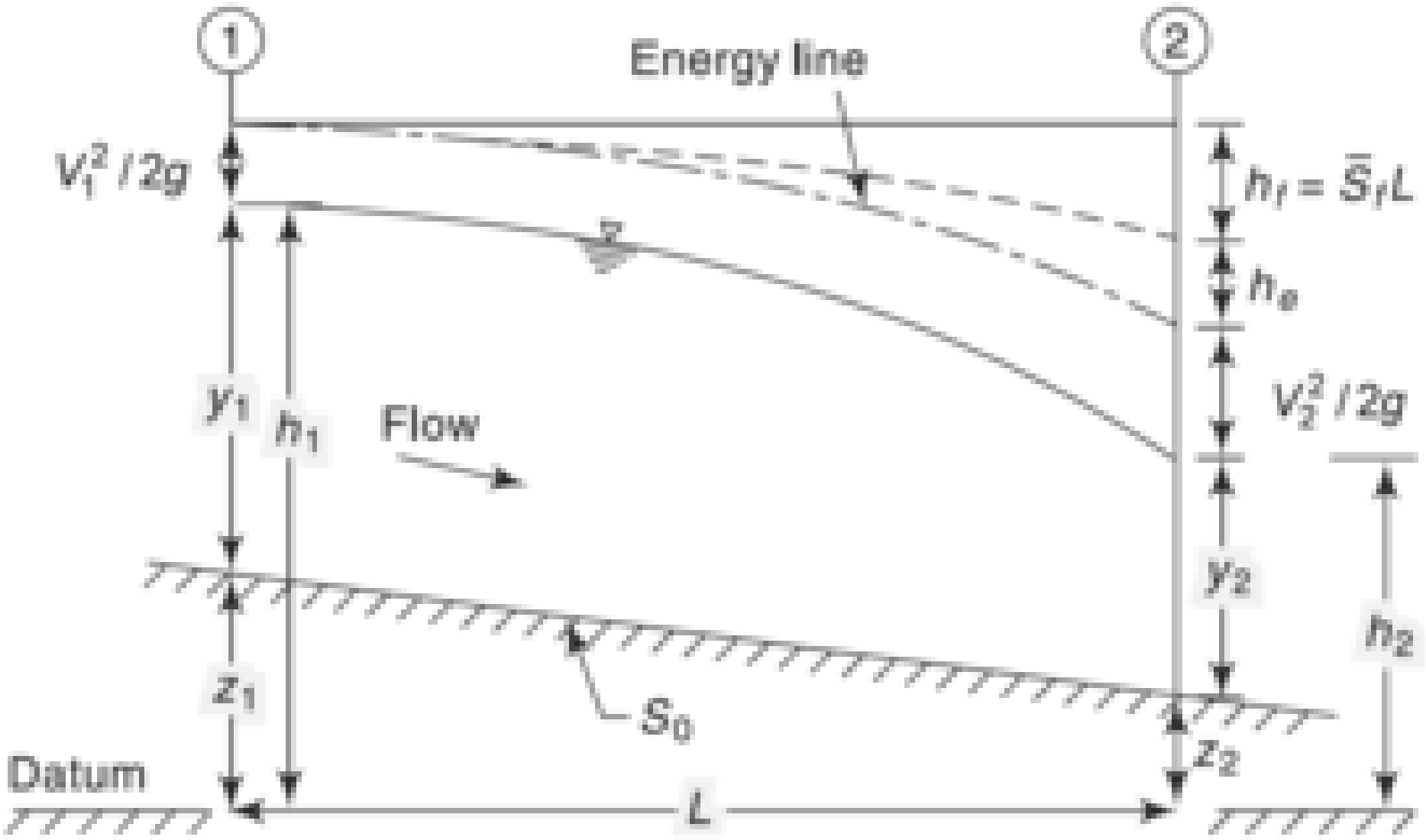

Fig. 4.21 *Slope-area Method*

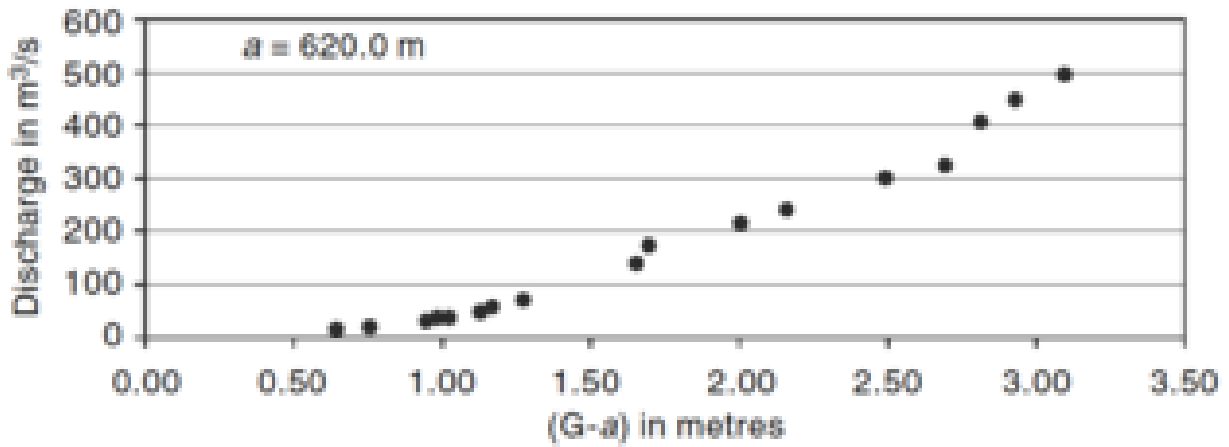

Fig. 4.22(a) *Stage-Discharge Curve: Arithmetic Plot*

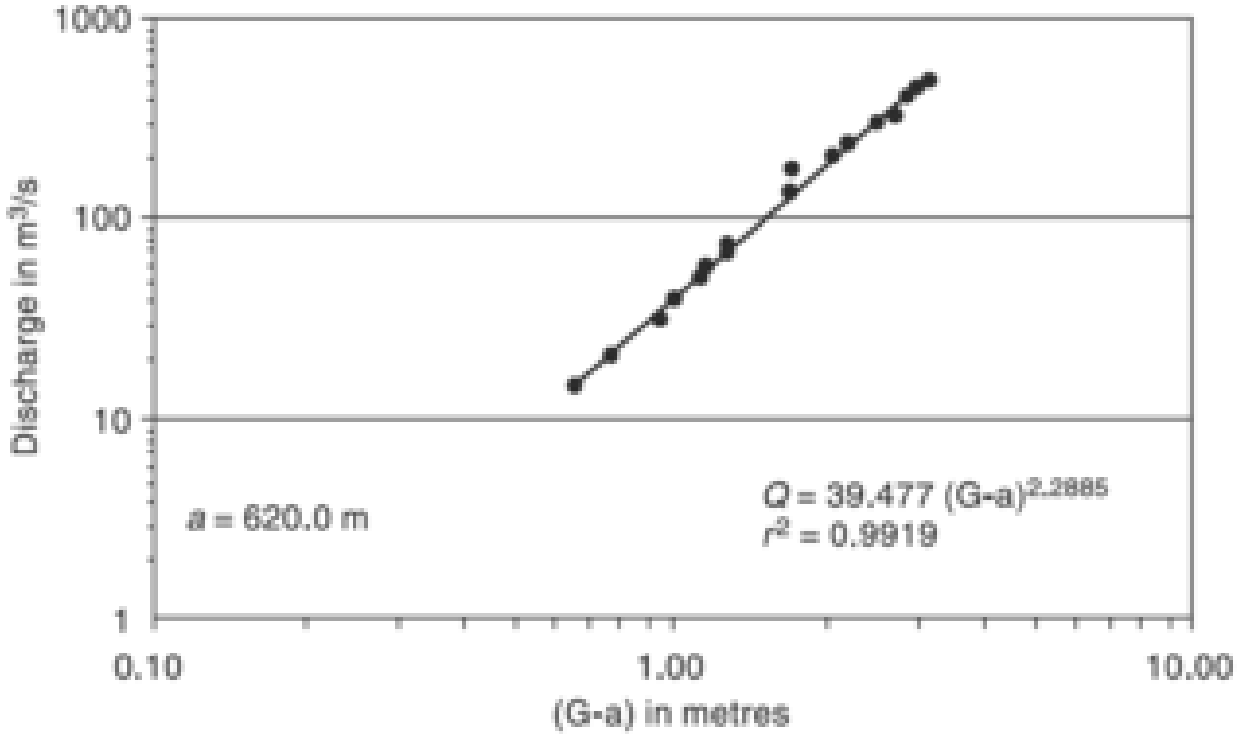

Fig. 4.22(b) *Stage-Discharge Curve: Logarithmic Plot*

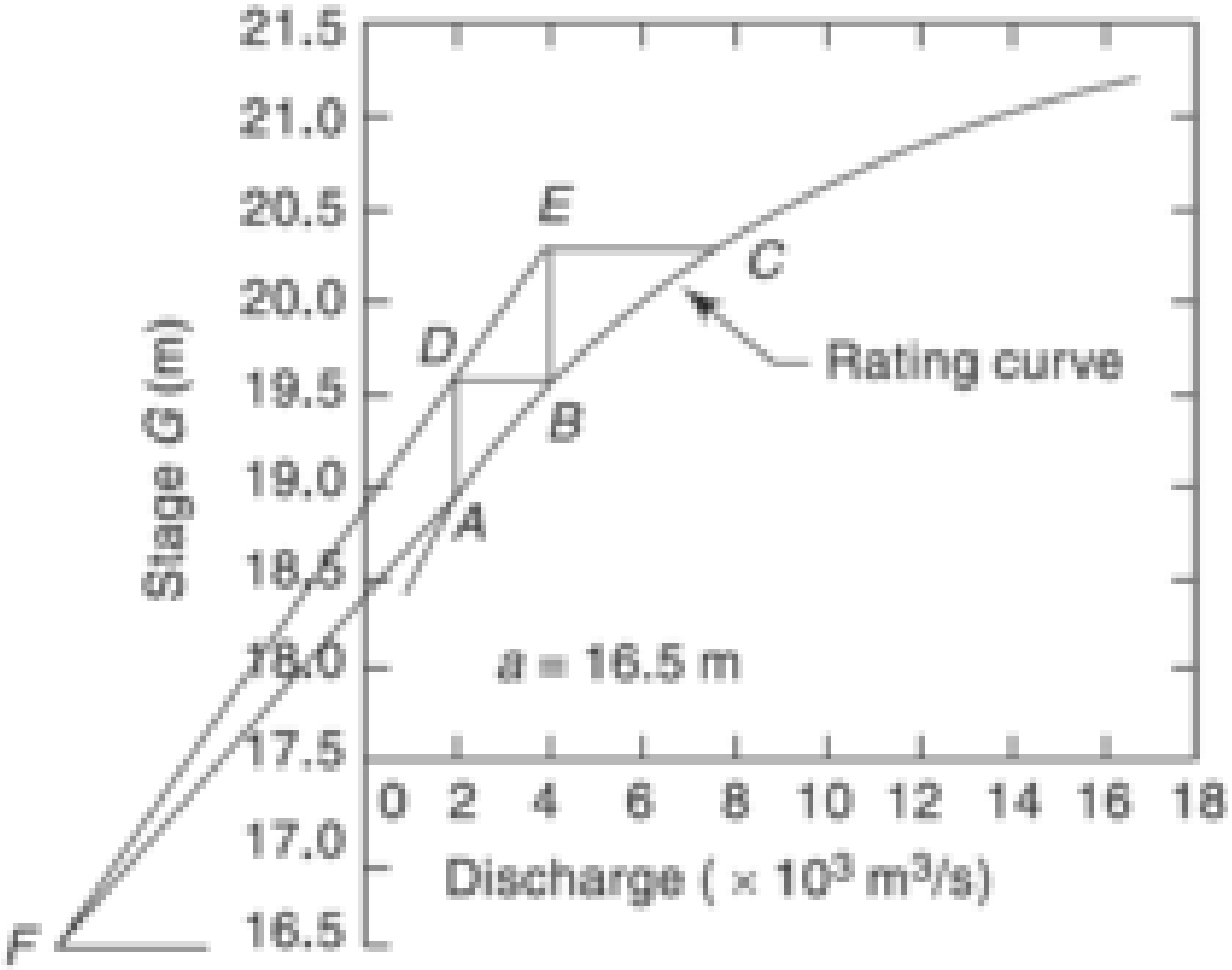

Fig. 4.23 ***Running's Method for Estimation of the Constant a***

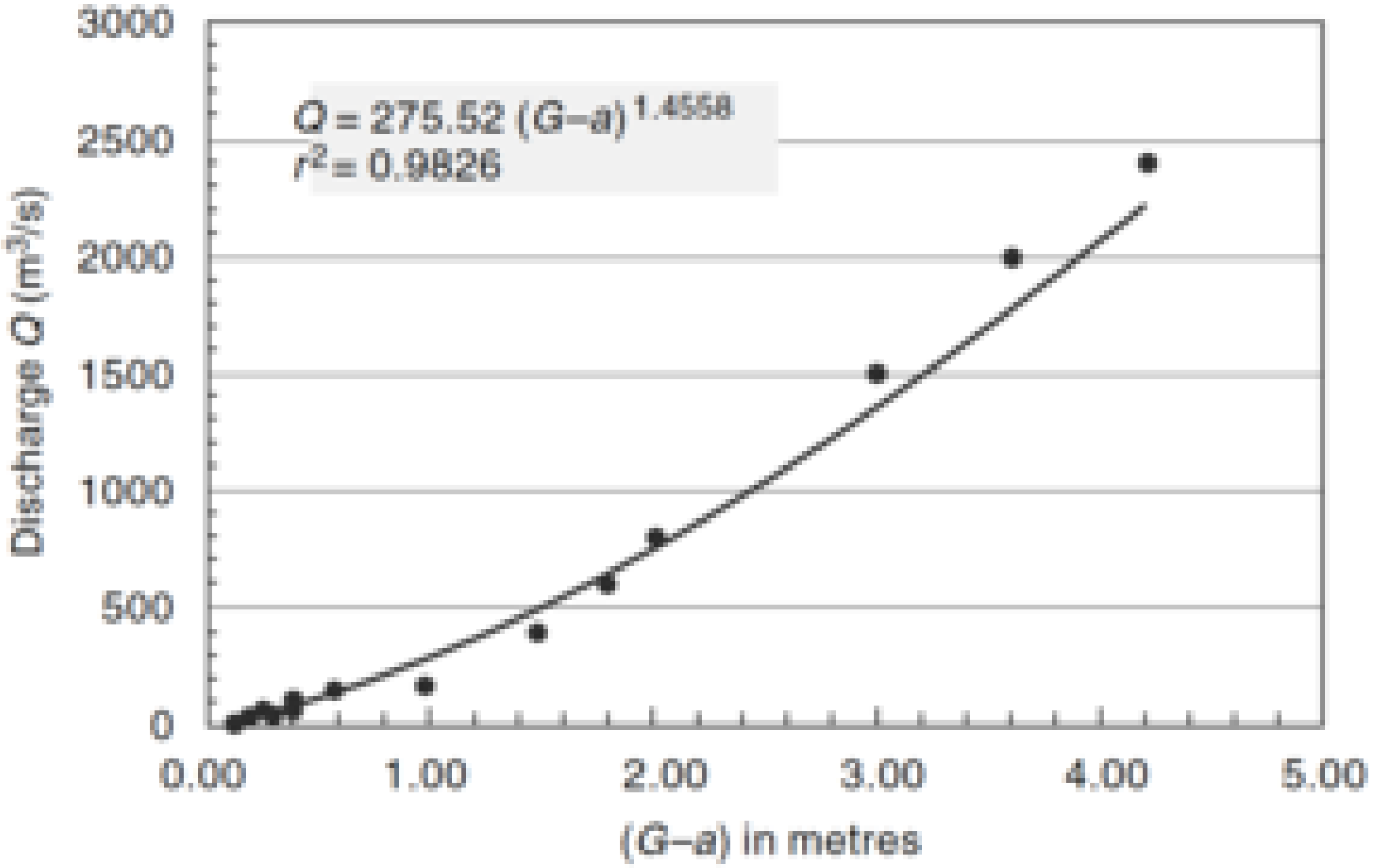

Fig. 4.24(a) *Stage-discharge Relation (Arithmetic Plot)—Example 4.5*

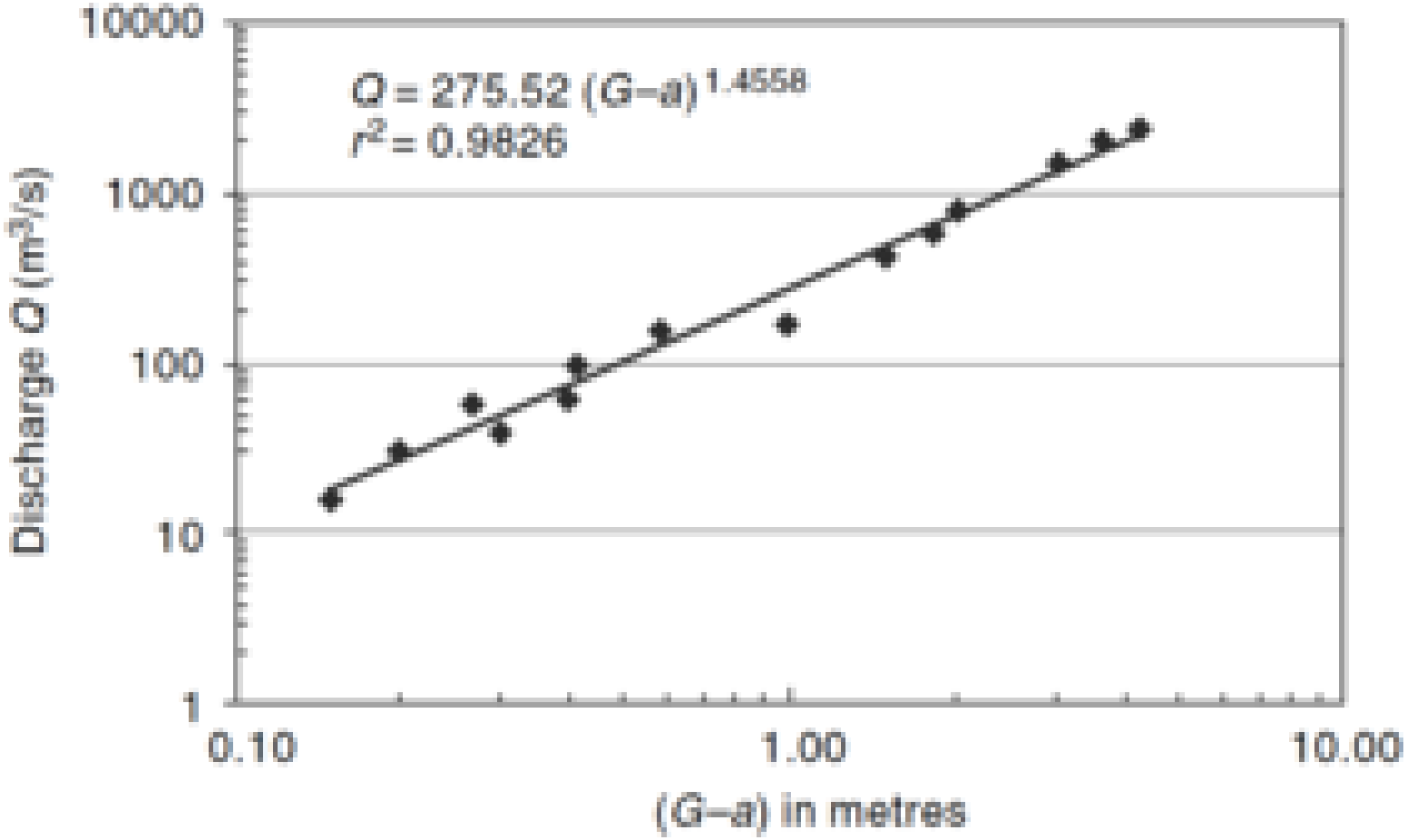

Fig. 4.24(b) *Stage-discharge Relationship (Logarithmic Plot)—Example 4.5*

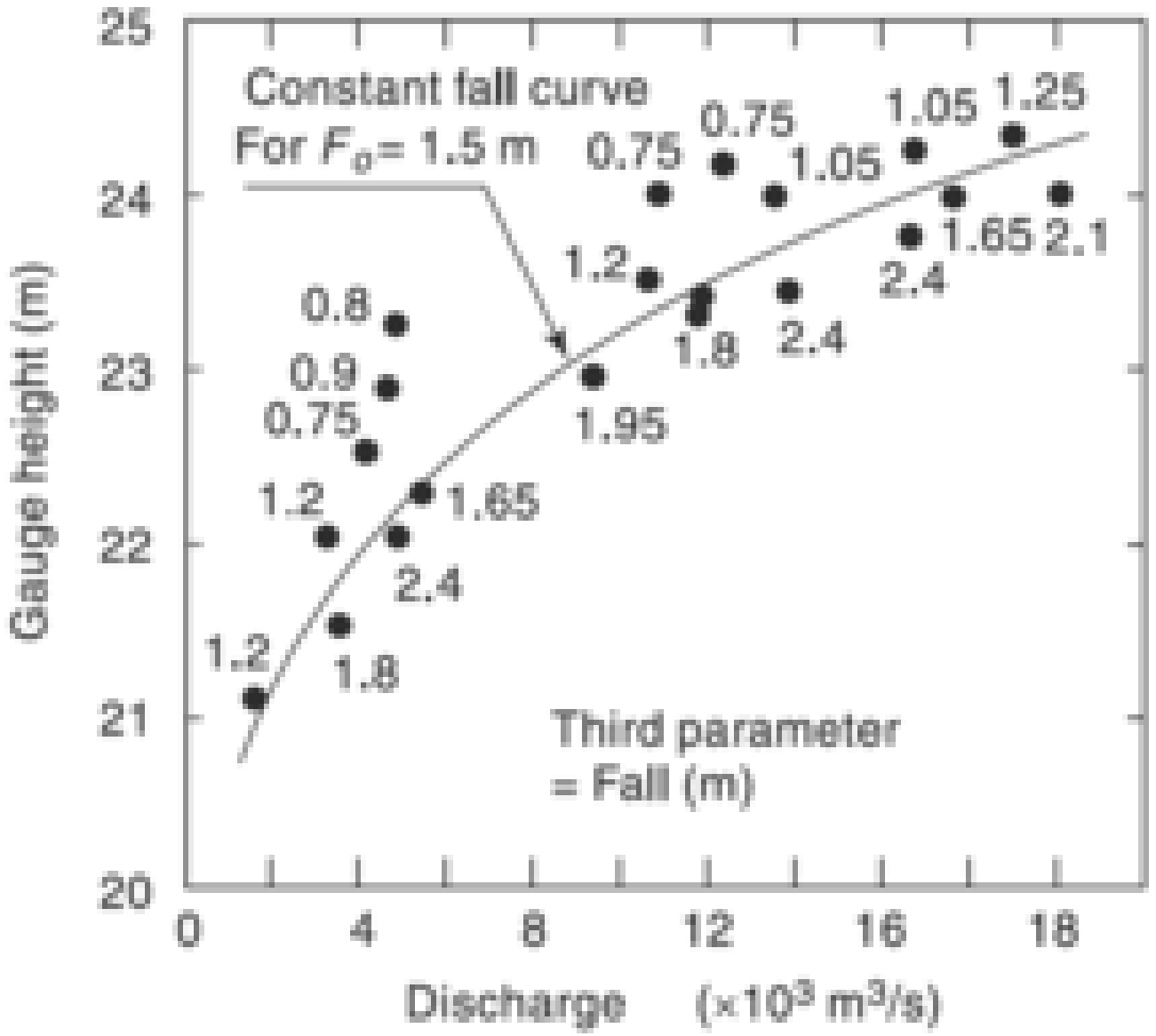

Fig. 4.25 ***Backwater Effect on a Rating Curve—Normalised Curve***

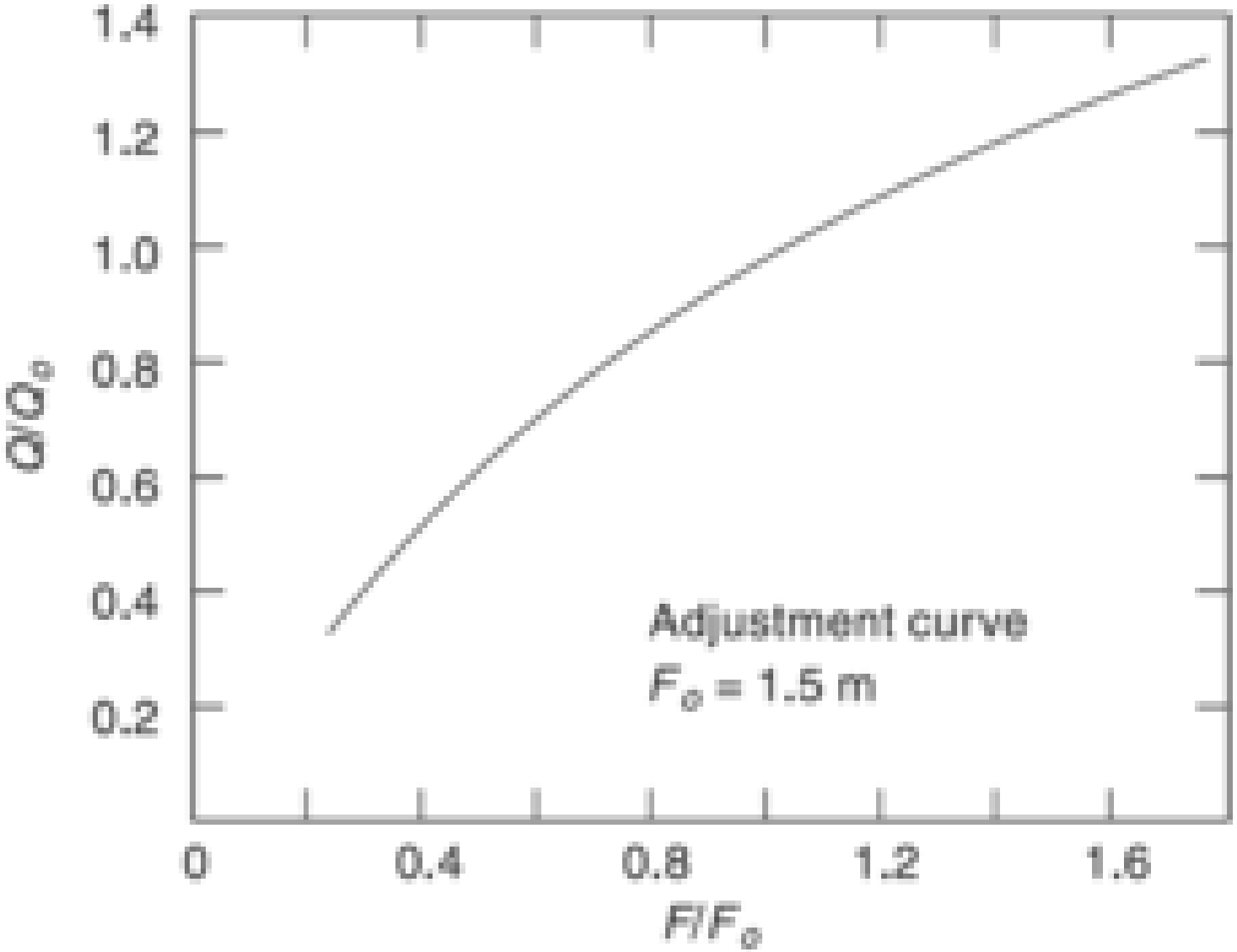

Fig. 4.26 ***Backwater Effect on a Rating Curve—Adjustment Curve***

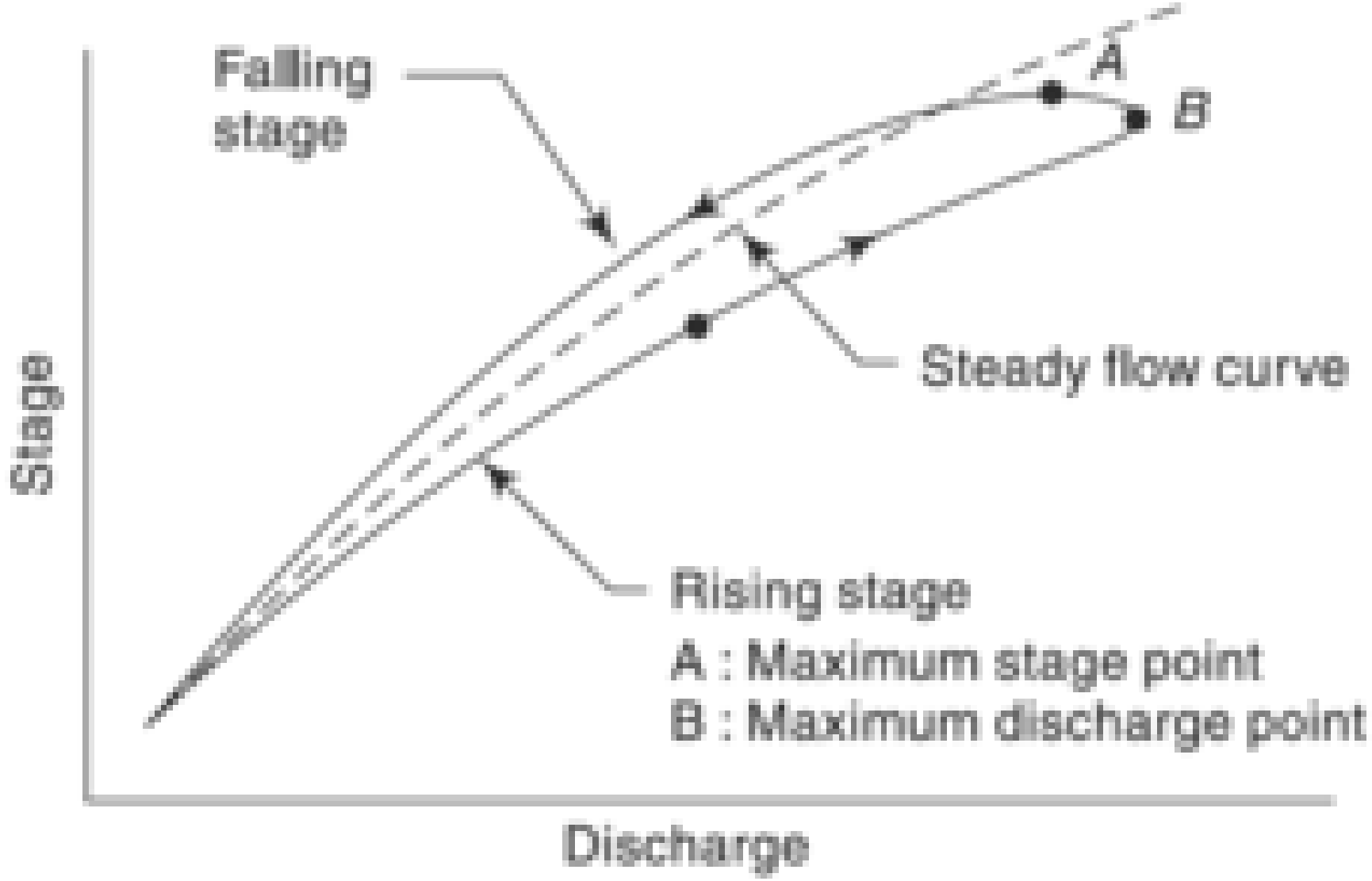

Fig. 4.27 *Loop Rating Curve*

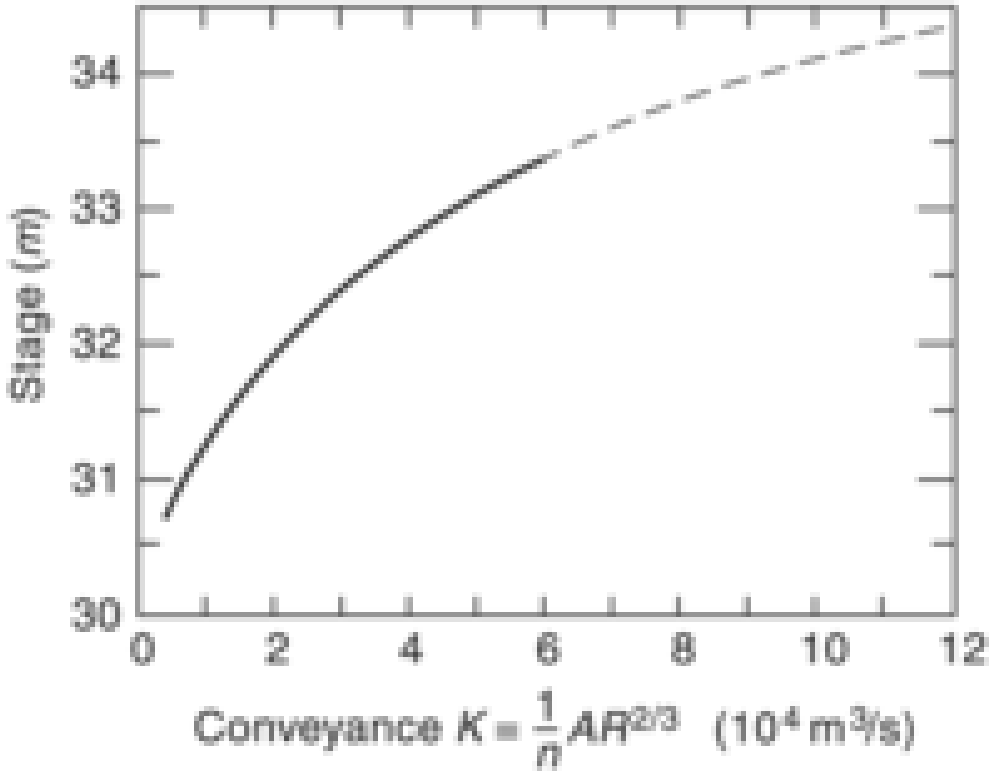

Fig. 4.28(a) *Conveyance Method of Rating Curve Extension: K vs Stage*

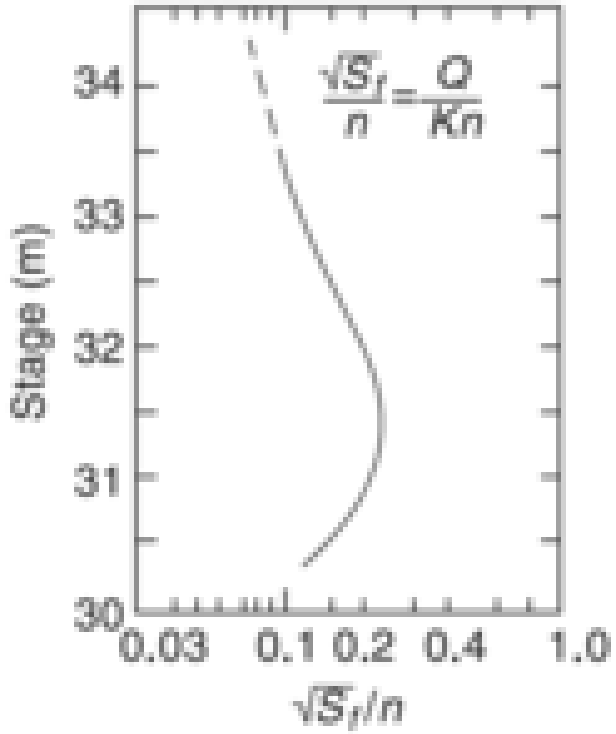

Fig. 4.28(b) *Conveyance Method of Rating Curve Extension: S_f vs Stage*

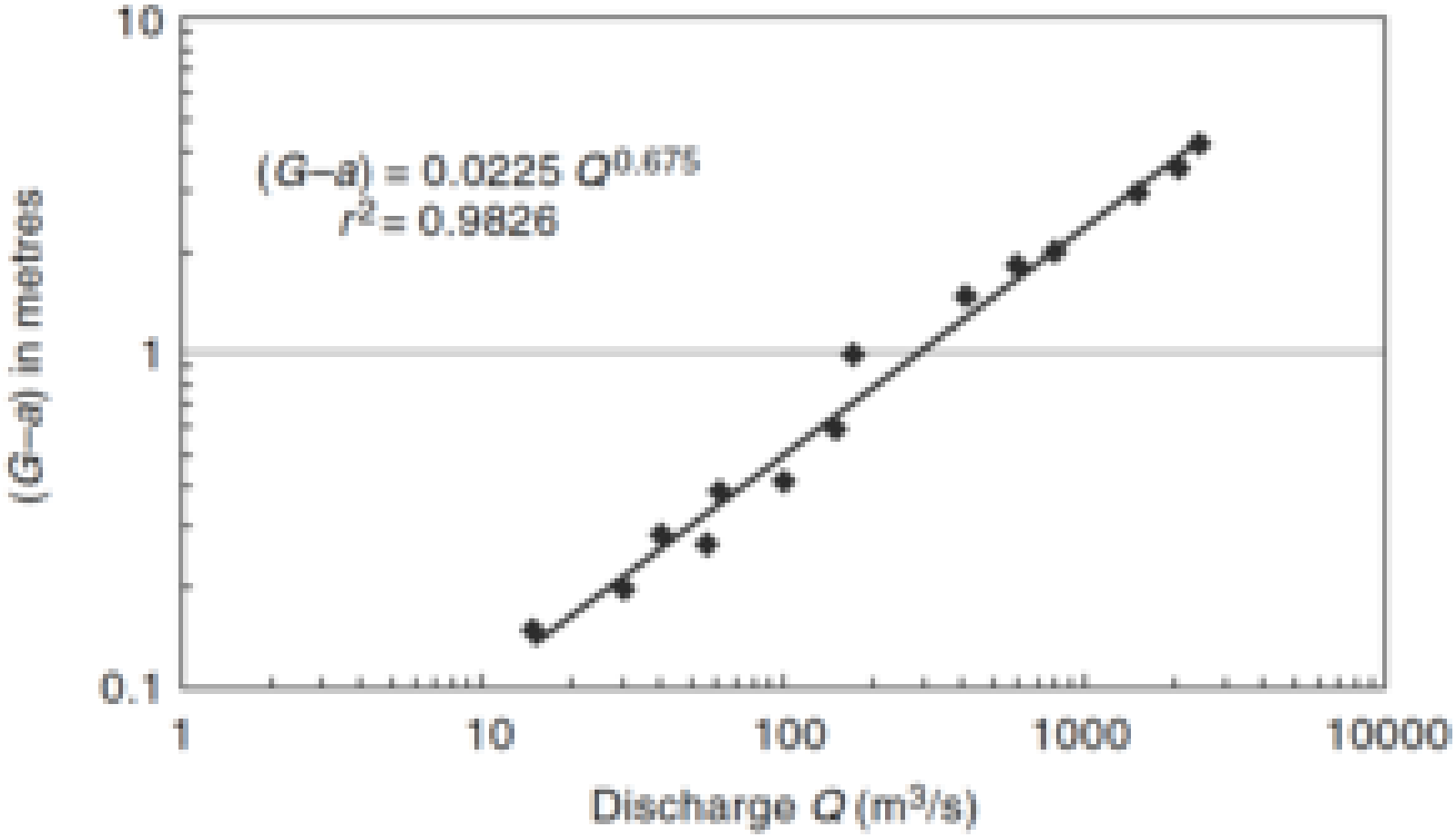

Fig. 4.29(a) *Discharge-stage Relationship: Example 4.7 (Logarithmic Plot)*

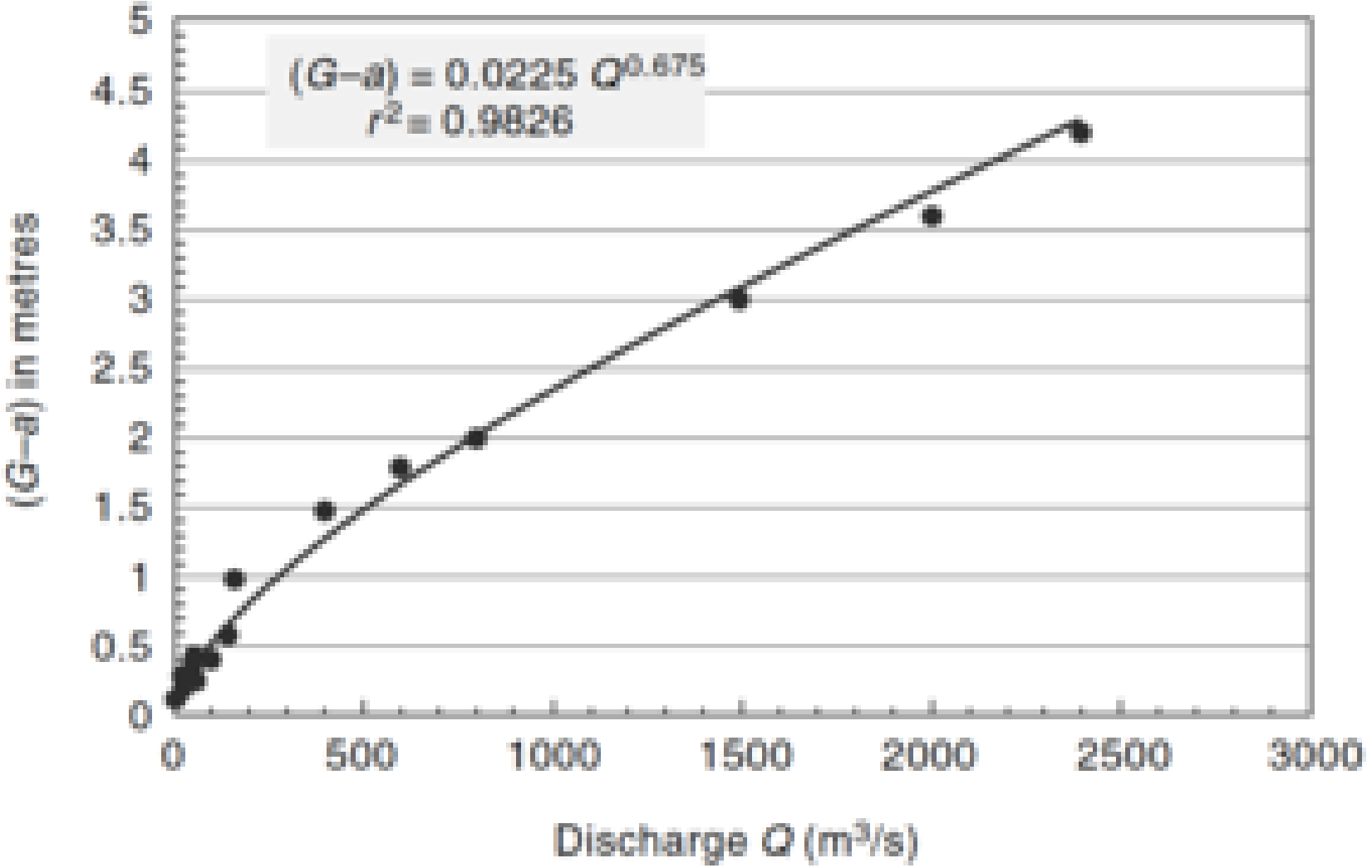

Fig. 4.29(b) ***Discharge-stage Relationship: Example 4.7 (Arithmetic Plot)***

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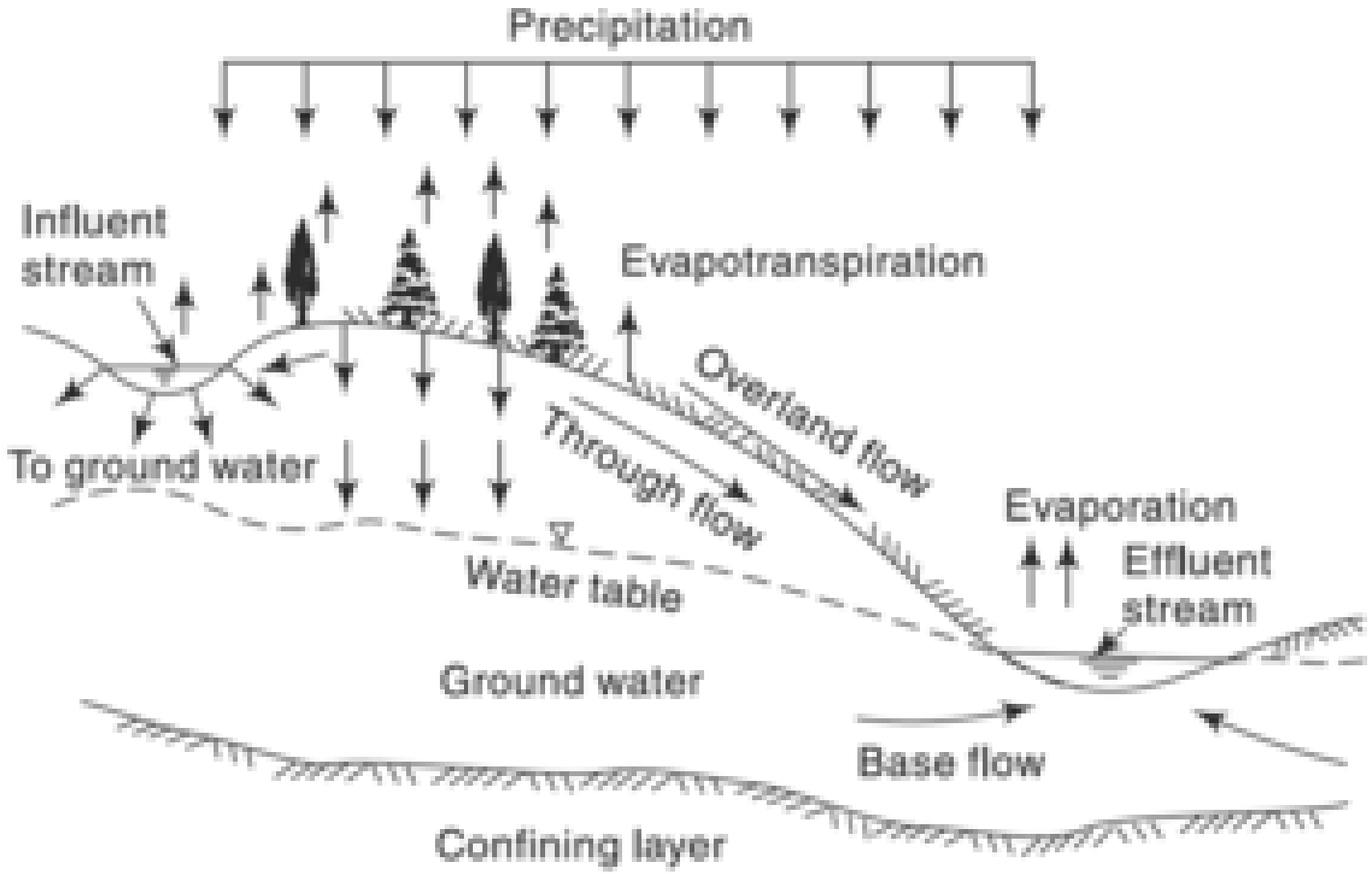

Fig. 5.1 ***Different Routes of Runoff***

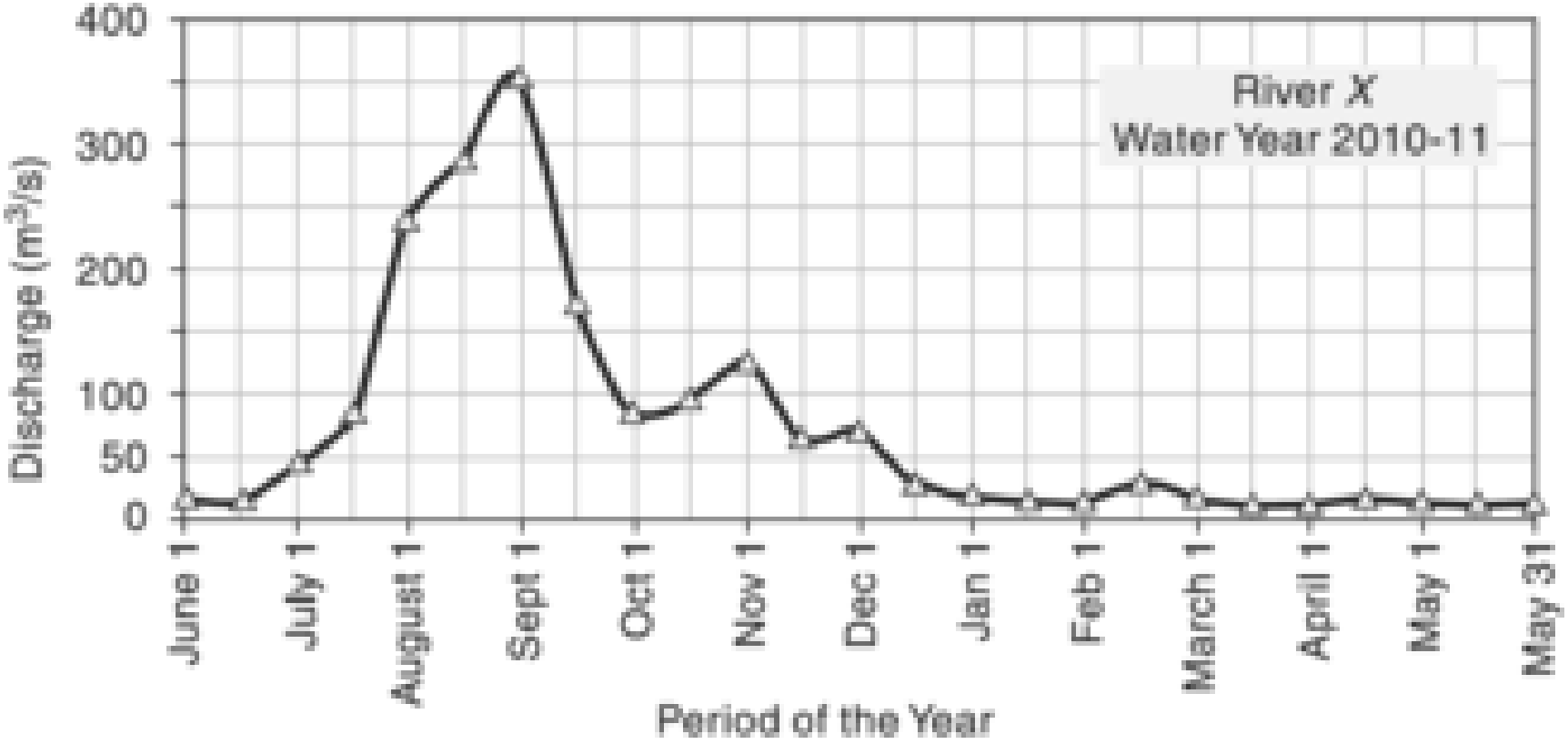

Fig. 5.2 ***Perennial stream***

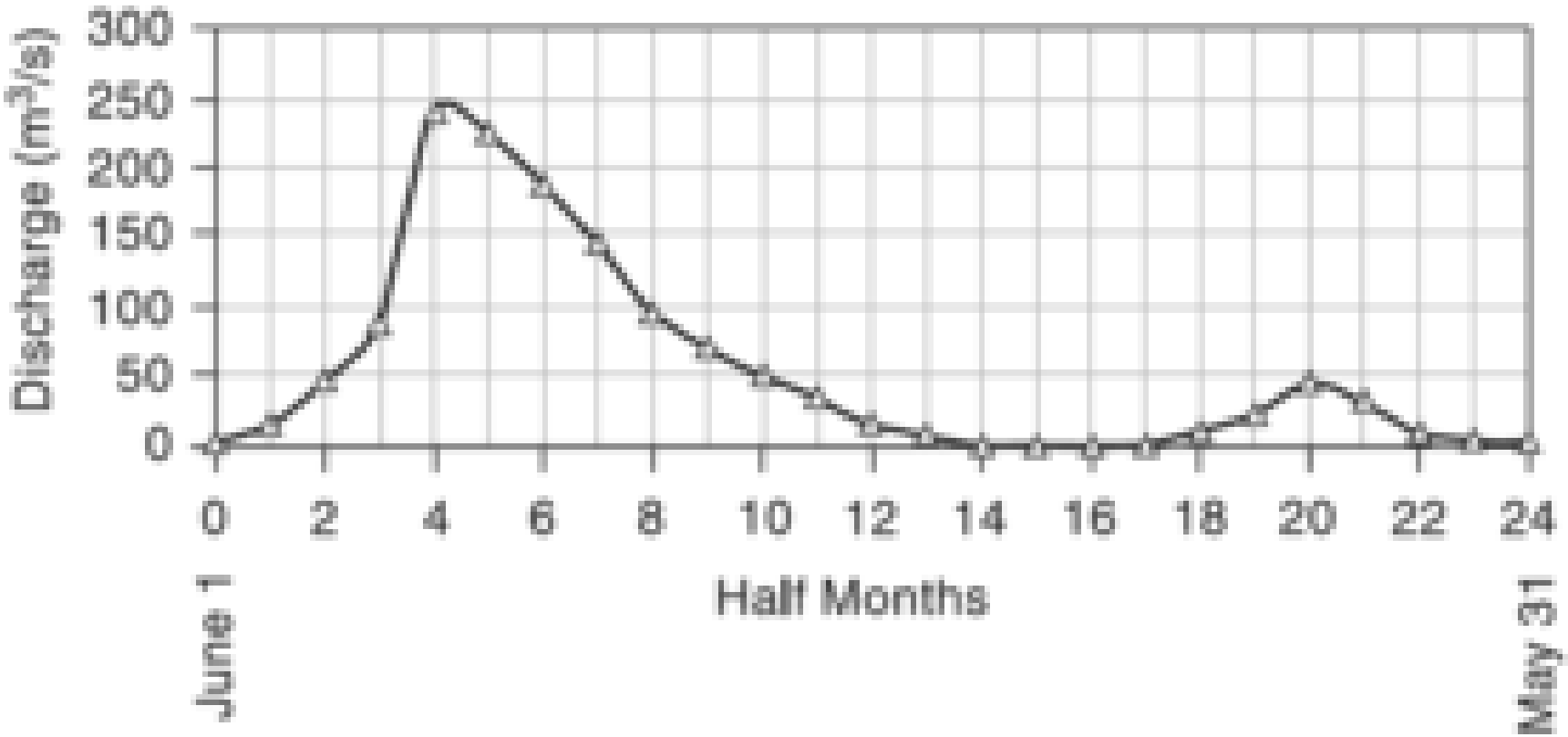

Fig. 5.3 *Intermittent Stream*

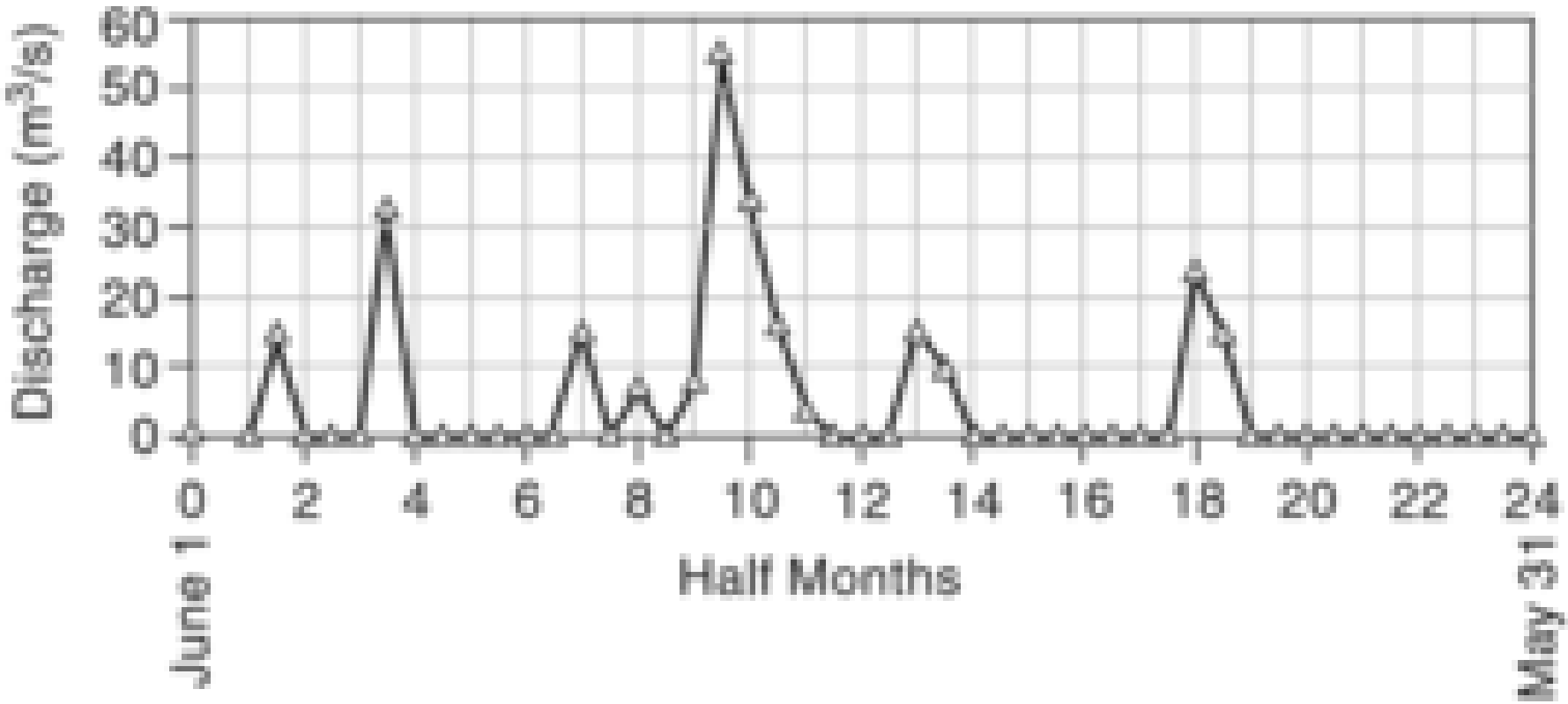

Fig. 5.4 *Ephemeral Stream*

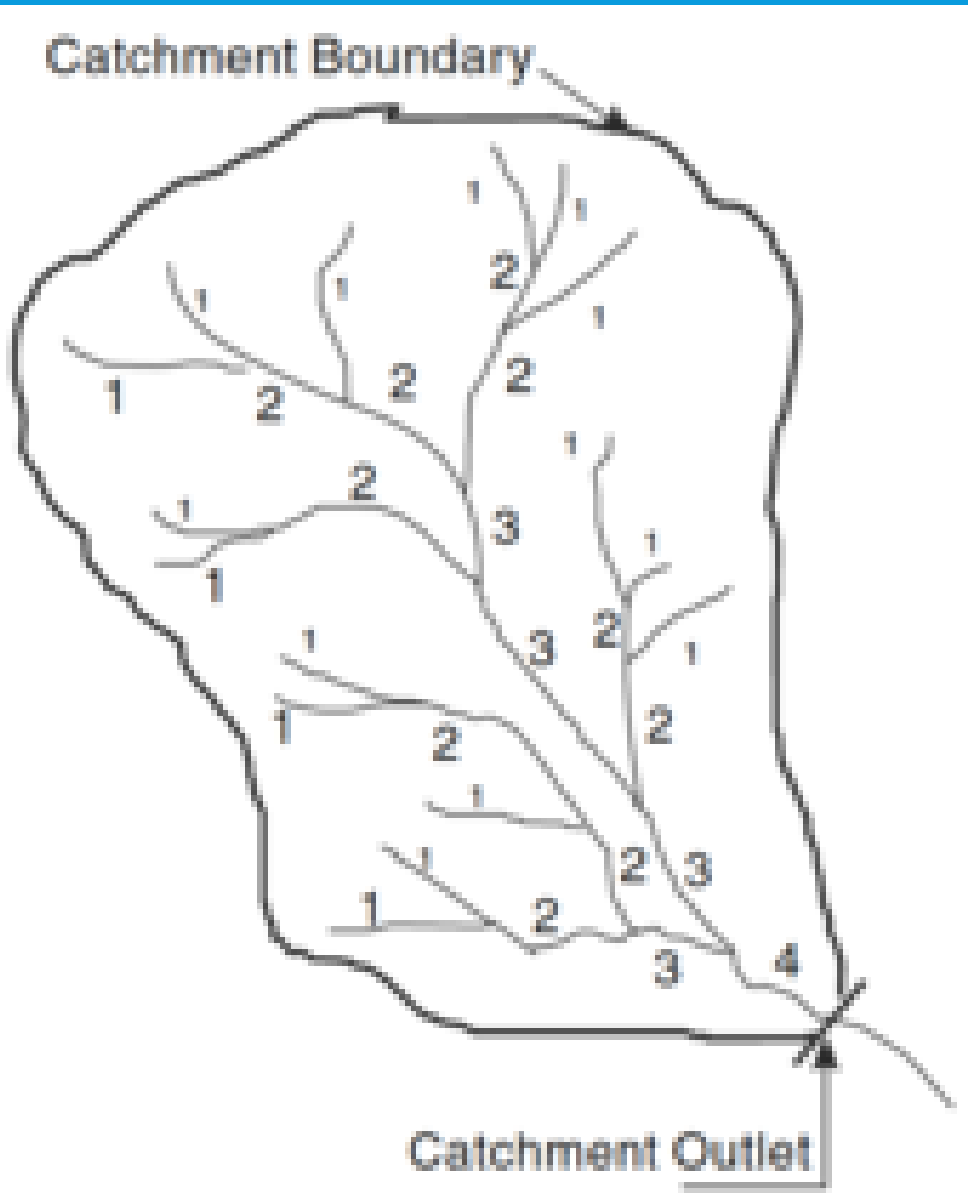

Fig. 5.5 ***Stream Channel Ordering in a Fourth-Order Stream***

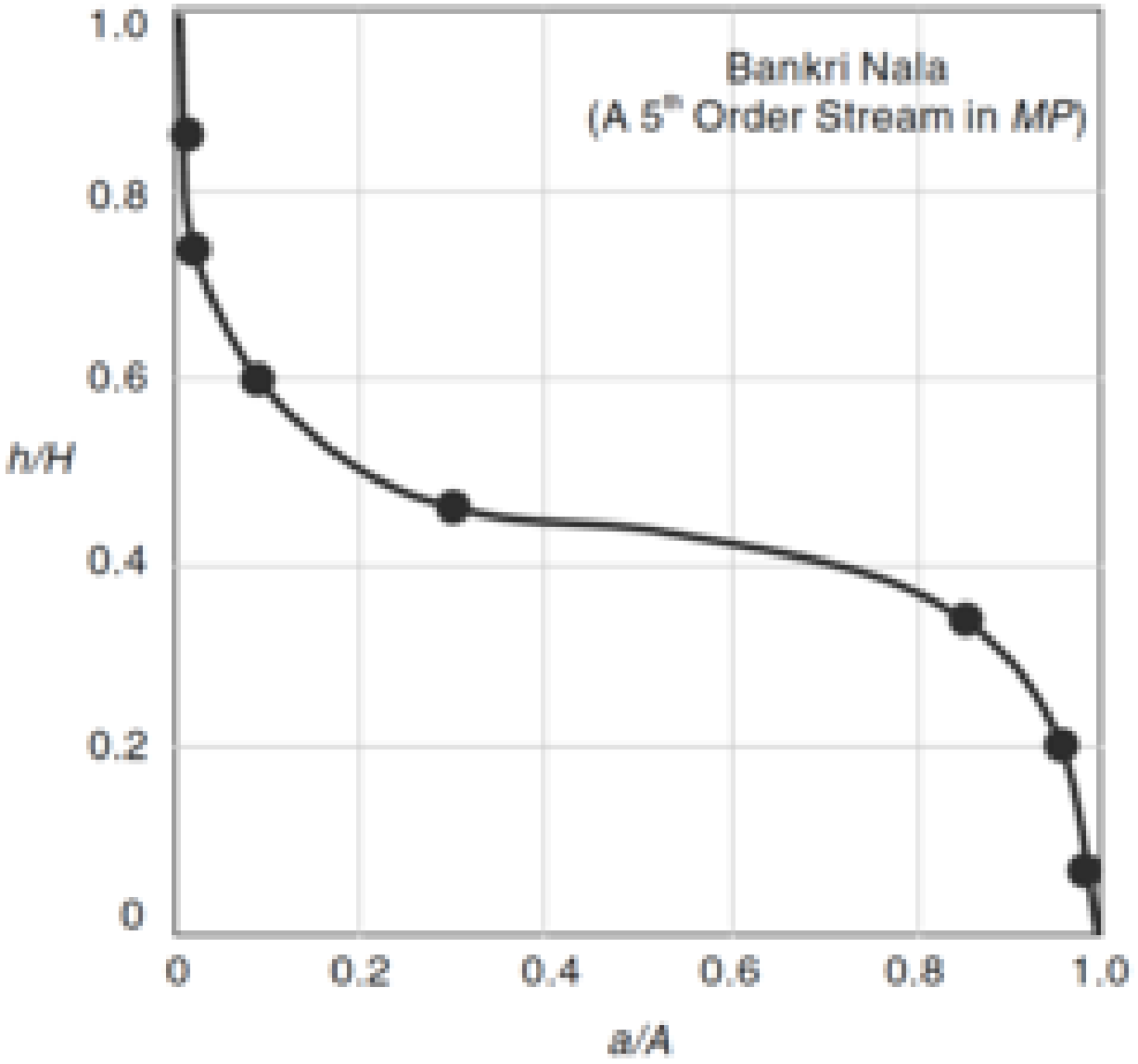

Fig. 5.6 ***Hypsometric curve of a 5th order Stream***

(Ref. INSA, Vol.40A, No.1)

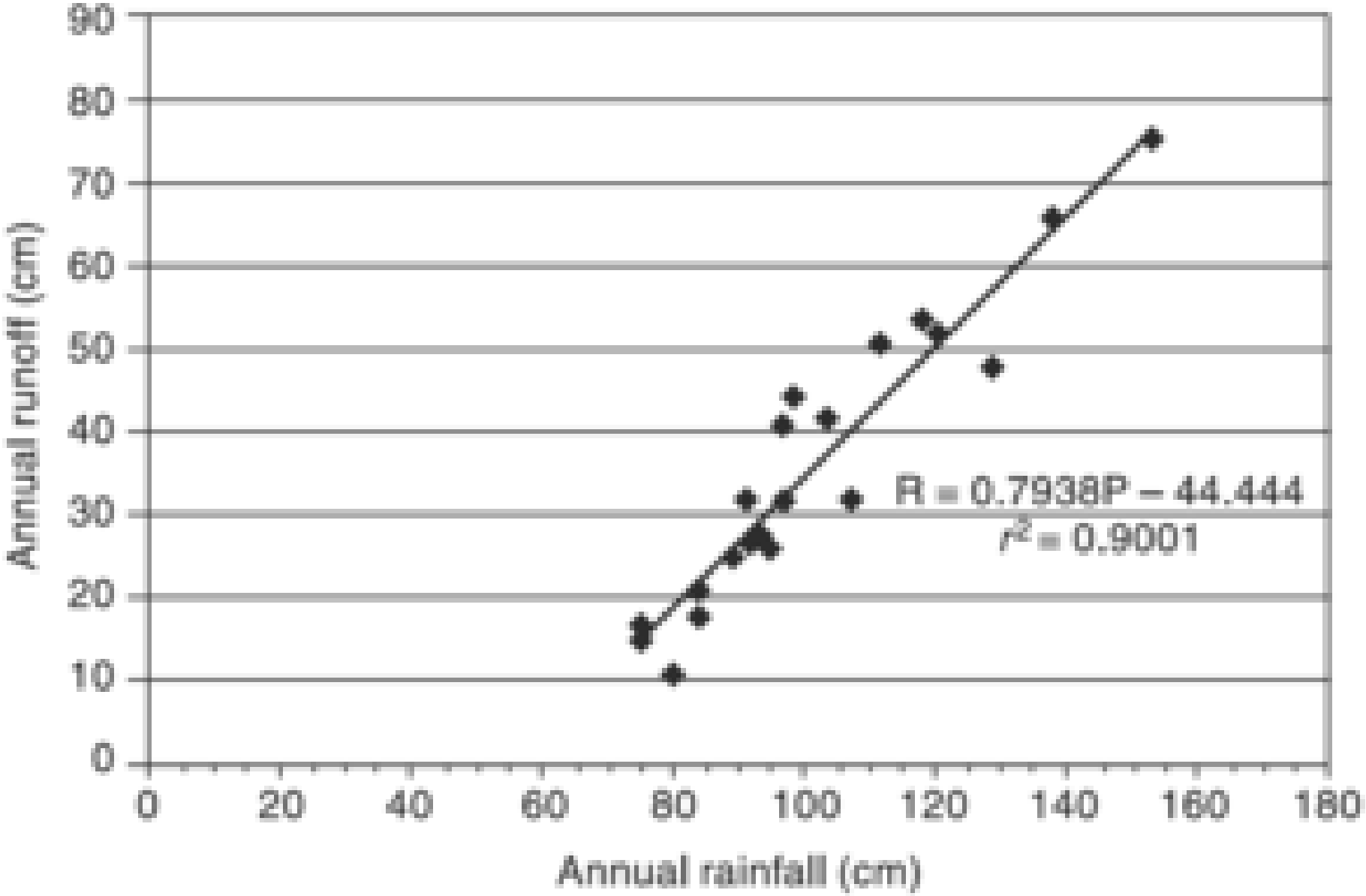

Fig. 5.7 *Annual Rainfall–Runoff Correlation—Example 5.2*

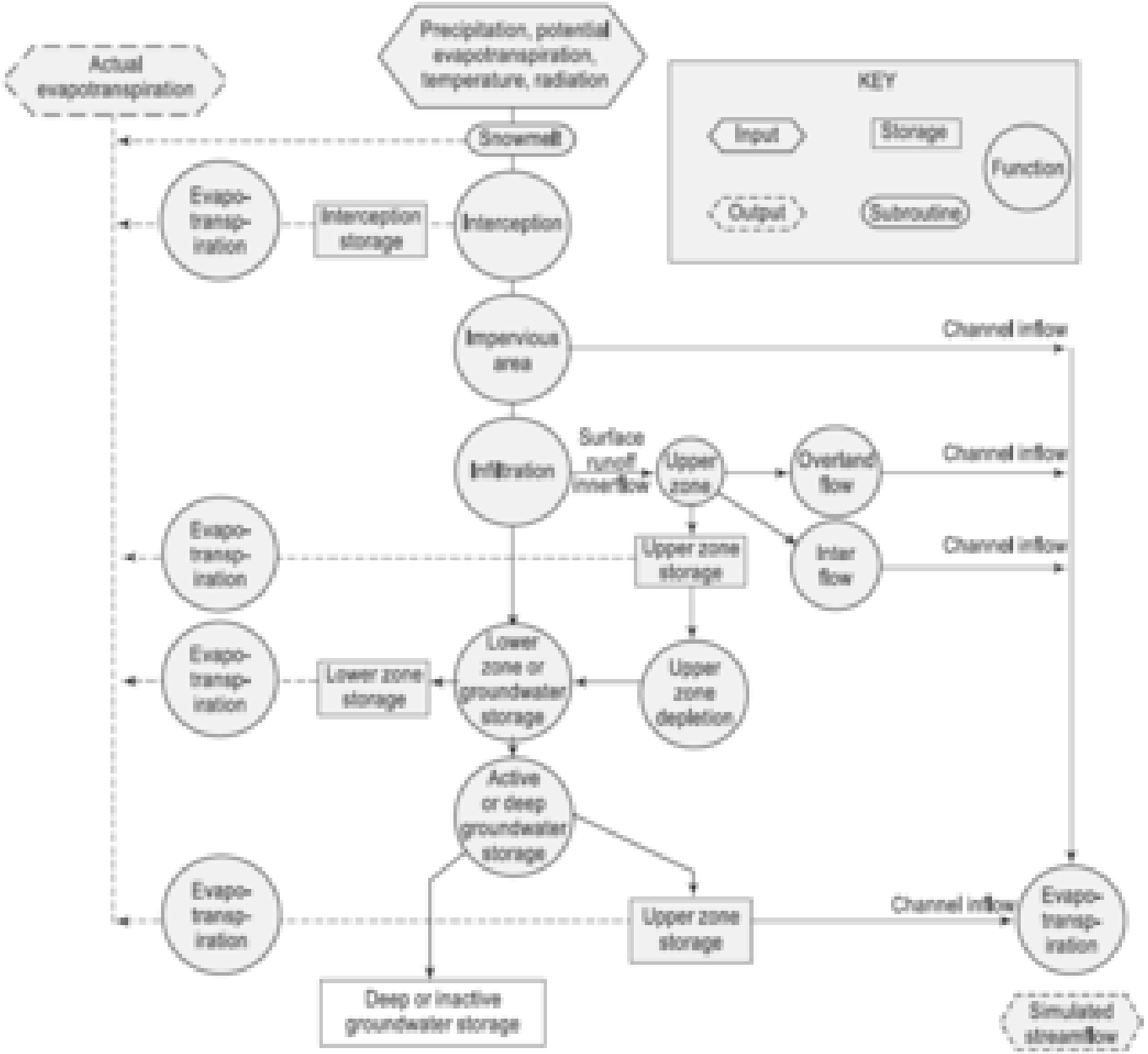

Fig. 5.8 *Flow chart of SWM-IV*

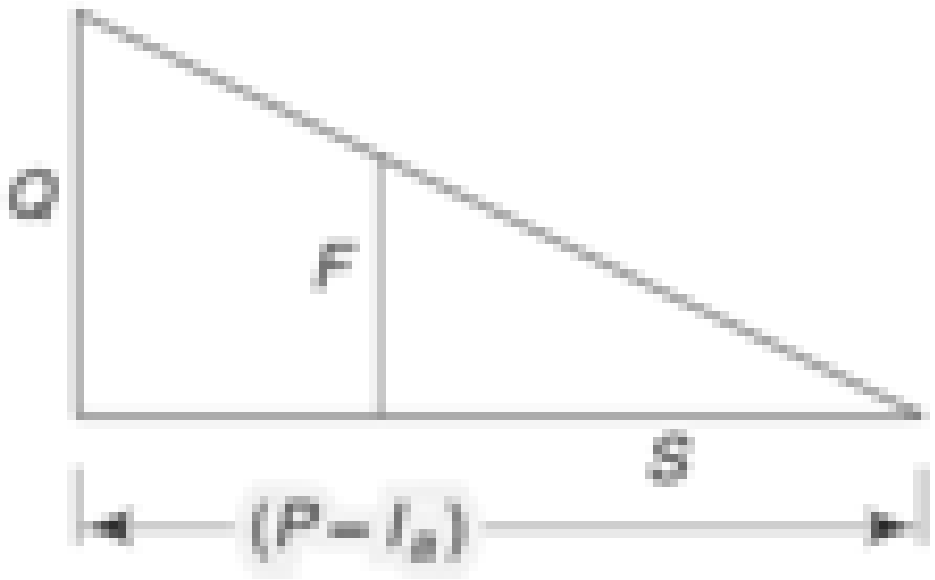

Fig. 5.9 *Proportionality concept*

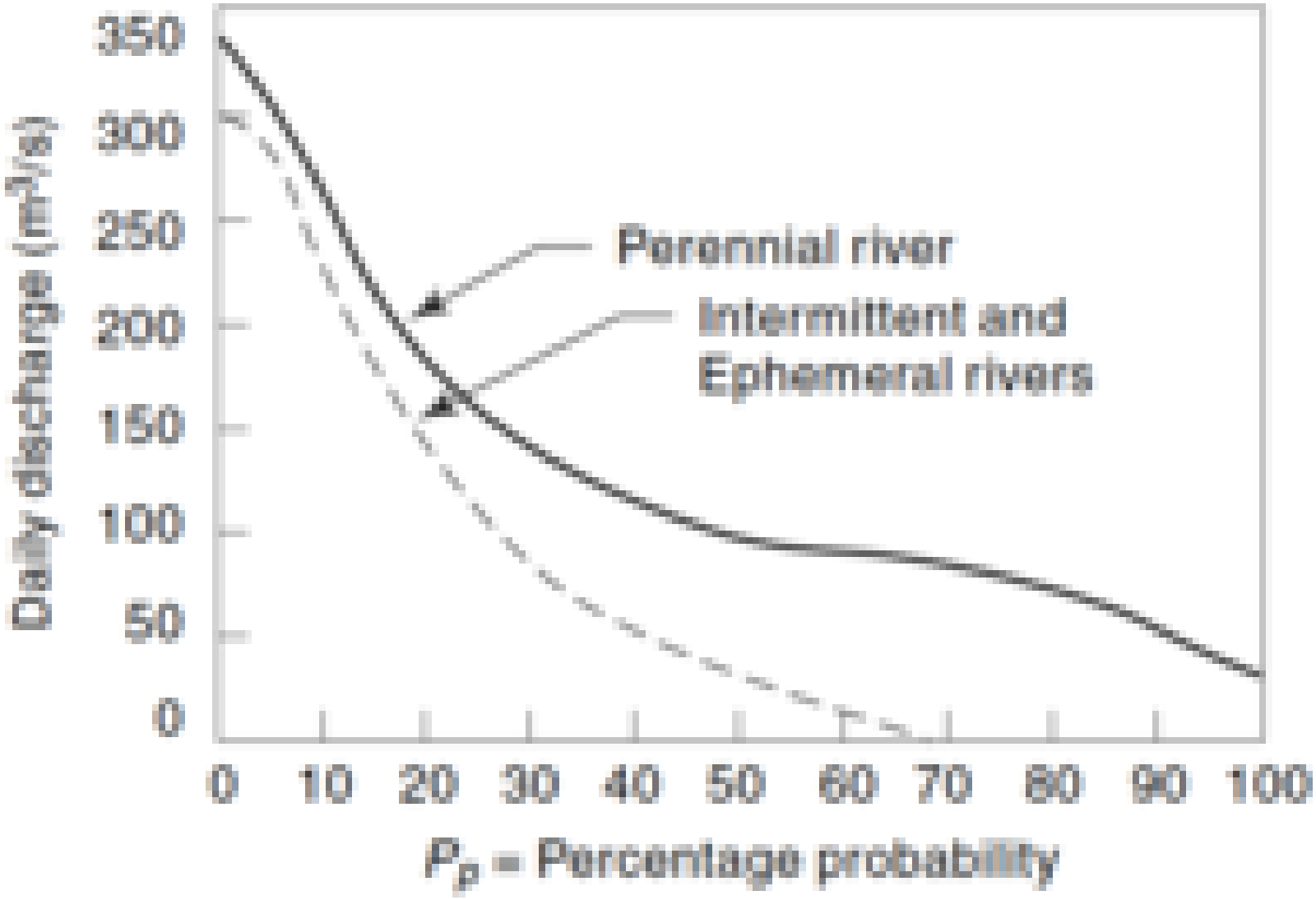

Fig. 5.10 *Flow Duration Curve*

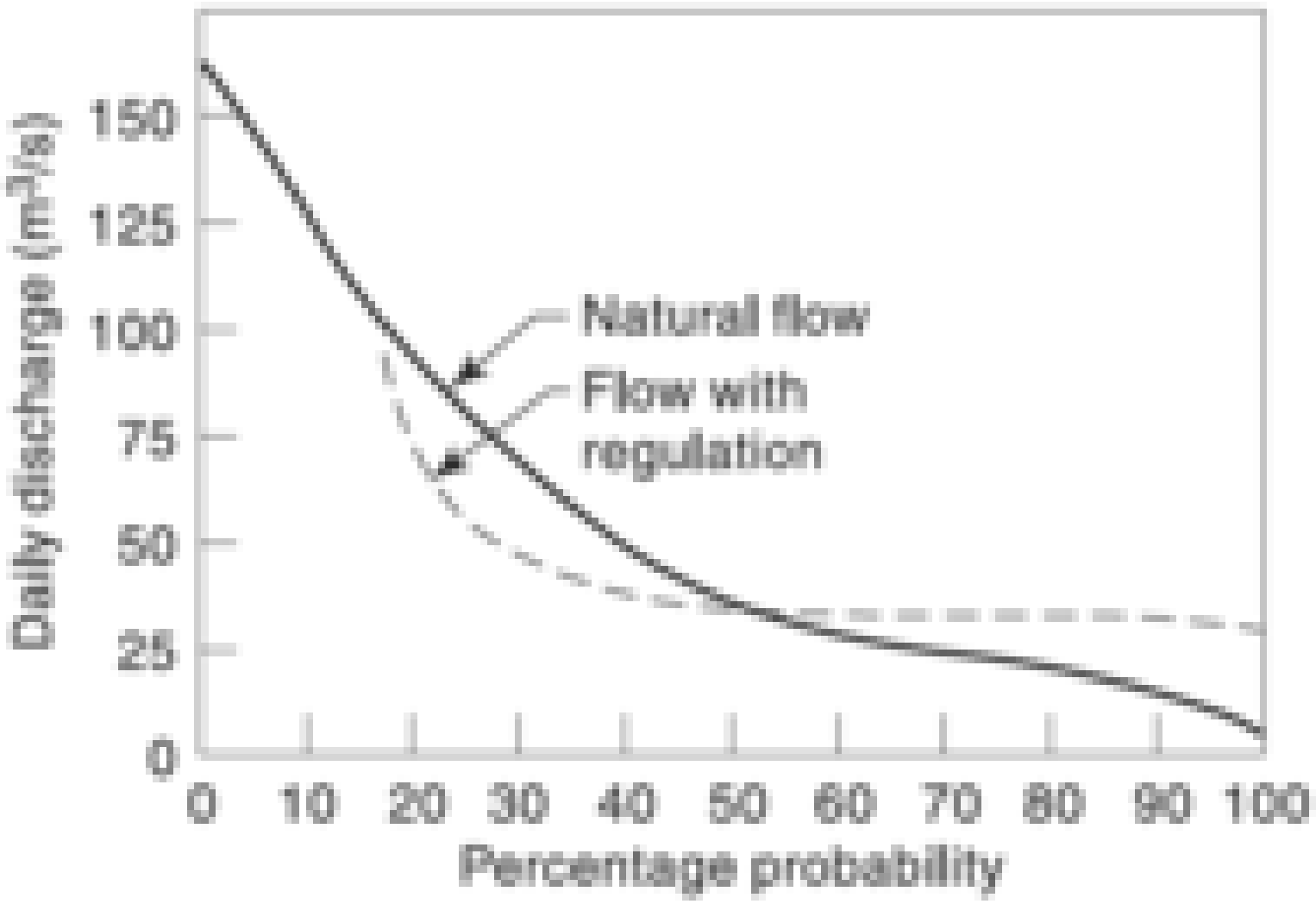

Fig. 5.11 ***Reservoir Regulation Effect***

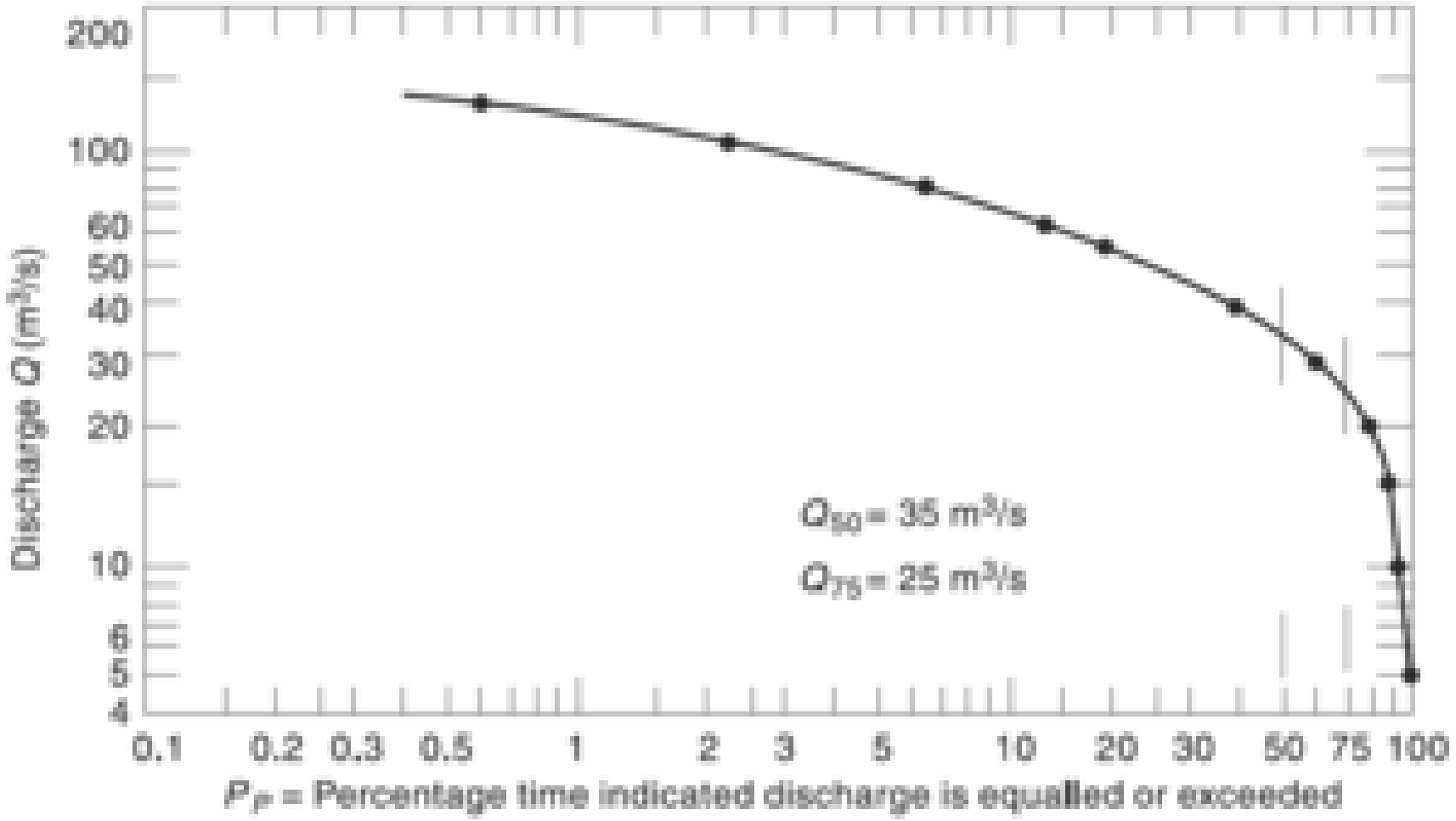

Fig. 5.12 *Flow-Duration Curve—Example 5.8*

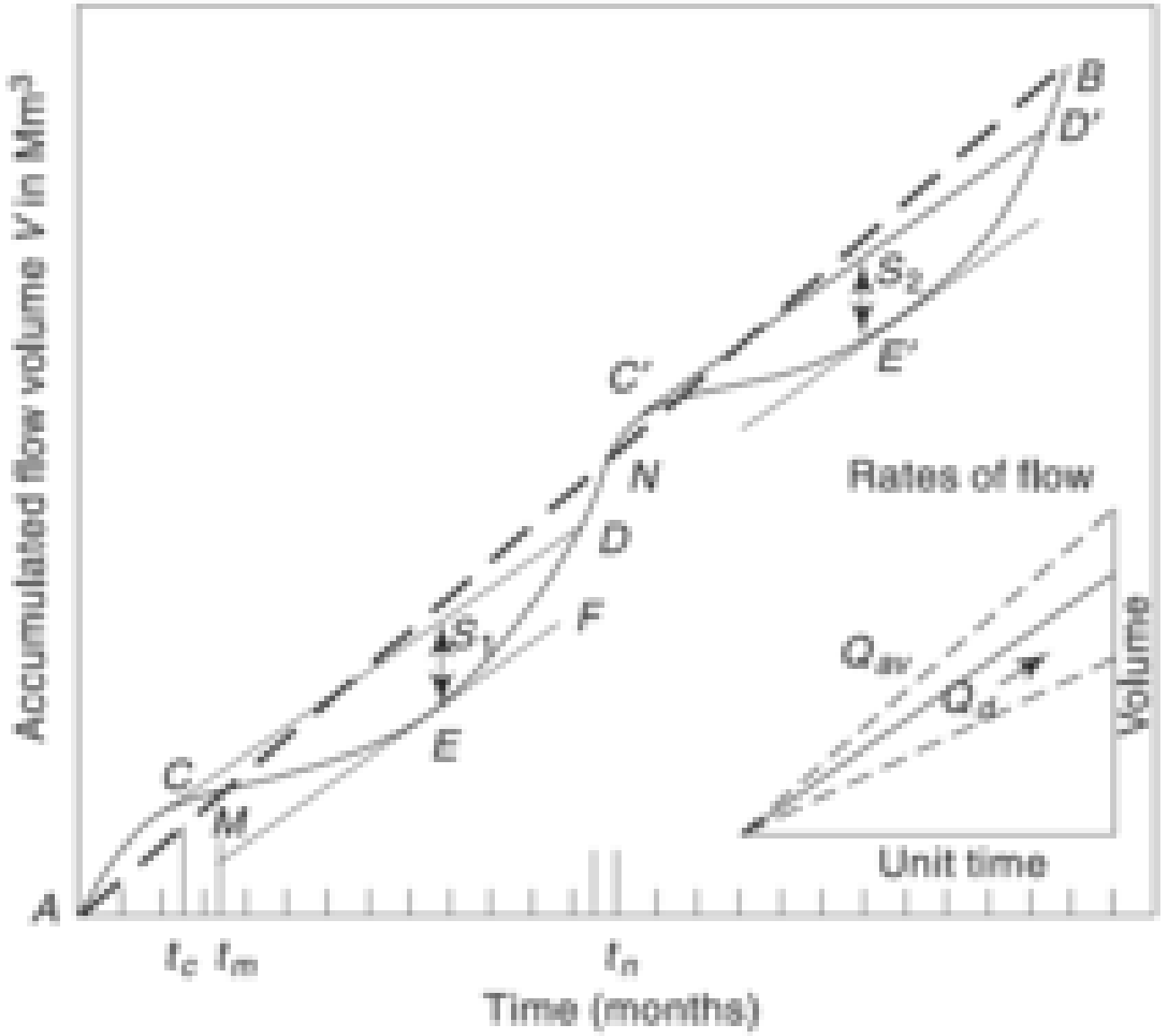

Fig. 5.13 *Flow–Mass Curve*

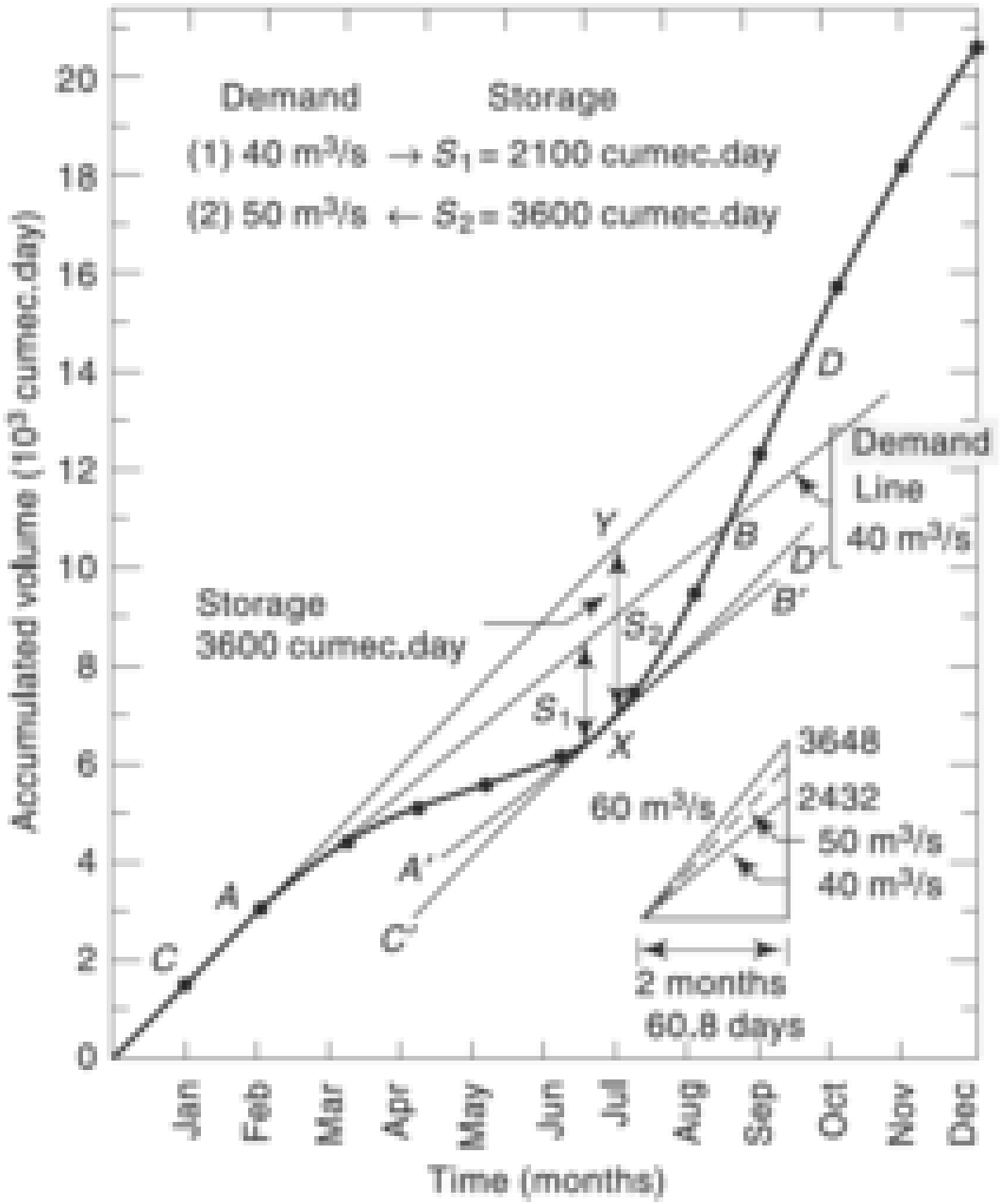

Fig. 5.14 *Flow-Mass Curve—Example 5.9*

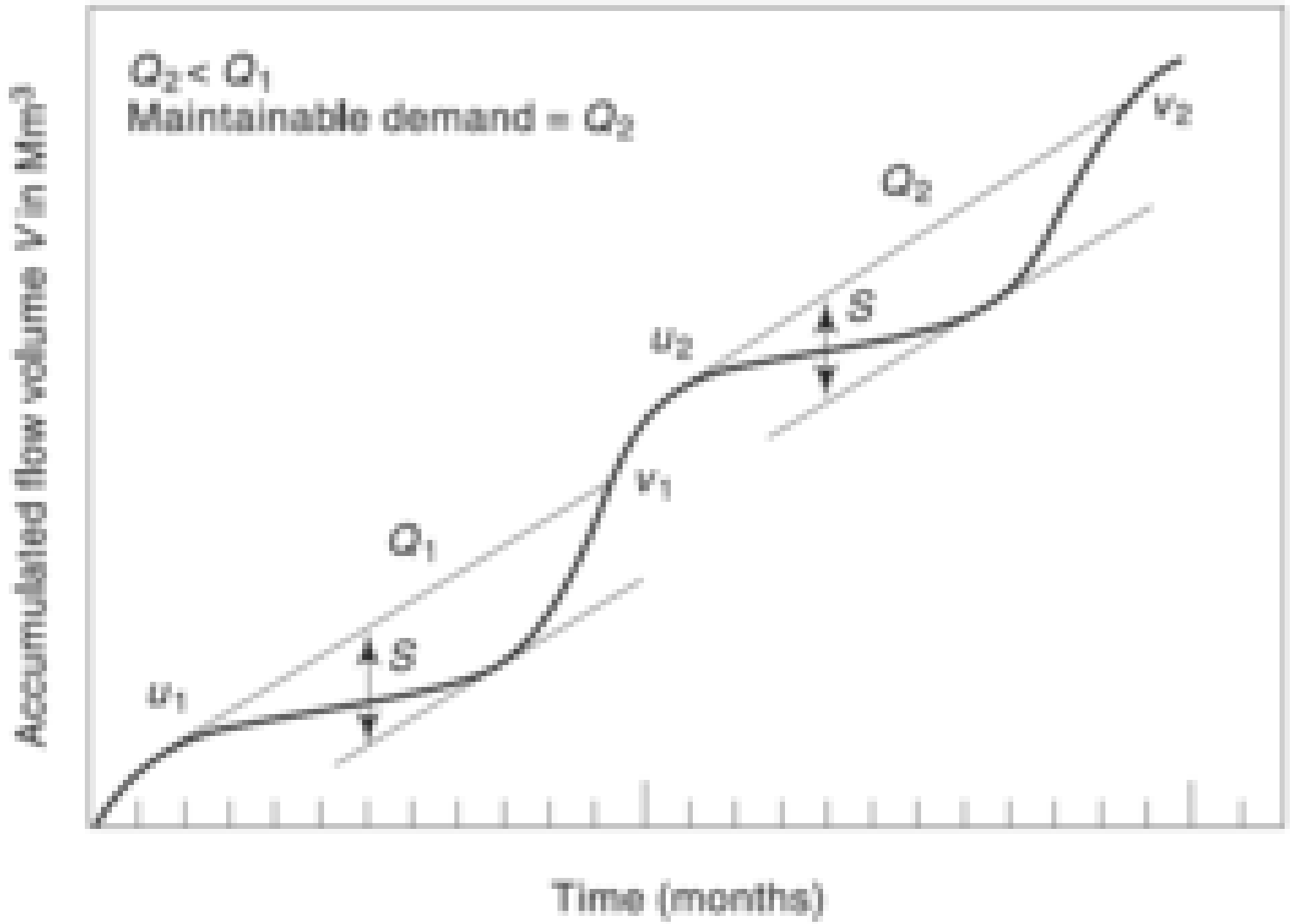

Fig. 5.15 *Determination of Maintainable Demand*

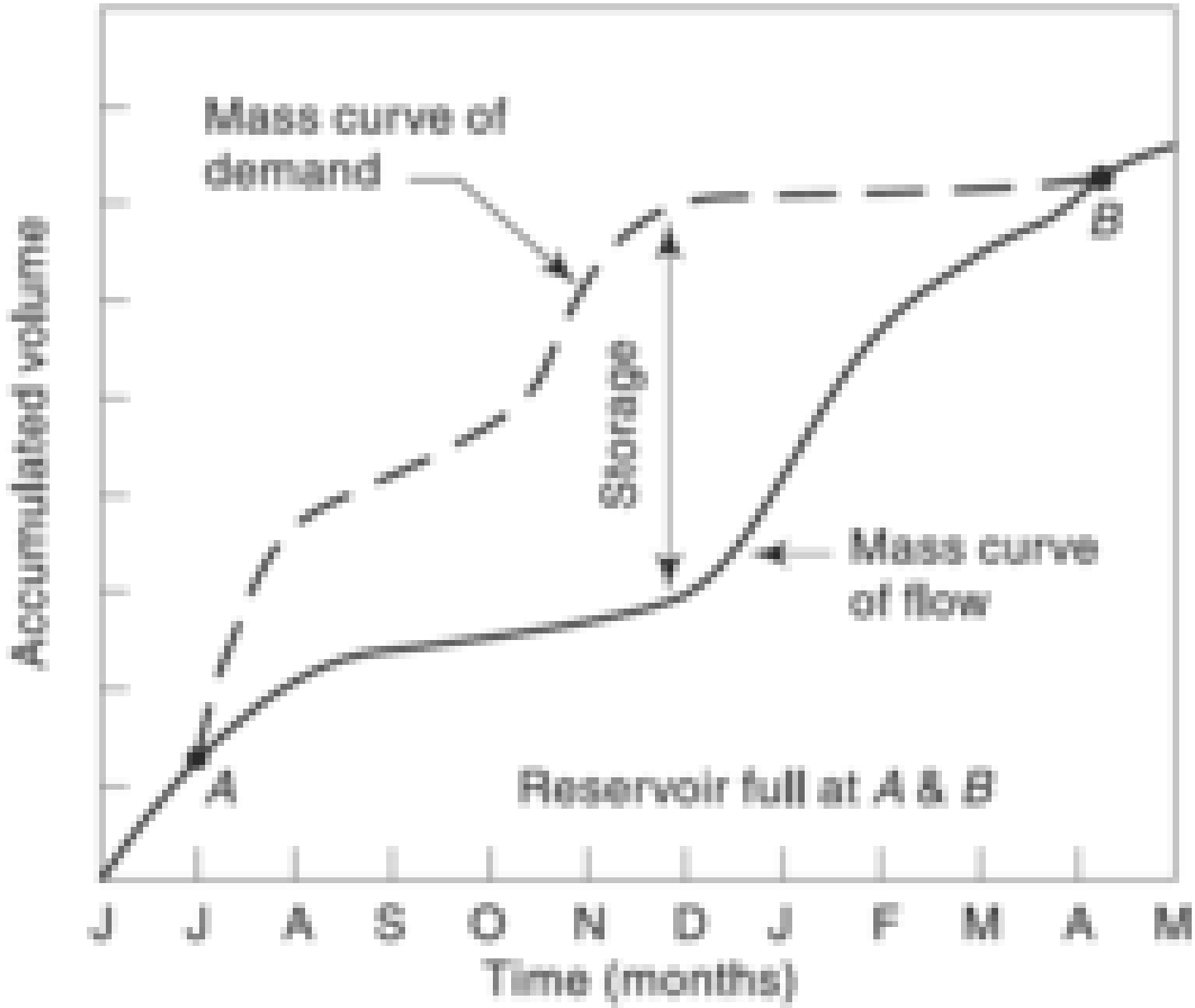

Fig. 5.16 *Variable Use Line*

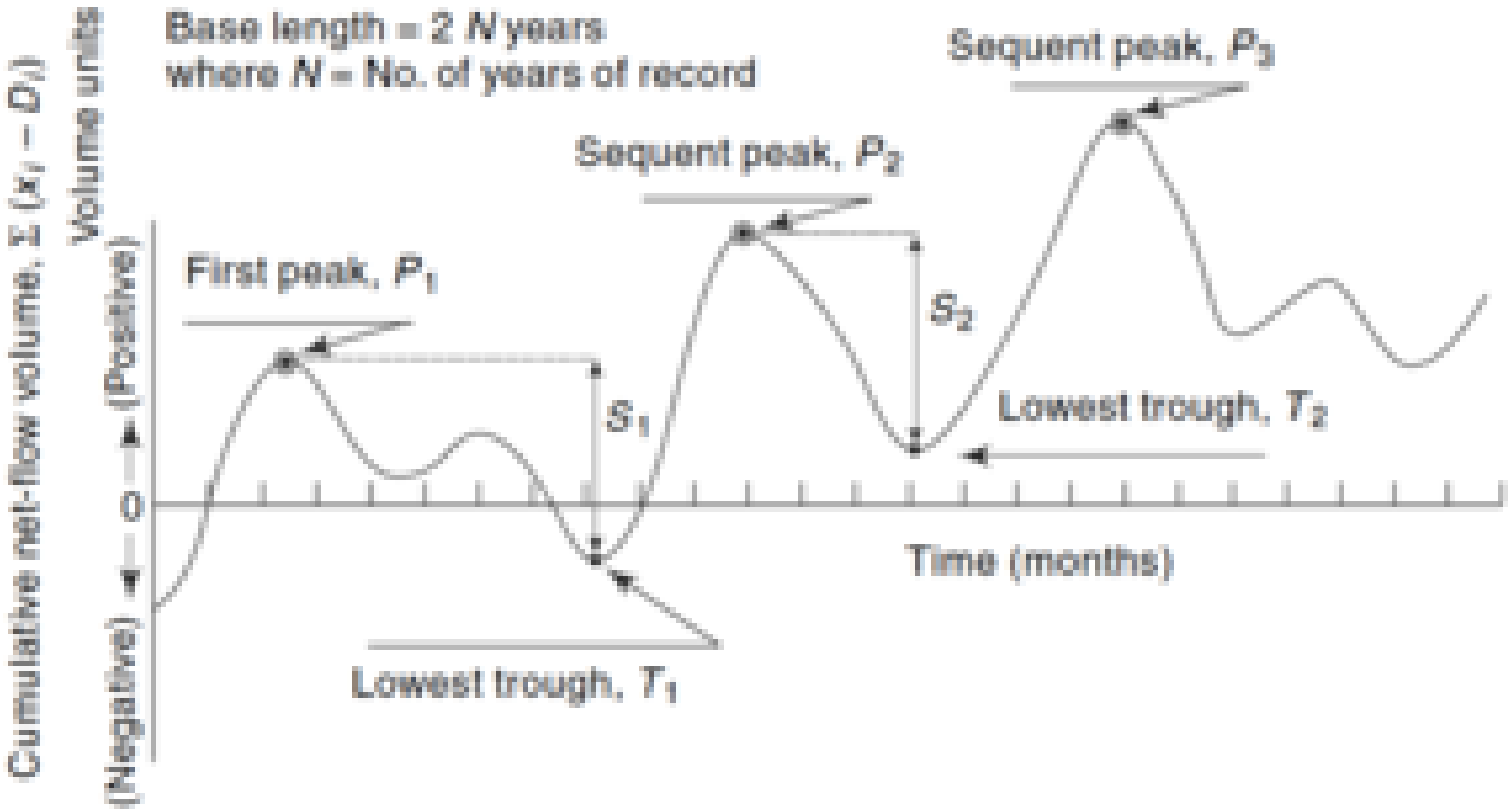

Fig. 5.17 *Residual Mass Curve—Definition Sketch for Sequent Peak Algorithm*

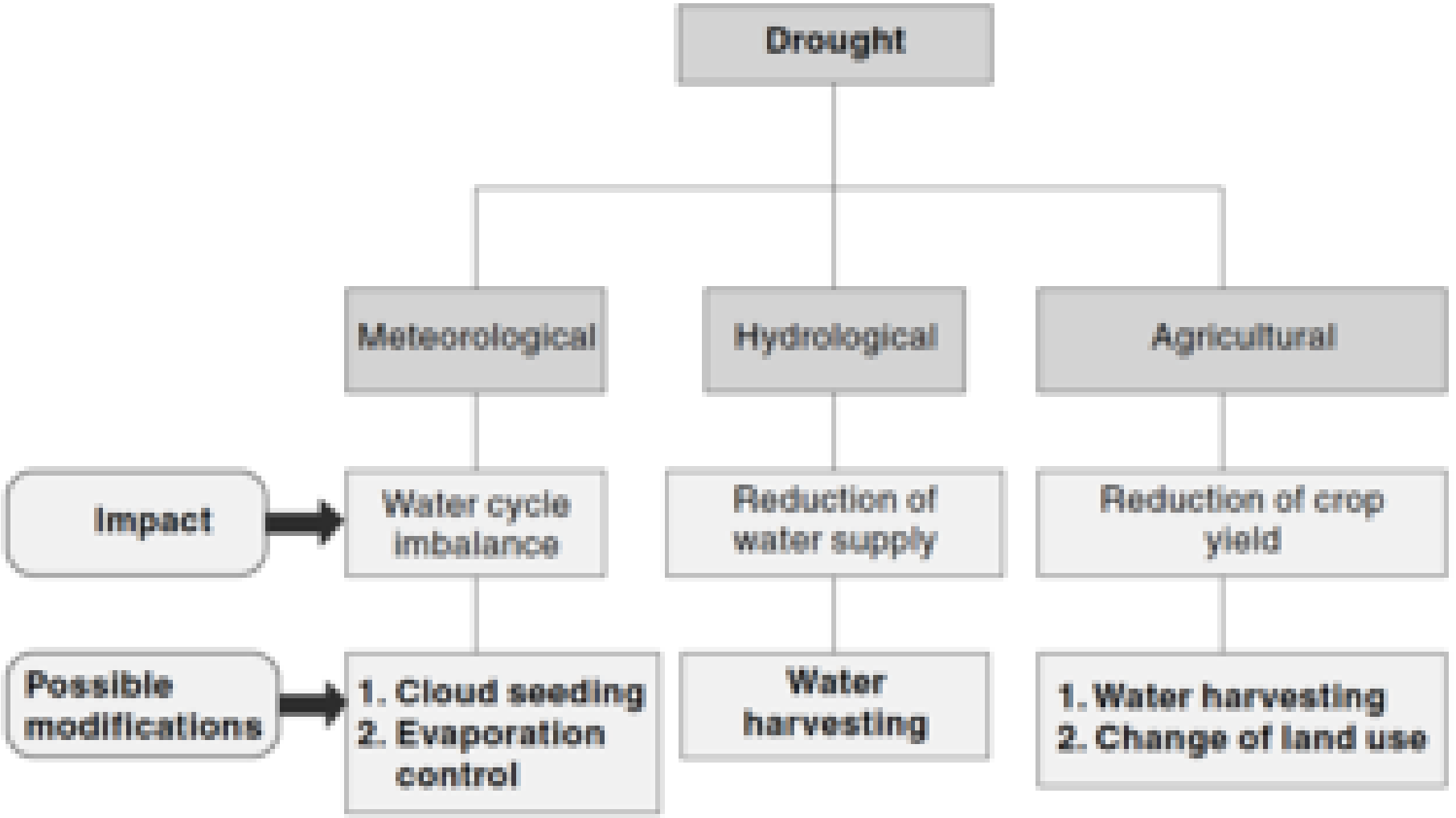

Fig. 5.18 *Impact and Possible Modification of Drought Components*

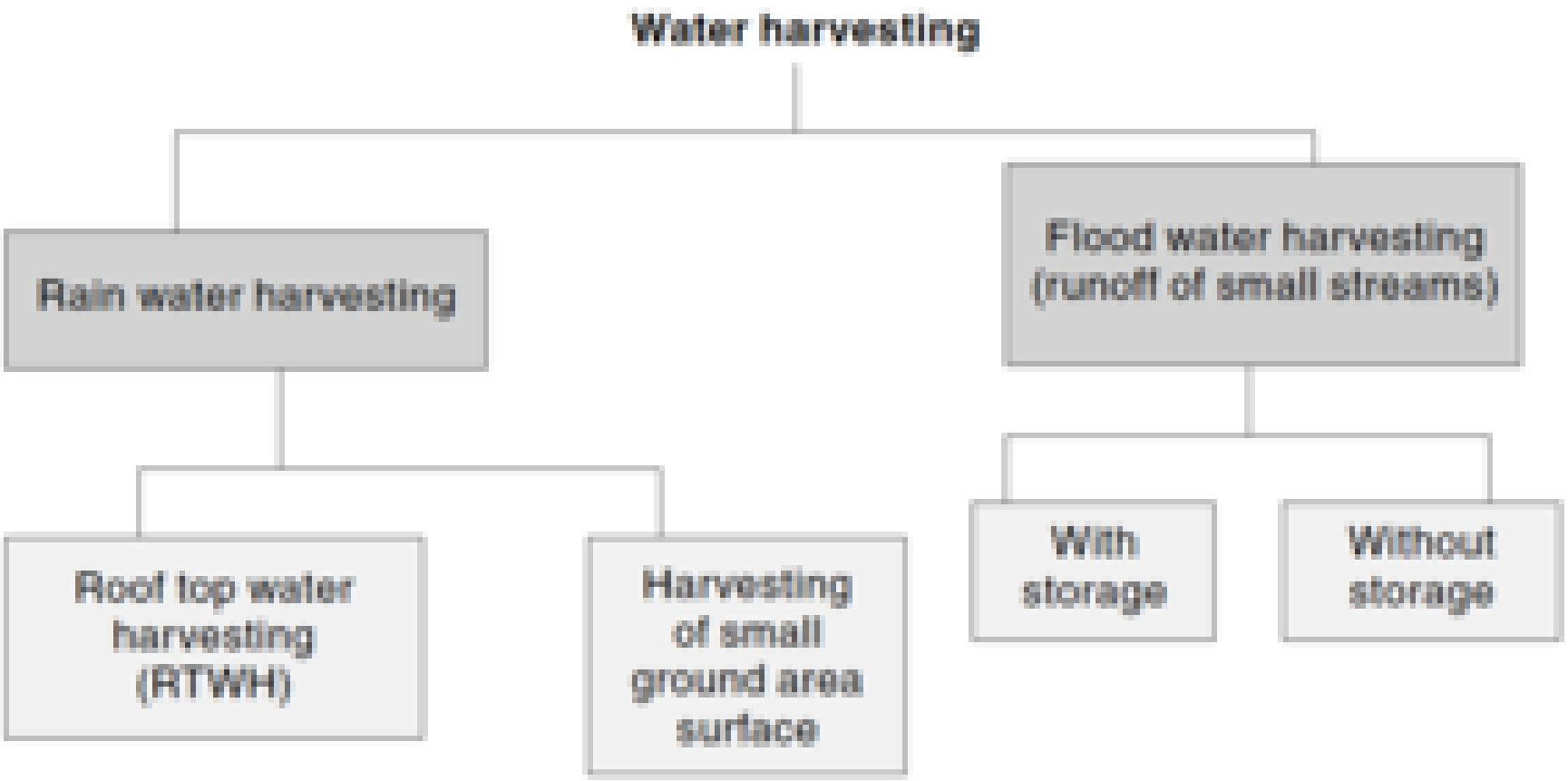

Fig. 5.19 *Classification of Water Harvesting Techniques*

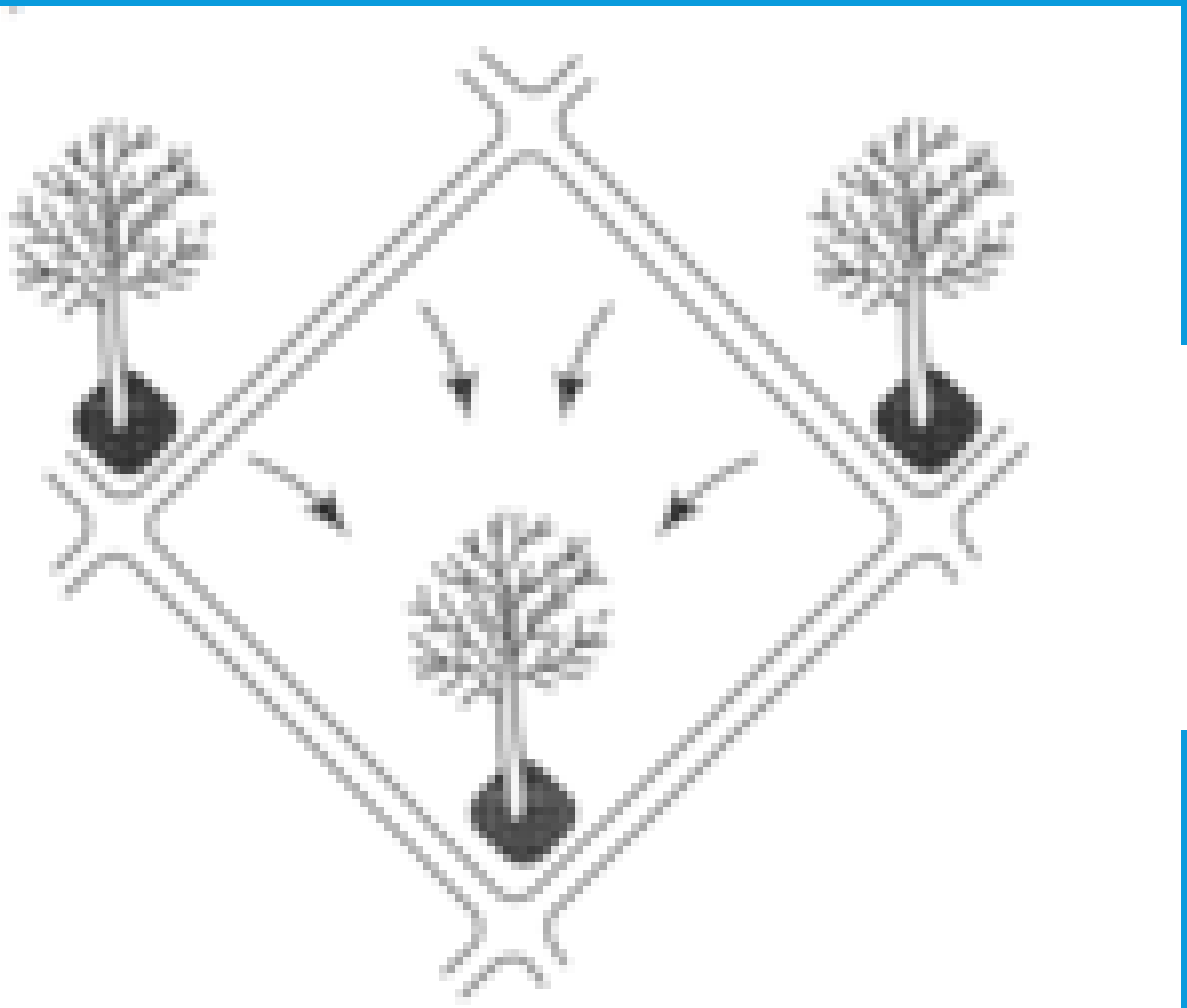

Fig. 5.20 *Micro Catchment System: Negarim Micro Catchment for Trees*

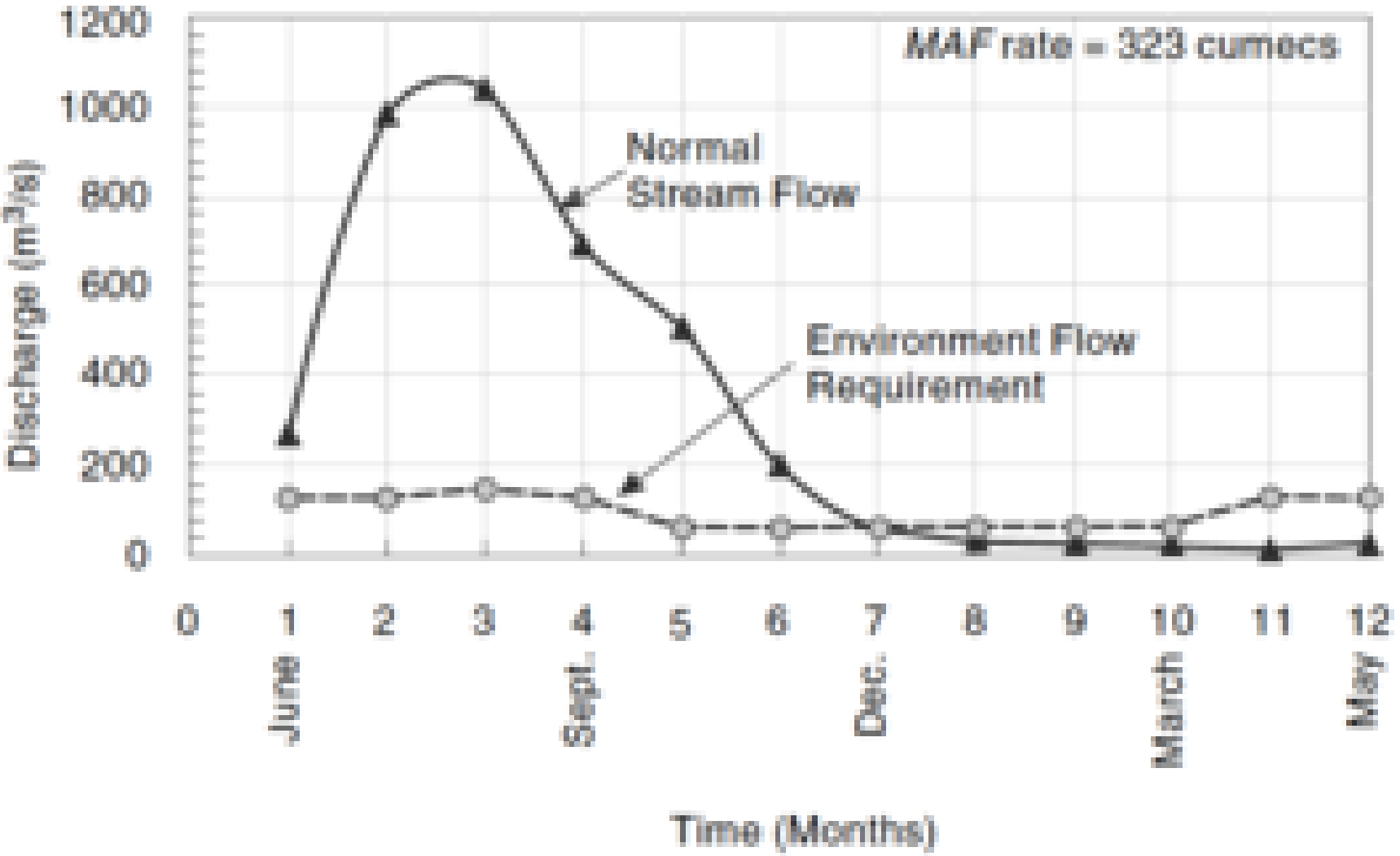

Fig. 5-21 *Hydrographs of Normal Stream Flow and EFR – Example 5.14*

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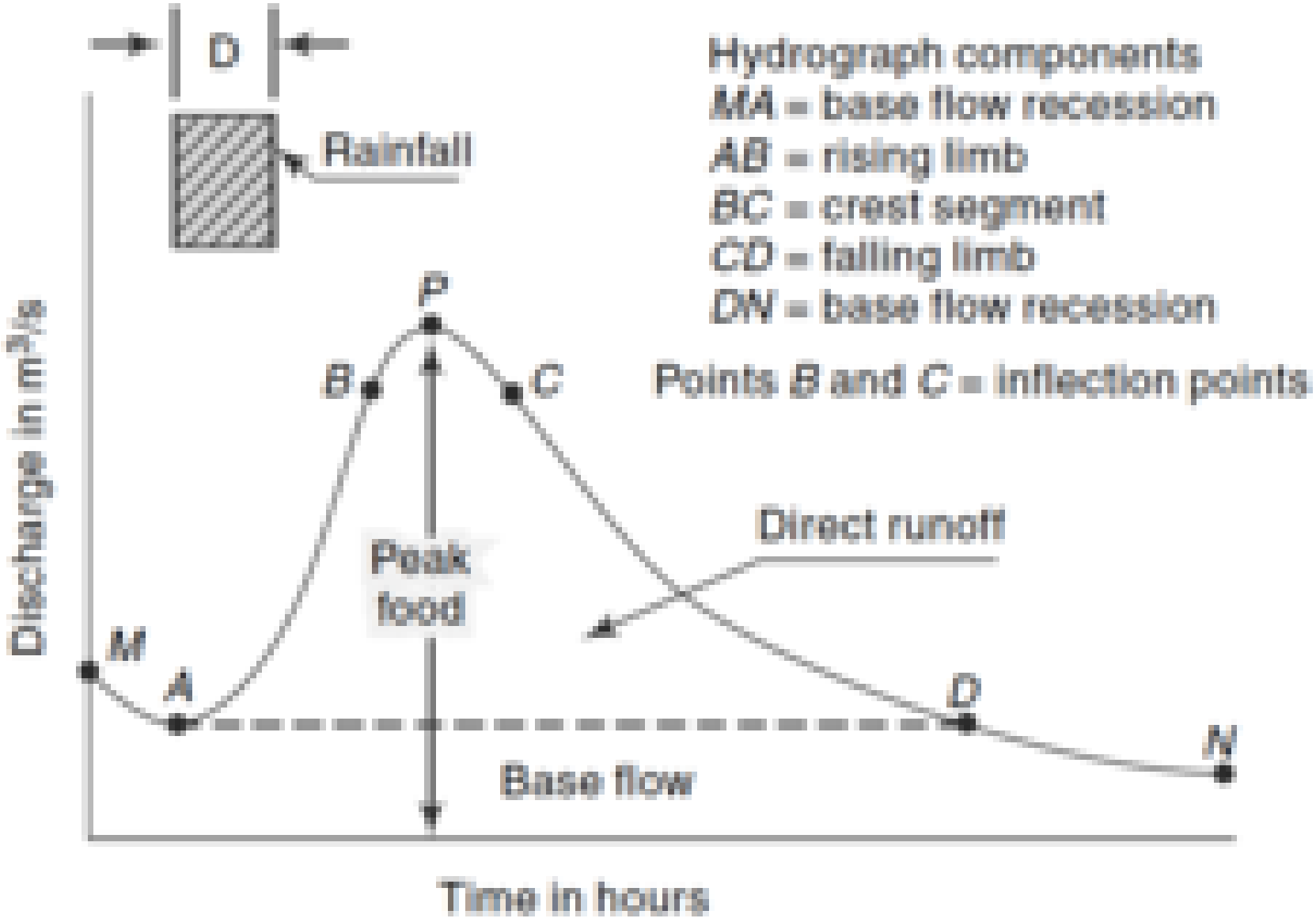


Fig. 6.1 *Elements of a Flood Hydrograph*

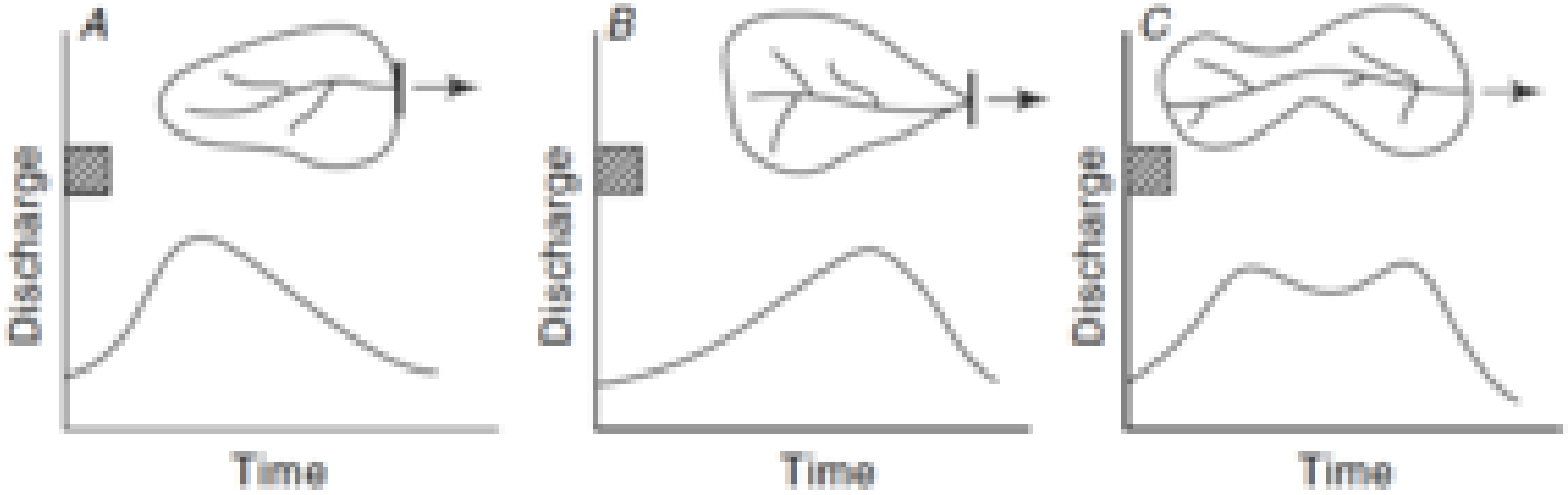


Fig. 6.2(a) ***Effect of Catchment Shape on the Hydrograph***

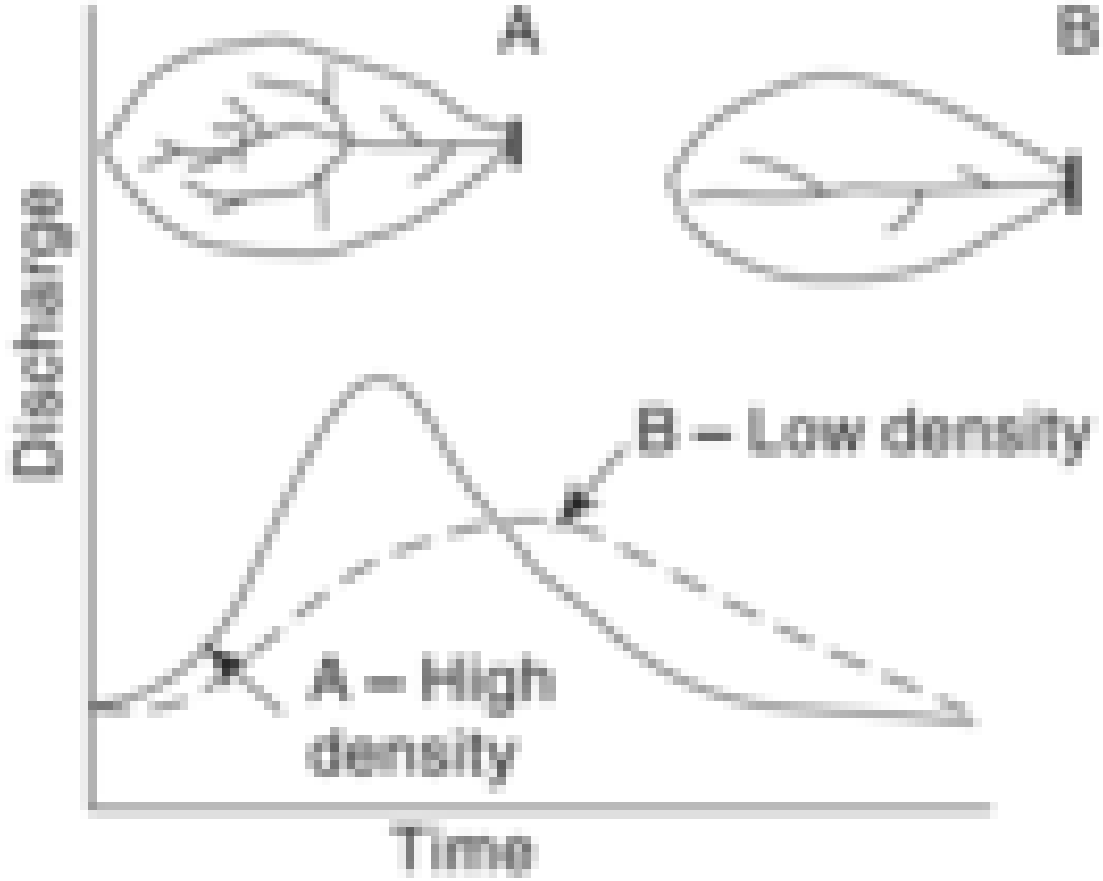


Fig. 6.2(b) ***Role of Drainage Density on the Hydrograph***

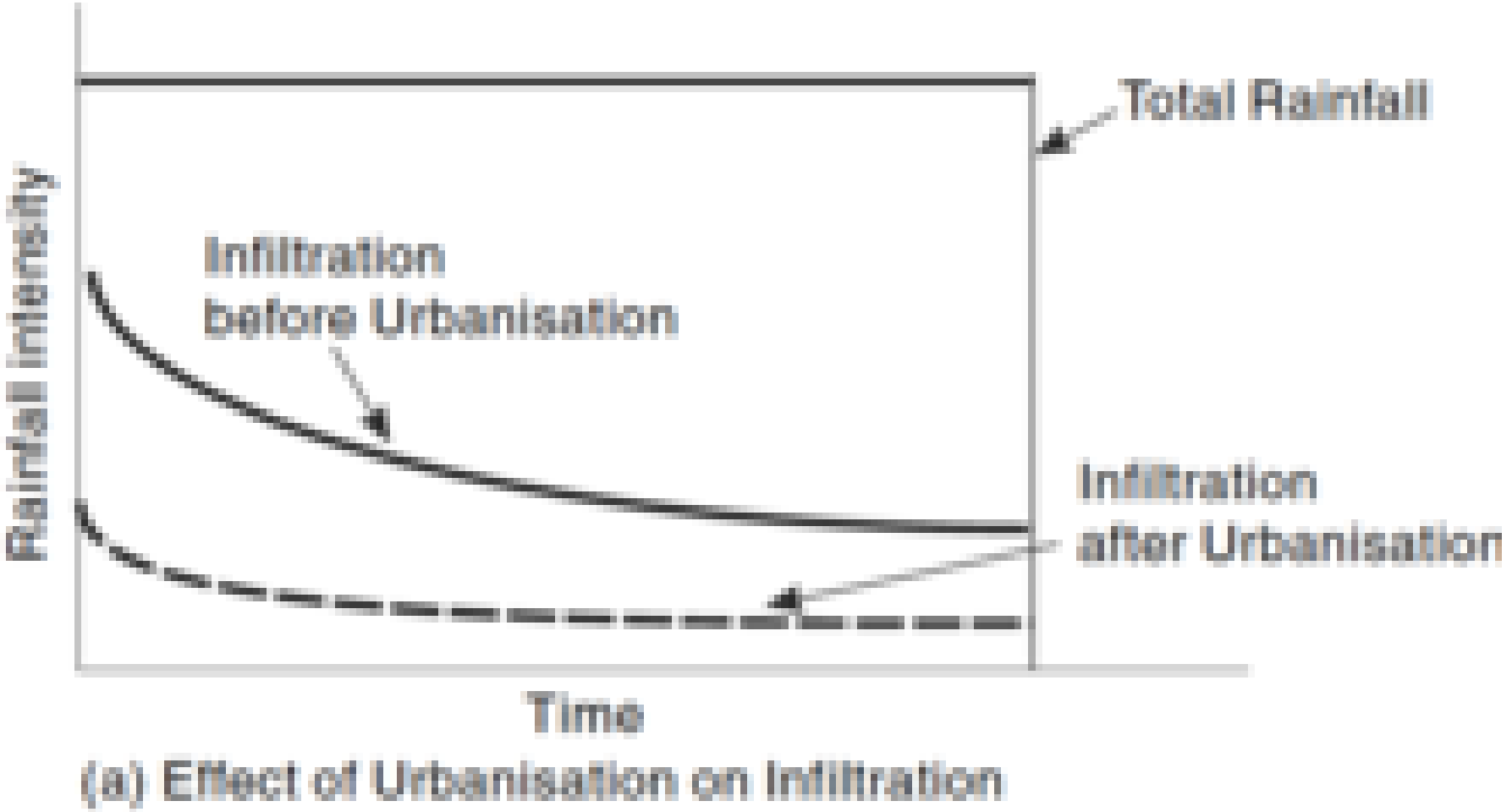
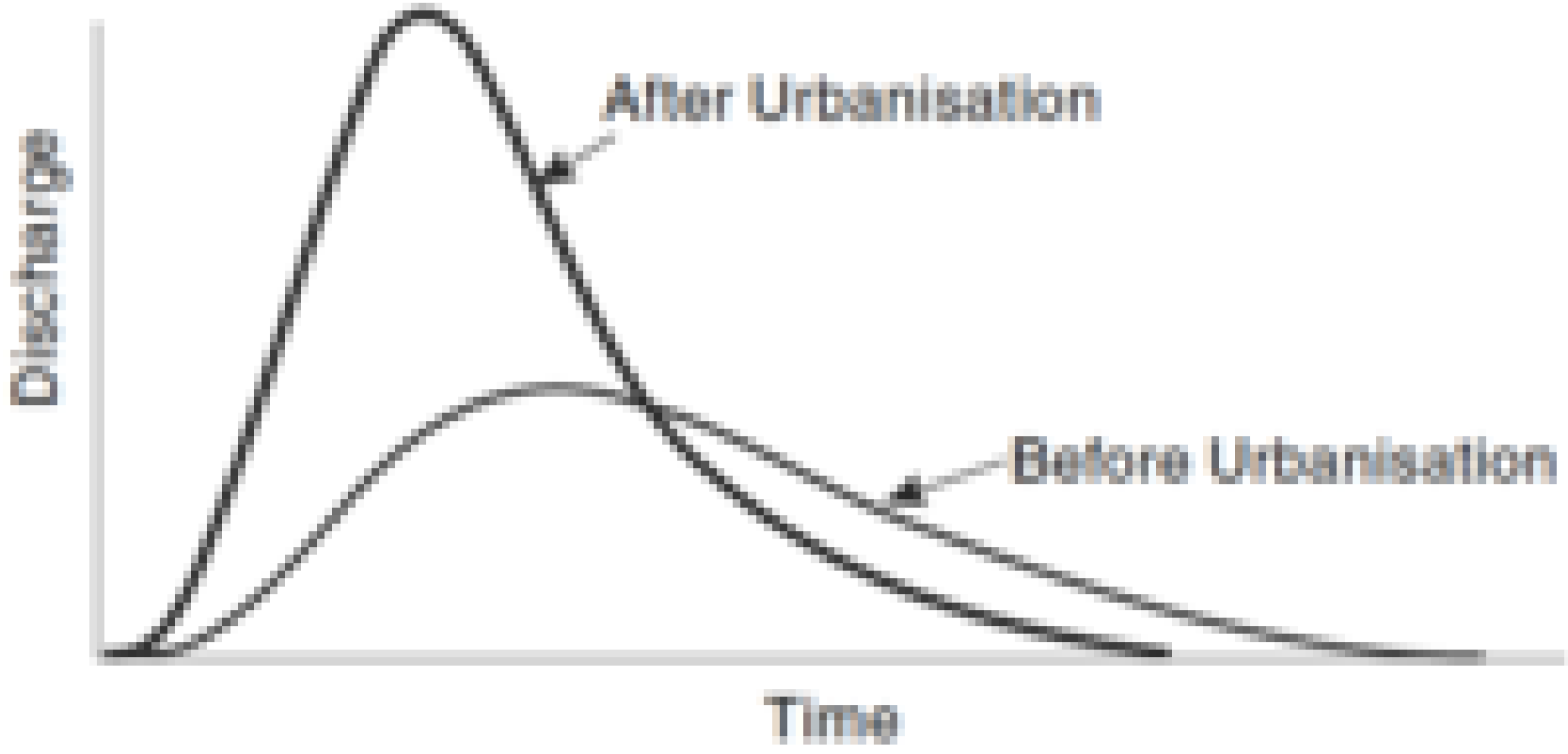


Fig. 6.3(a) ***Effect of Urbanisation***



(b) Effect of Urbanisation on the Hydrograph

Fig. 6.3(b) *Effect of Urbanisation*

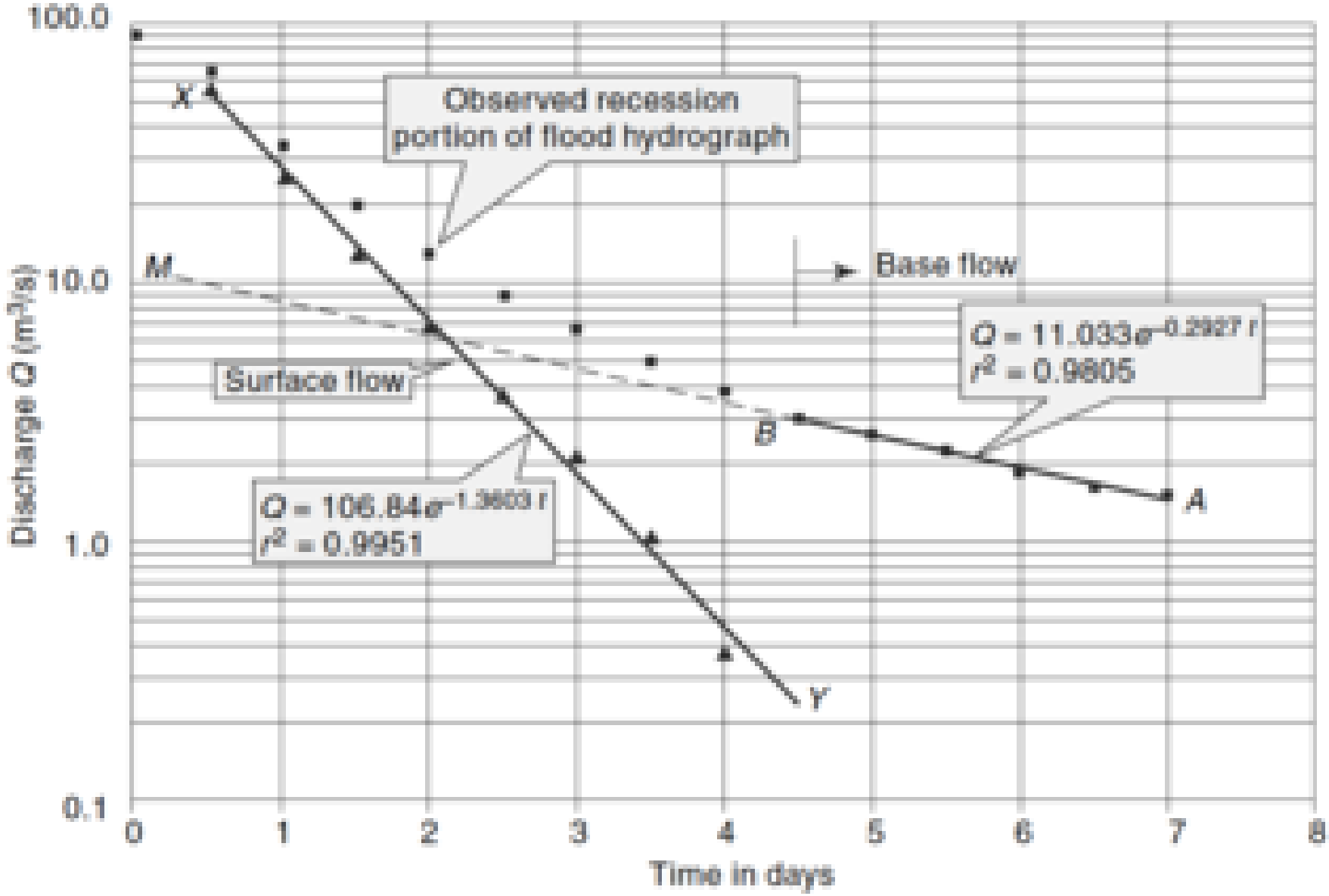


Fig. 6.4 *Storage Recession Curve—Example 6.1*

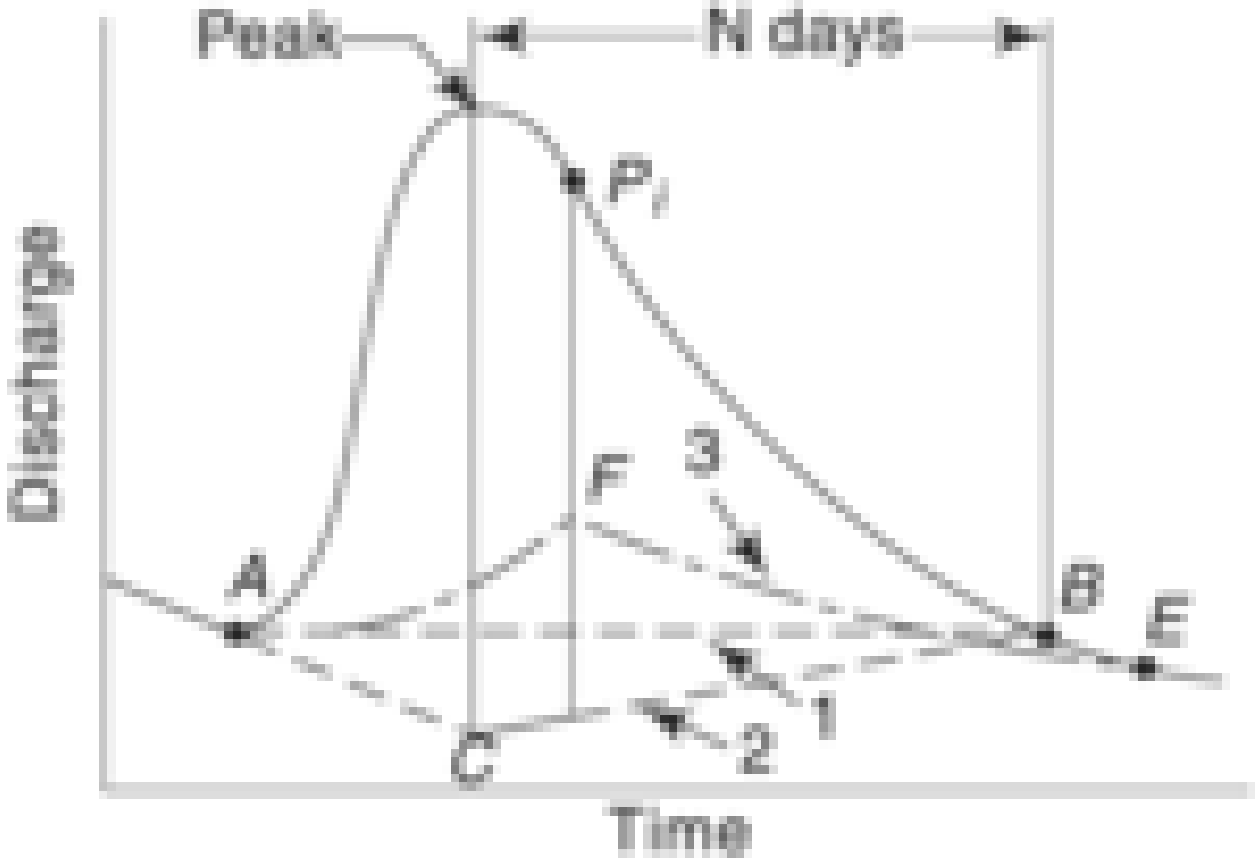


Fig. 6.5 *Base Flow Seperation Methods*

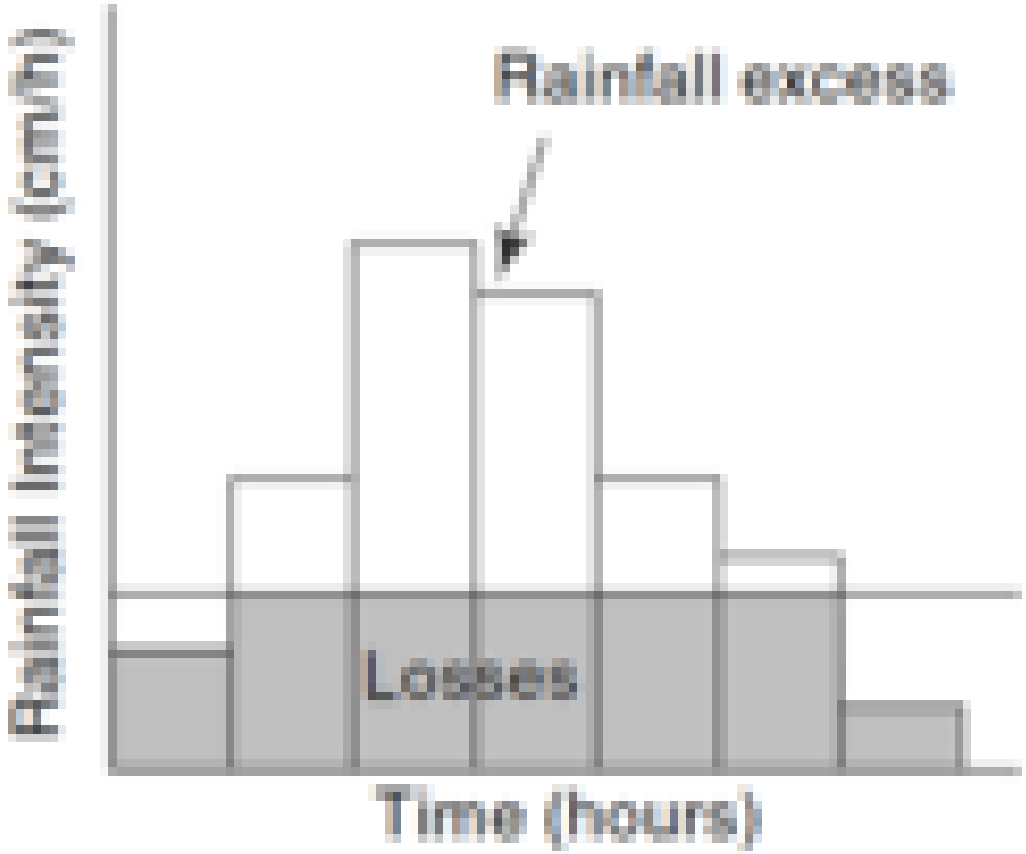


Fig. 6.6 *Effective Rainfall Hyetograph (ERH)*

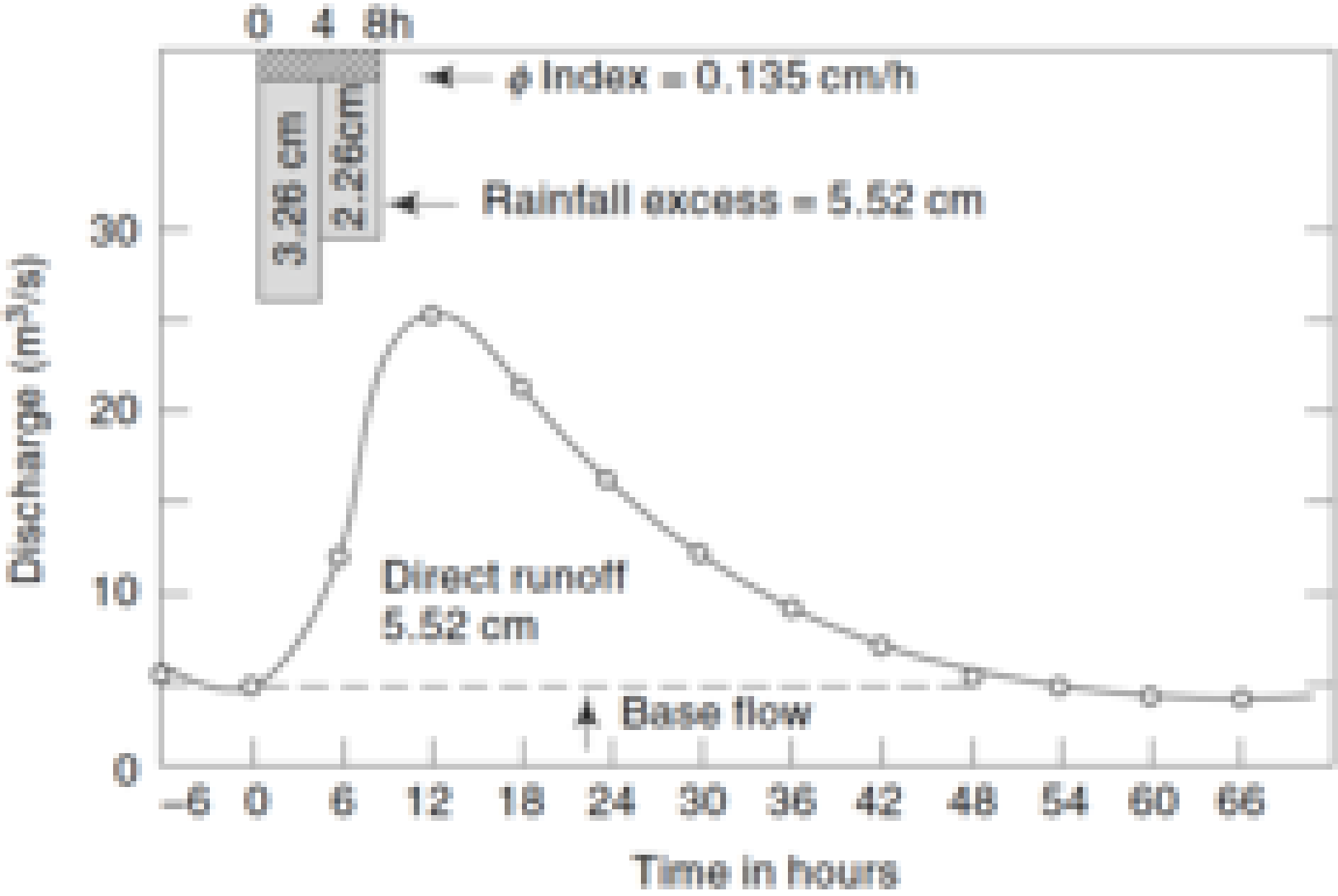


Fig. 6.7 ***Base Flow Separation—Example 6.2***

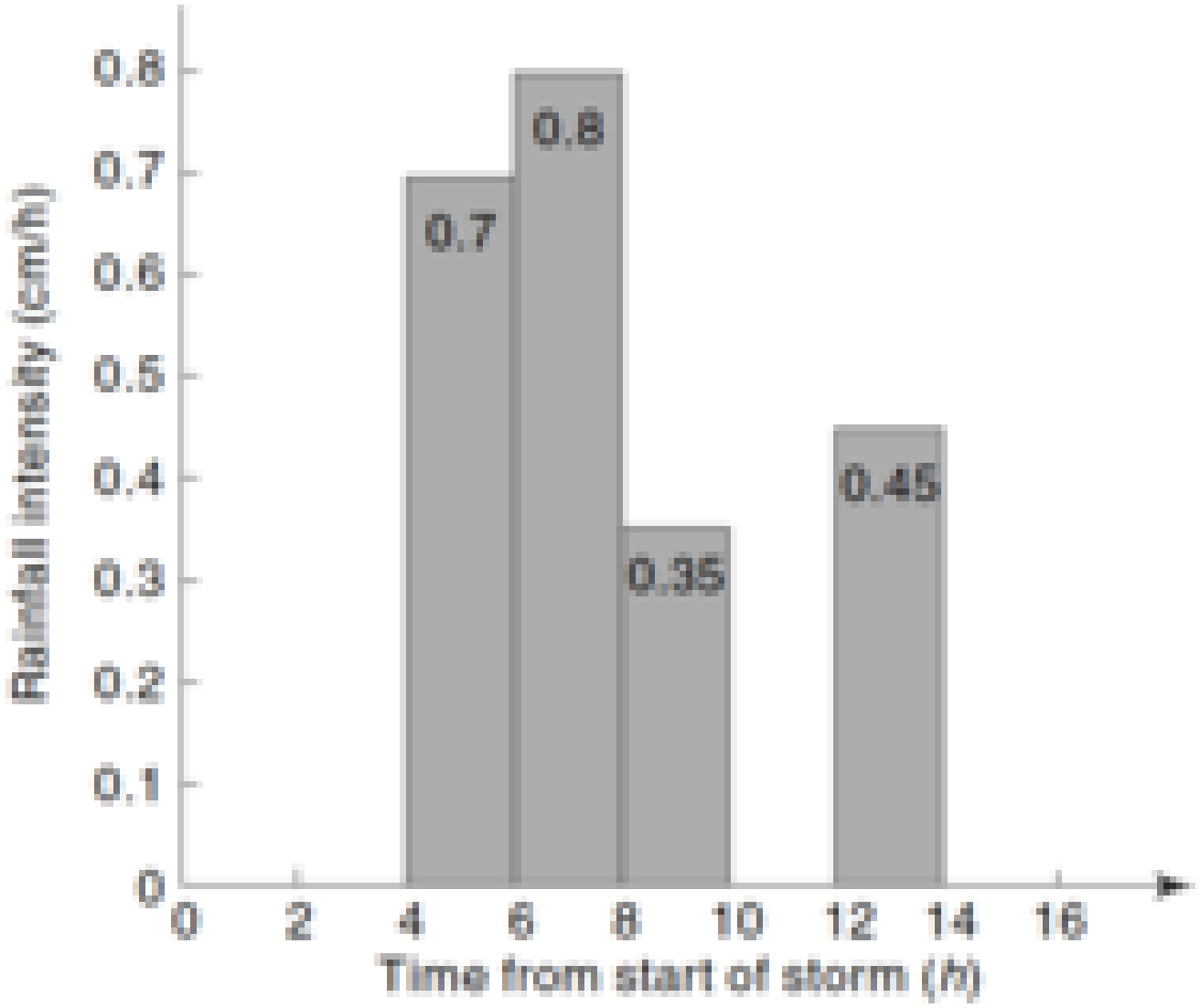


Fig. 6.8 *ERH of Storm—Example 6.3*

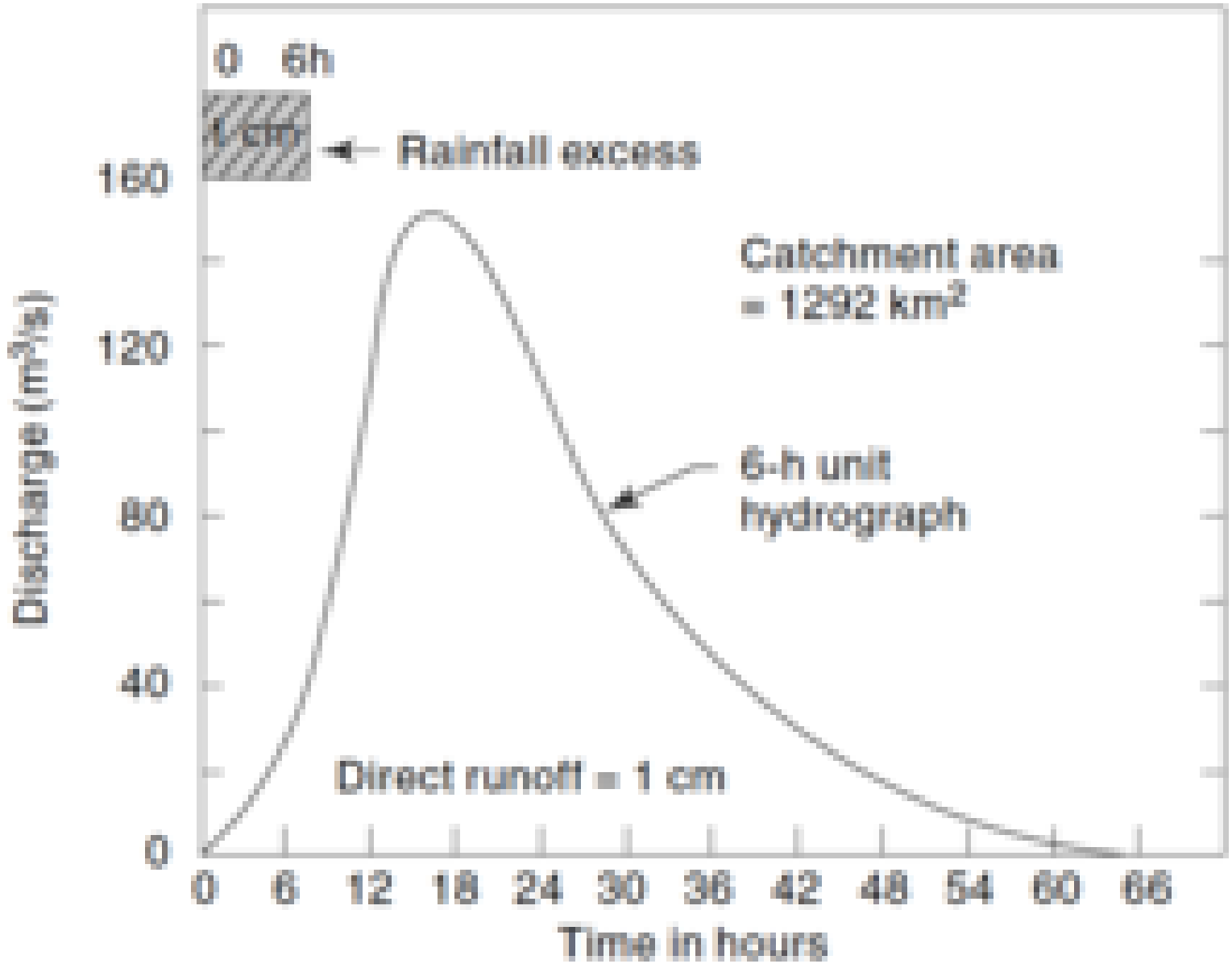


Fig. 6.9 *Typical 6-h Unit Hydrograph*

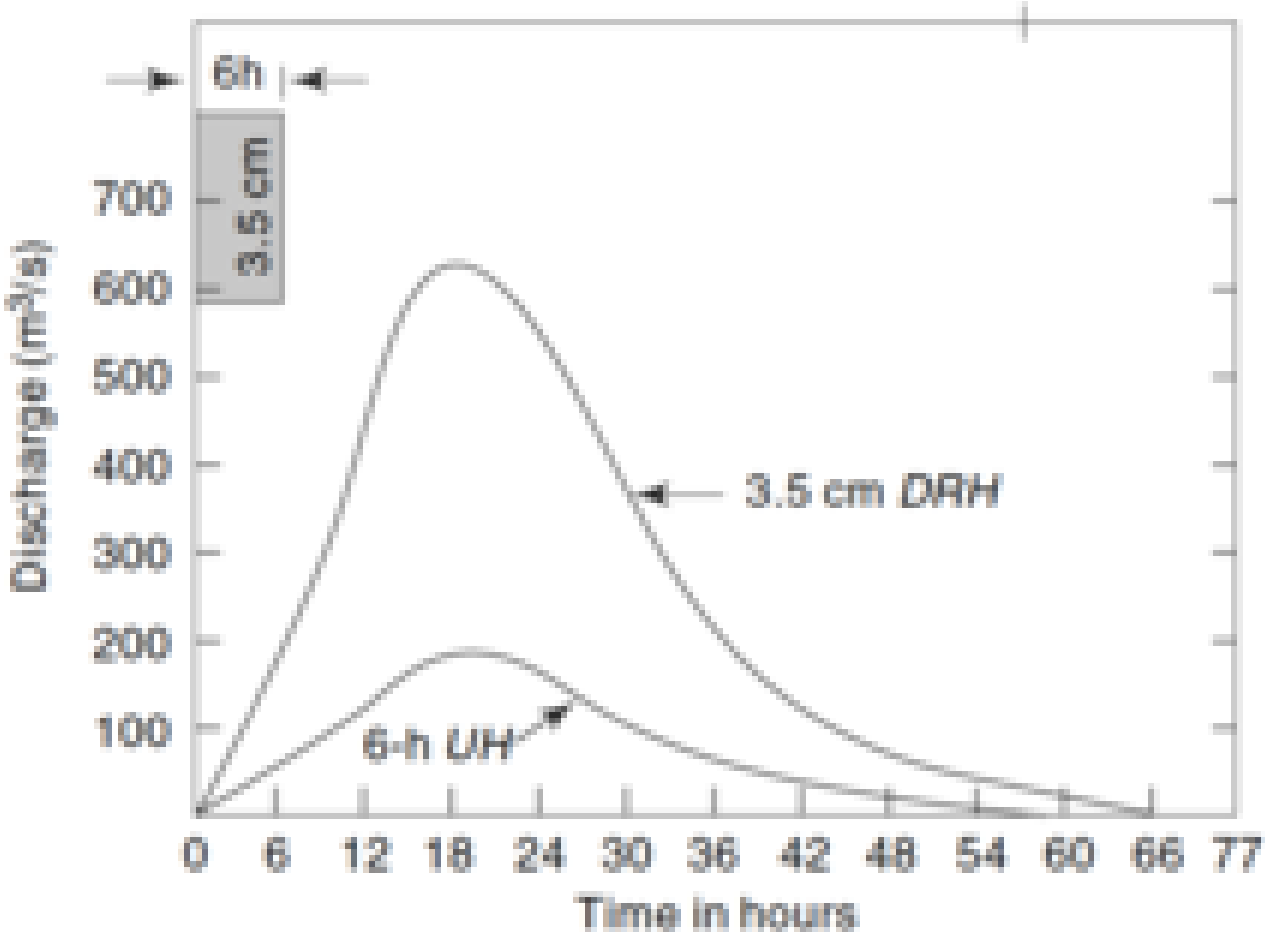


Fig. 6.10(a) *3.5 cm DRH derived from 6-h Unit Hydrograph—Example 6.4*

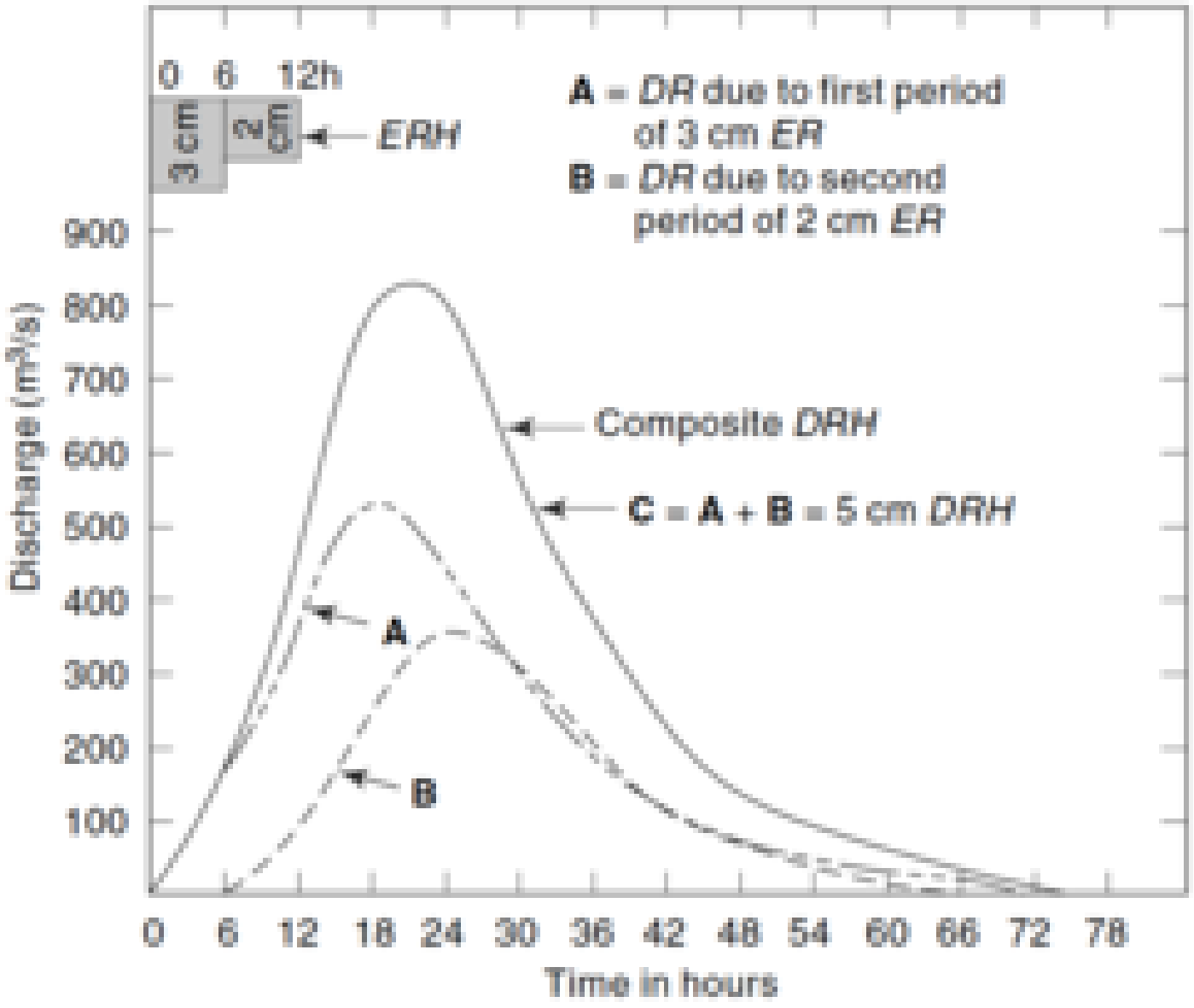


Fig. 6.10(b) *Principle of Superposition—Example 6.5*

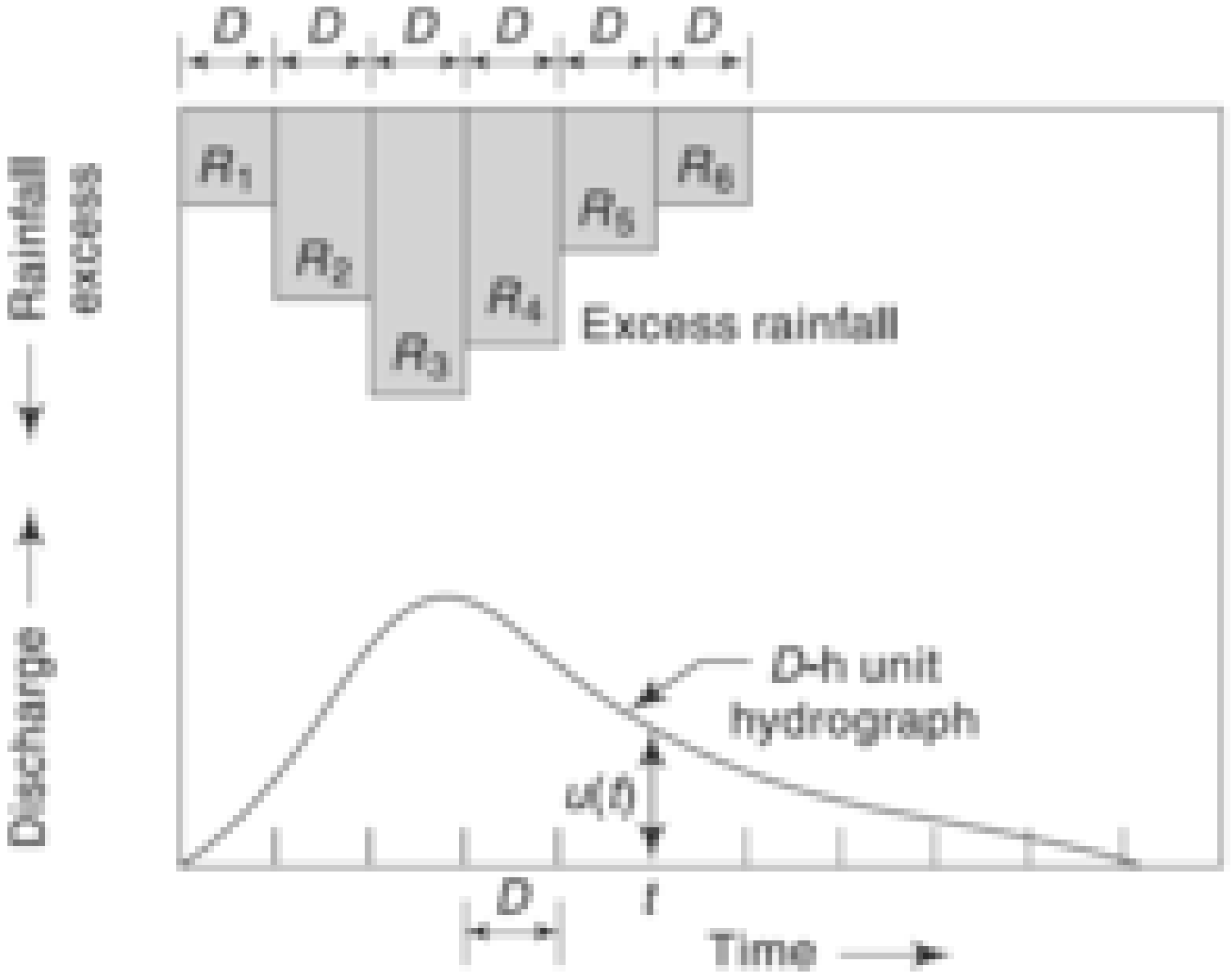


Fig. 6.11 *DRH due to an ERH*

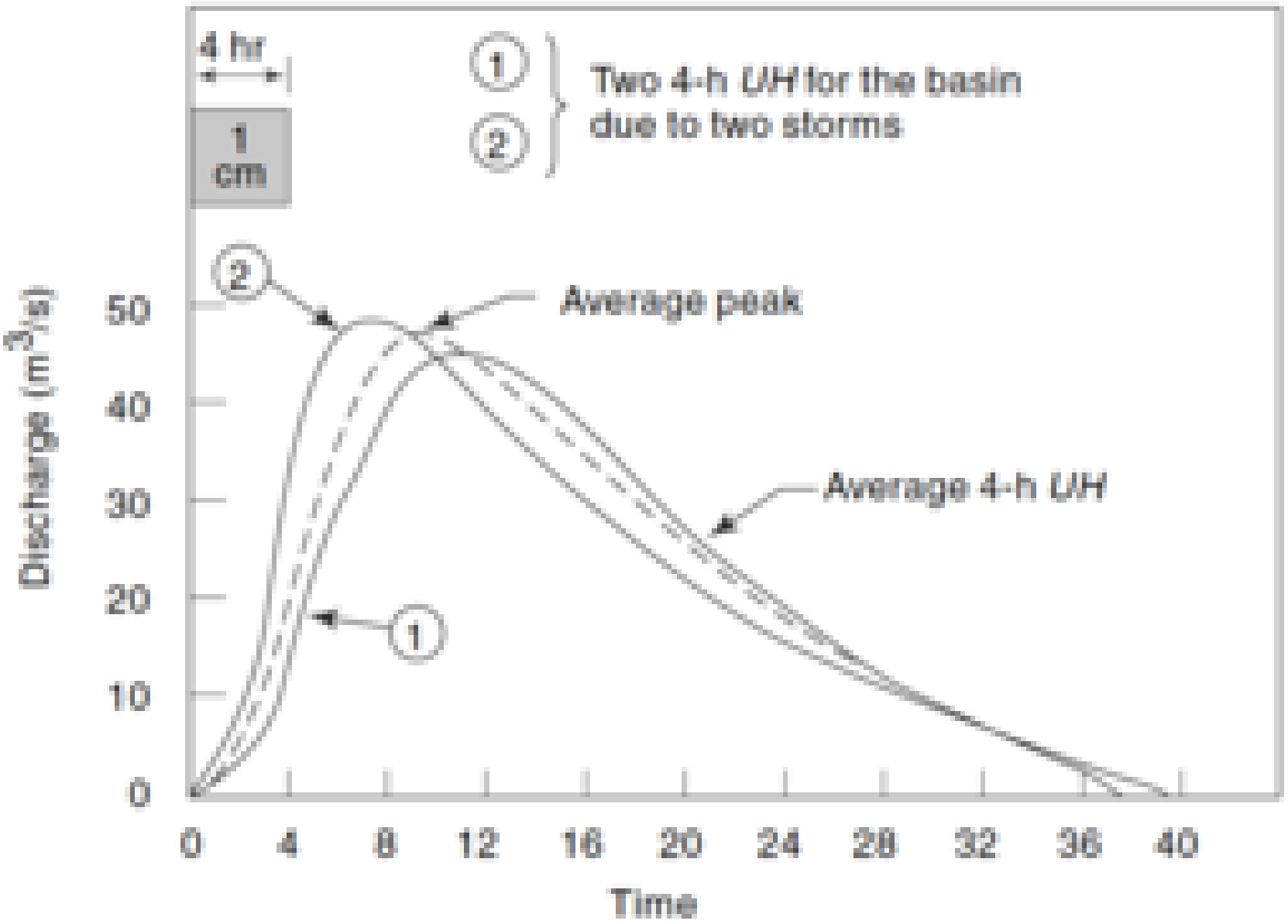


Fig. 6.12 *Derivation of an Average Unit Hydrograph*

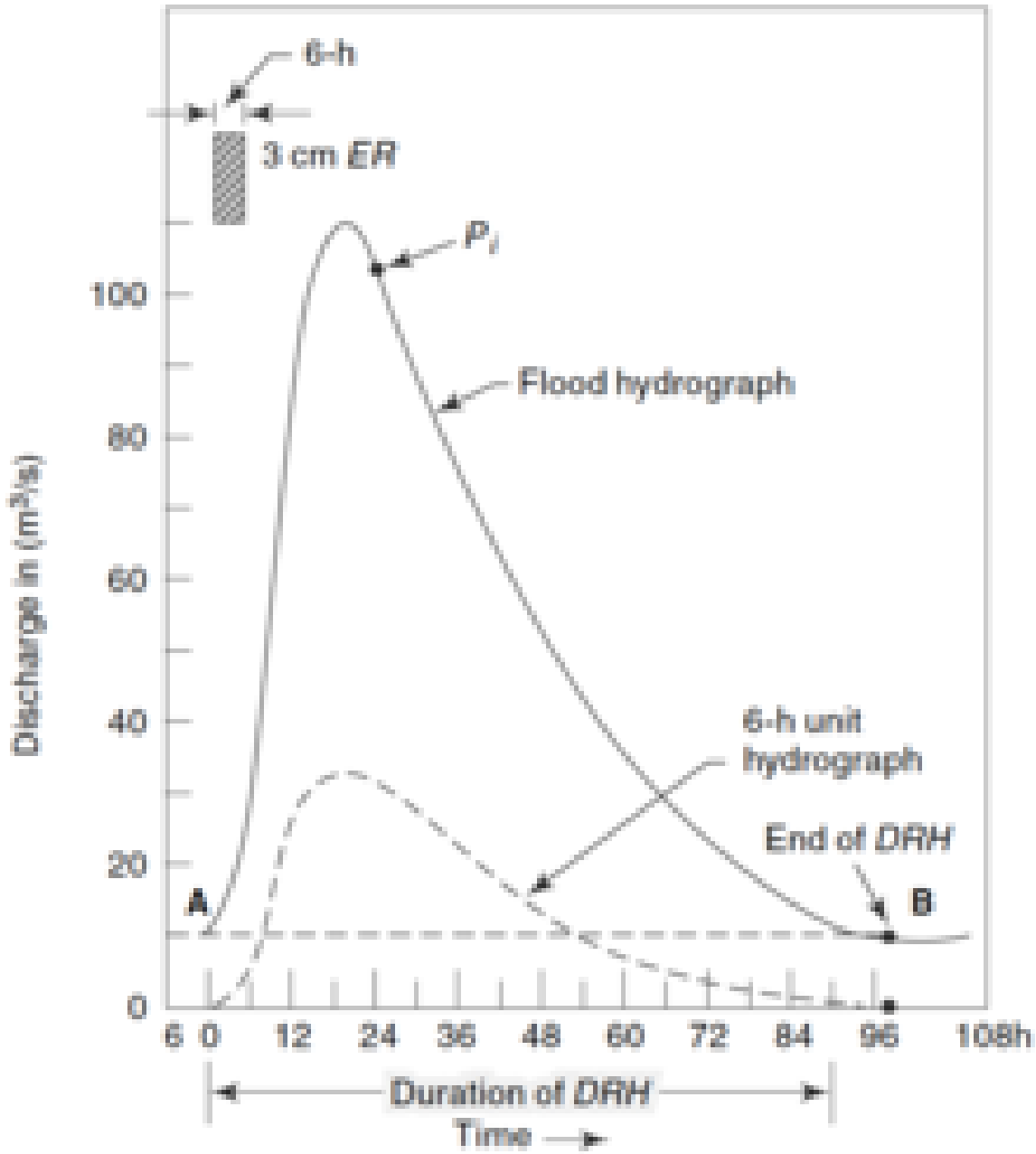


Fig. 6.13 *Derivation of Unit Hydrograph from a Flood Hydrograph*

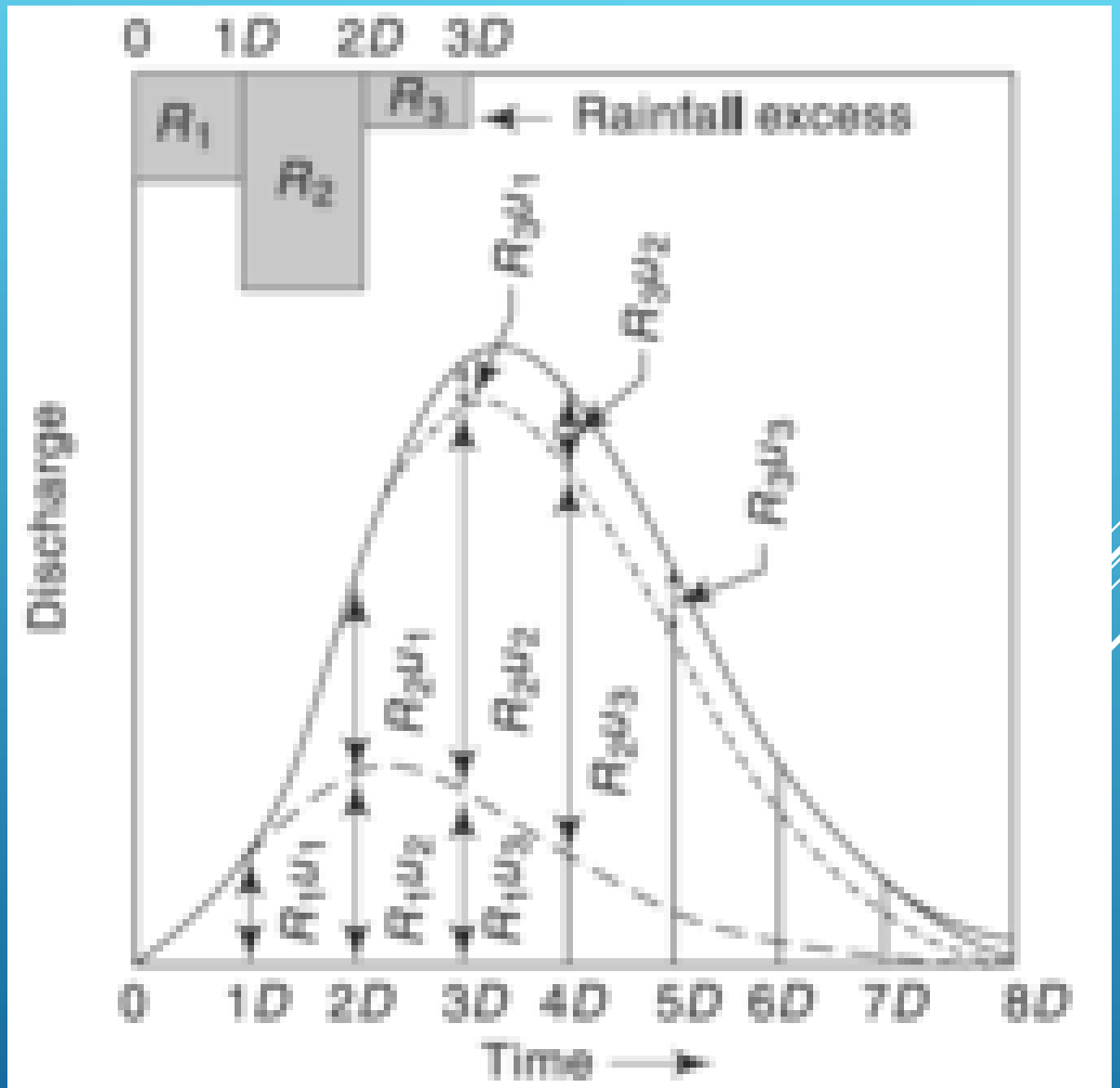


Fig. 6.14 *Unit Hydrograph from a Complex Storm*

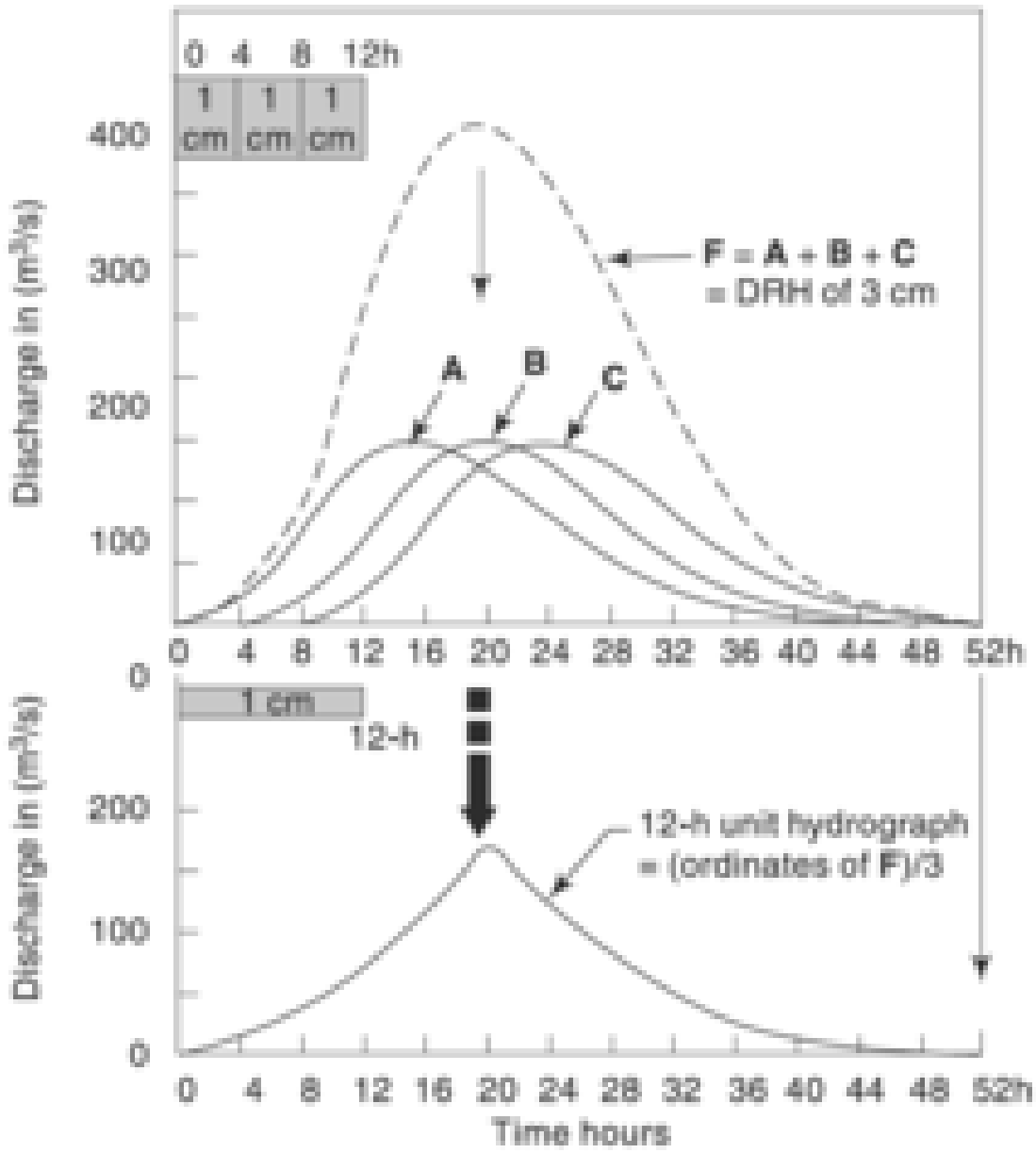


Fig. 6.15 *Construction of a 12-h Unit Hydrograph from a 4-h Unit Hydrograph—Example 6.9*

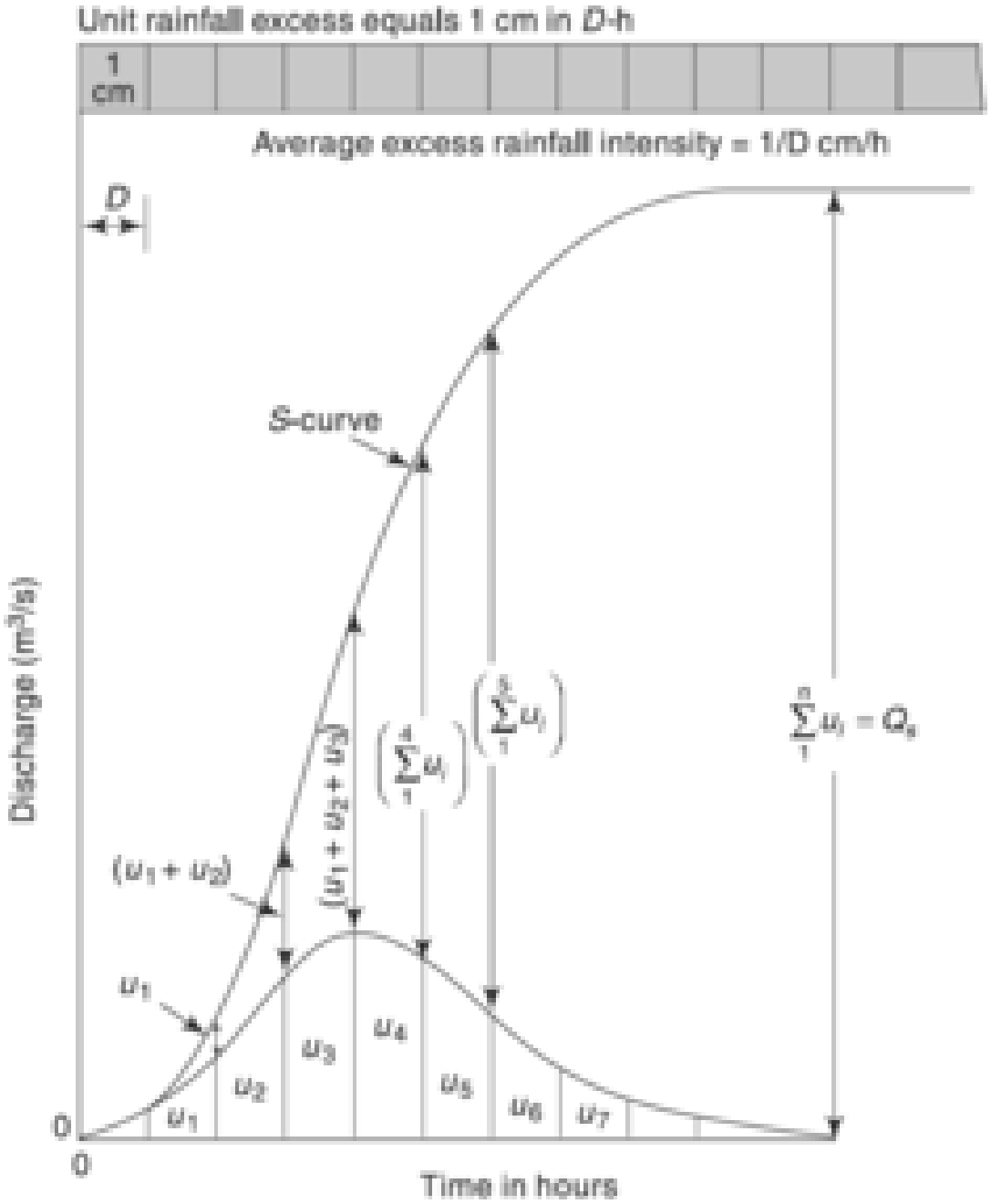


Fig. 6.16 *S-curve*

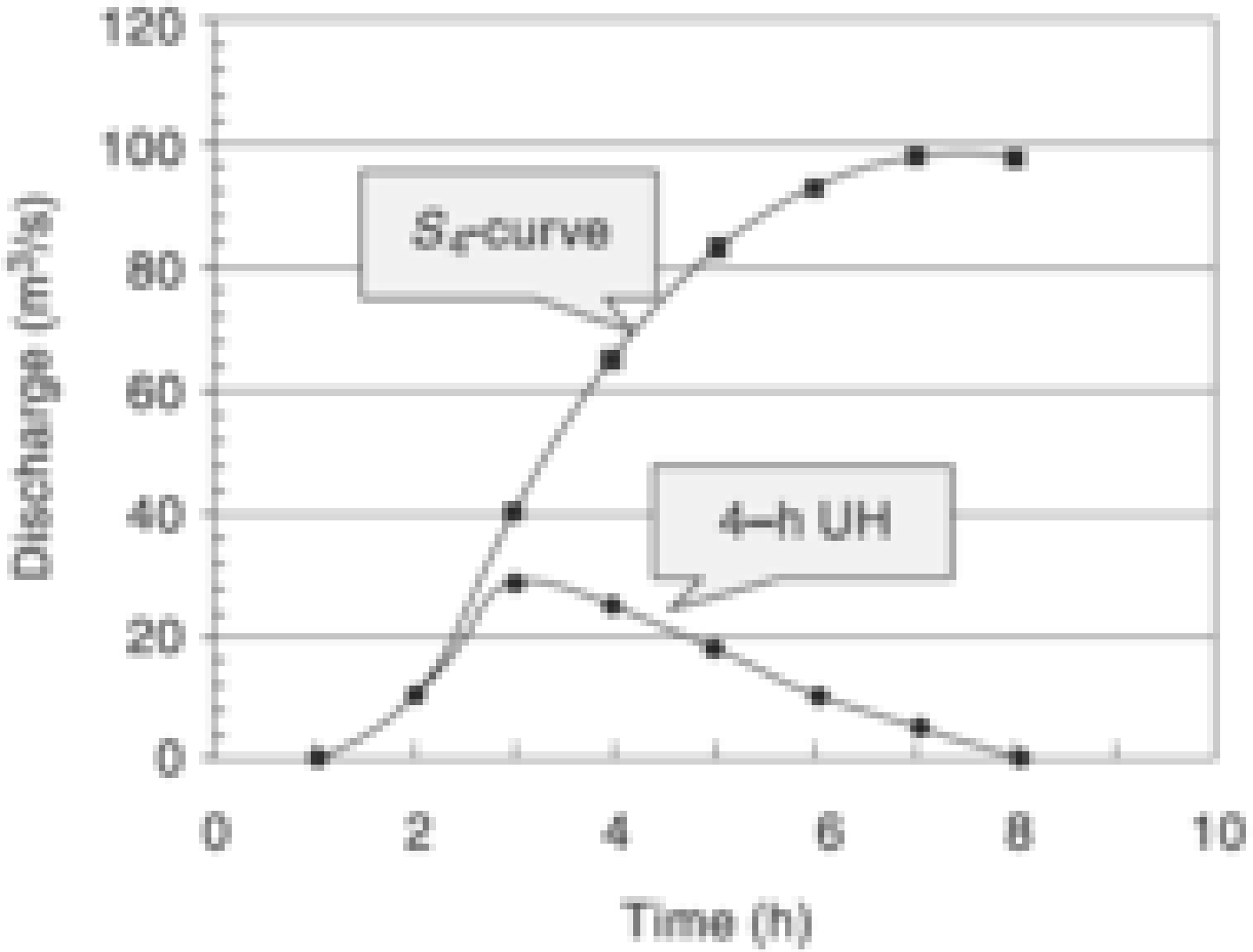


Fig. 6.17 *Construction of S_t-curve—(Example 6.10)*

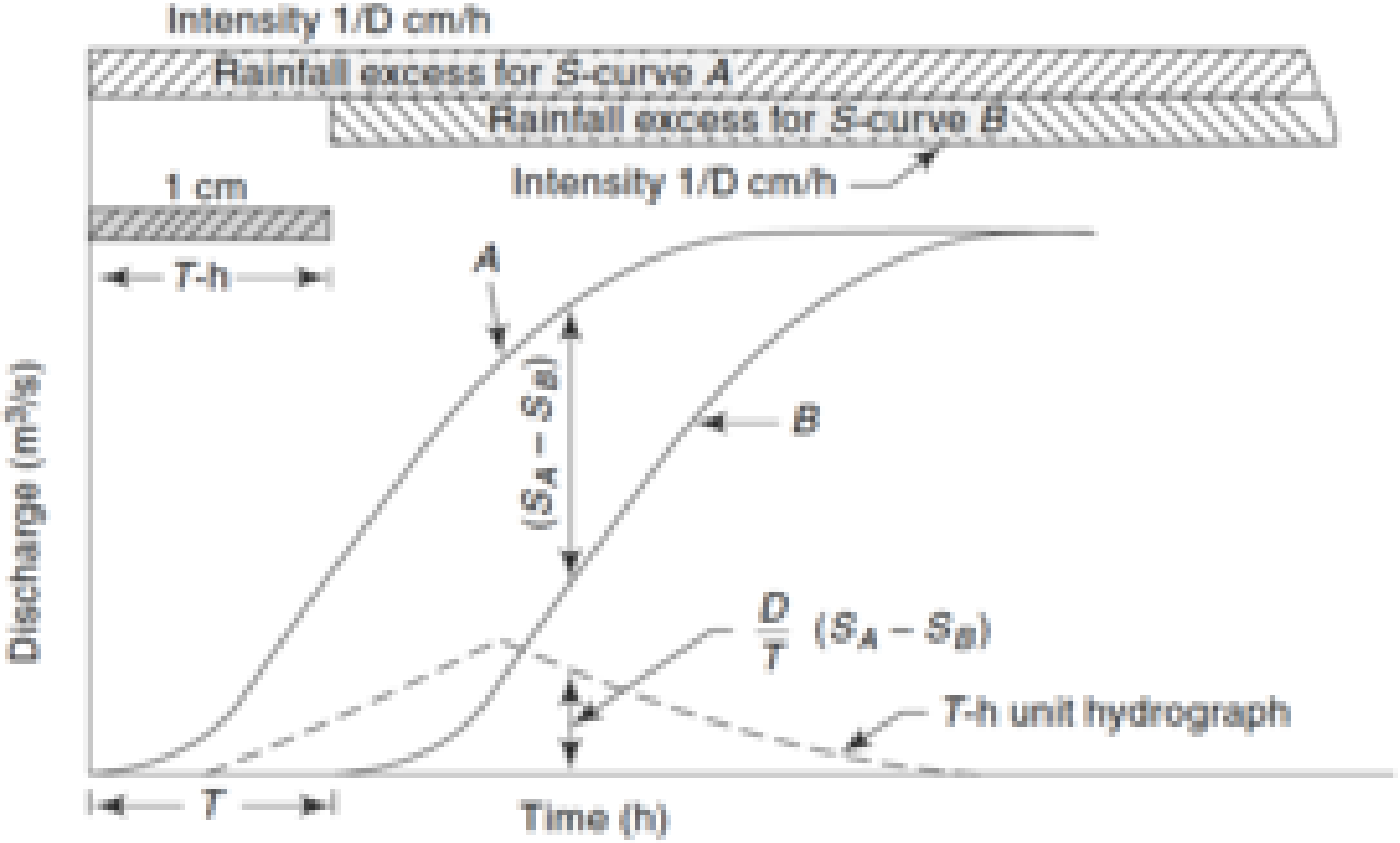


Fig. 6.18 *Derivation of a T-h Unit Hydrograph by S-curve Lagging Method*

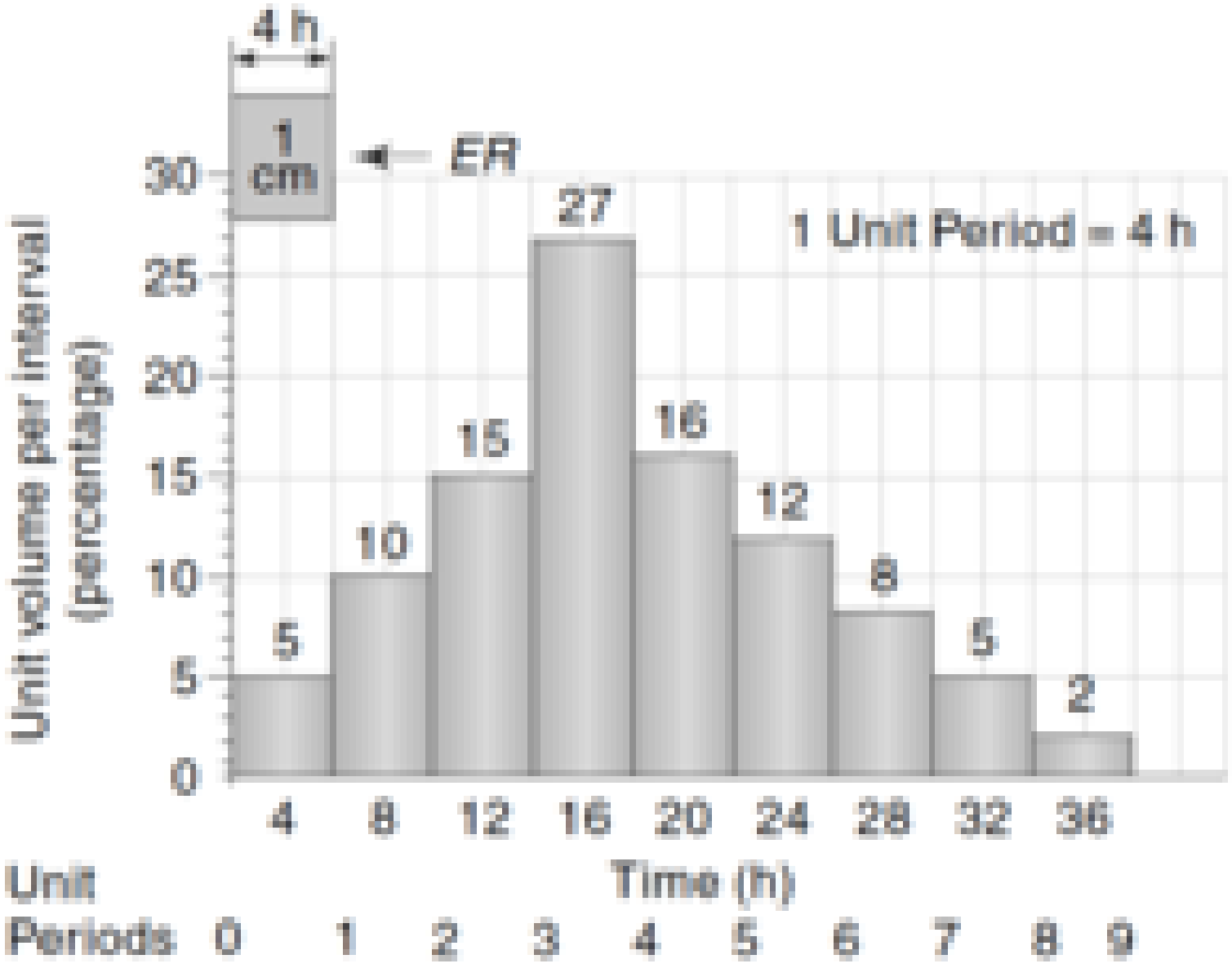


Fig. 6.19 *Four-hour Distribution Graph*

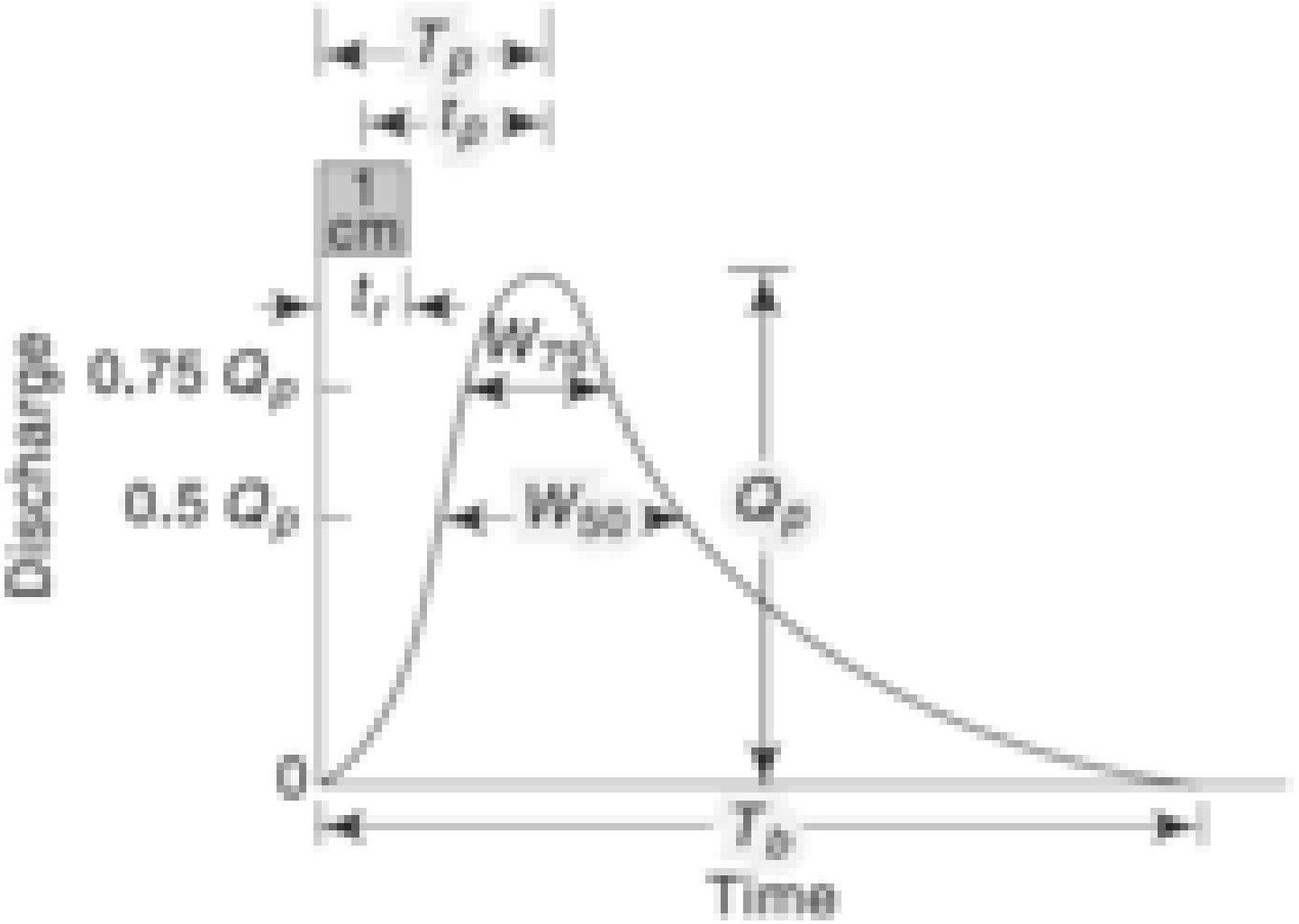


Fig. 6.20 *Elements of a Synthetic Unit Hydrograph*

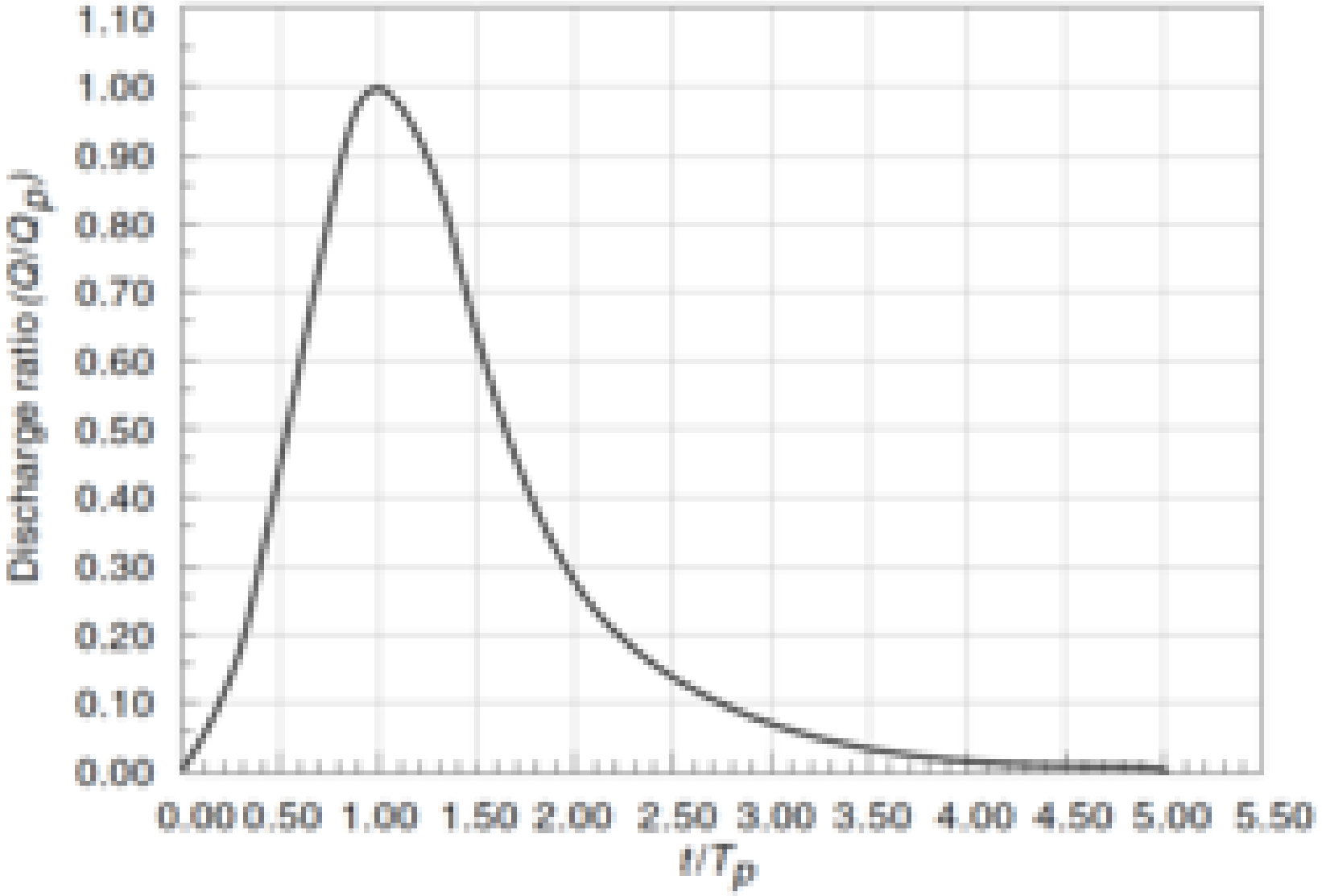


Fig. 6.21(a) *Dimensionless SCS Unit Hydrograph*

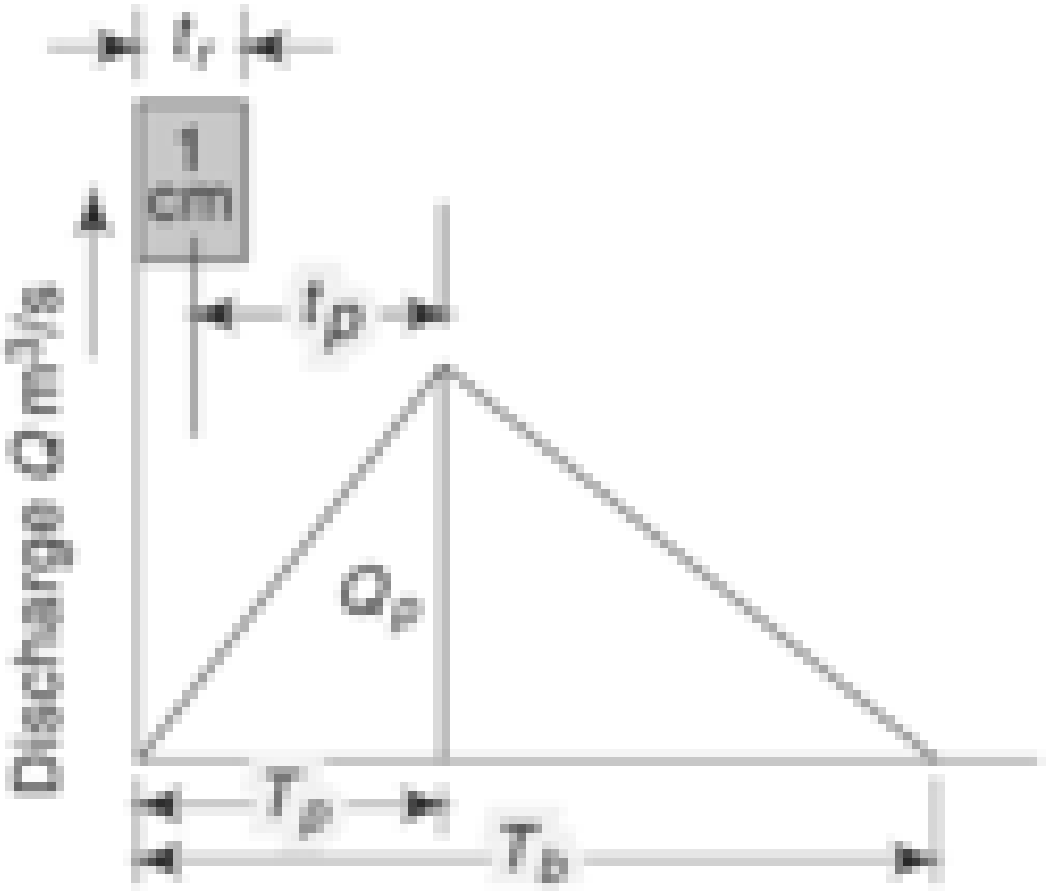


Fig. 6.21(b) *SCS Triangular Unit Hydrograph*

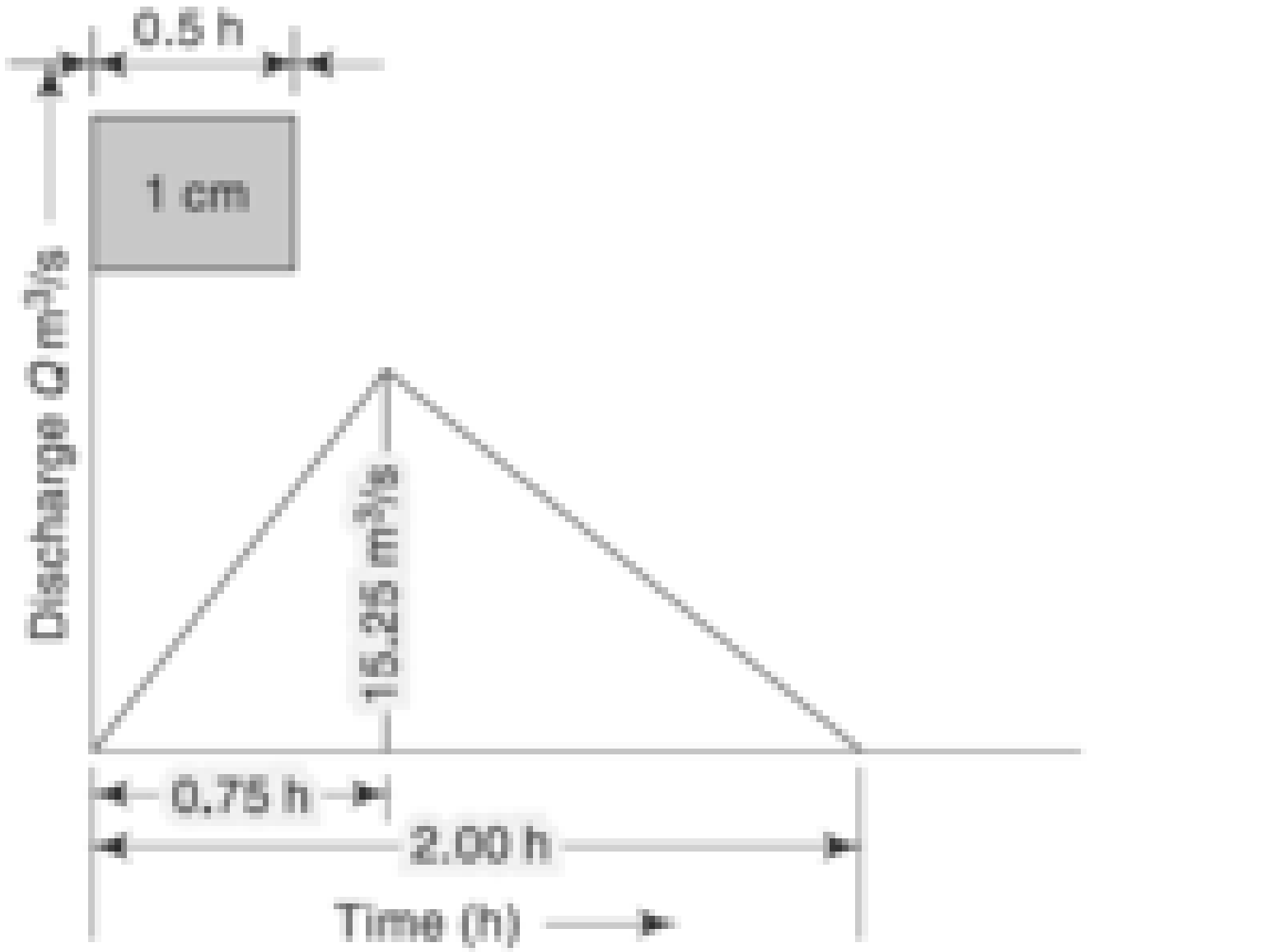


Fig. 6.22 *Triangular Unit Hydrograph—Example 6.15*

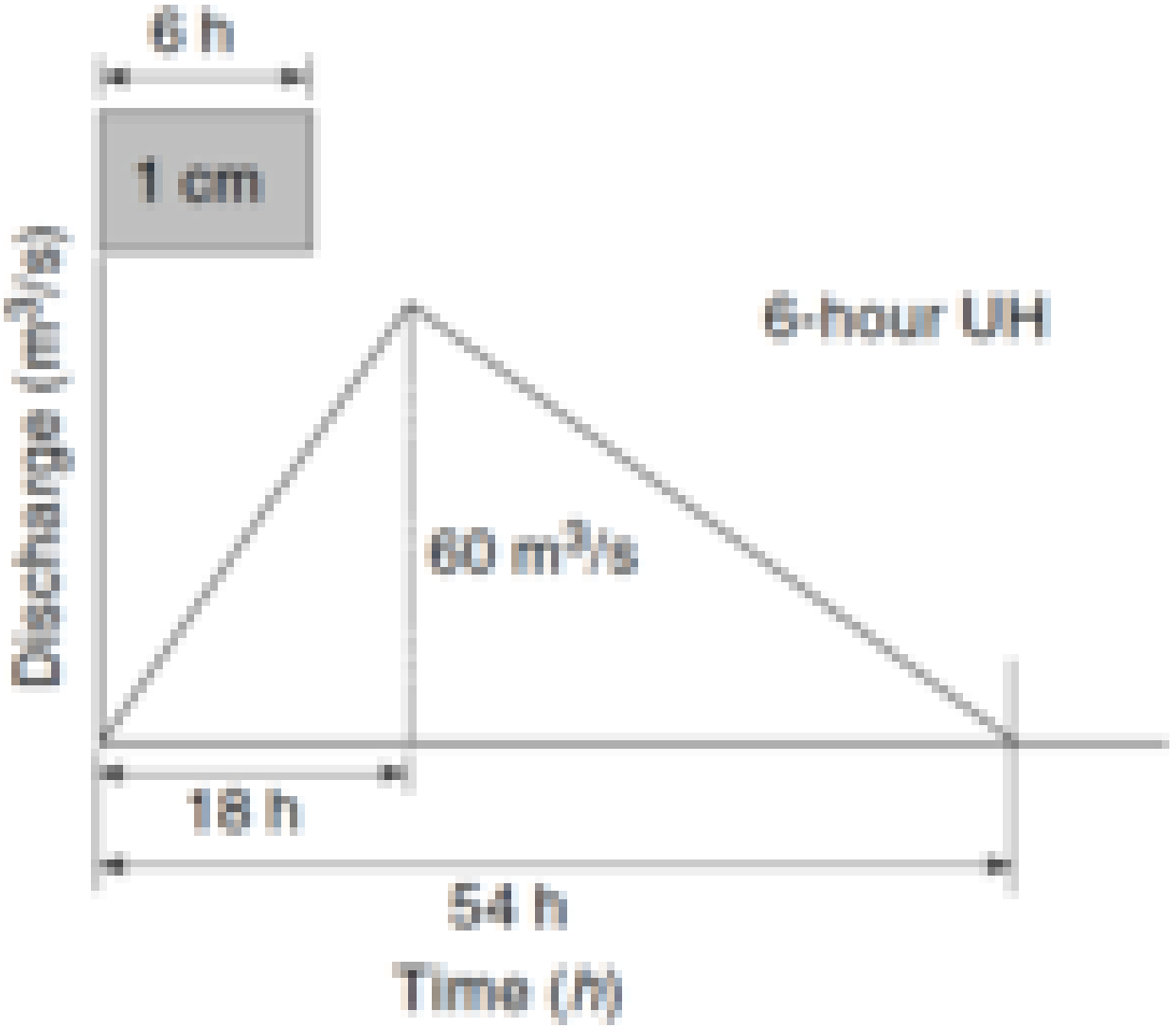
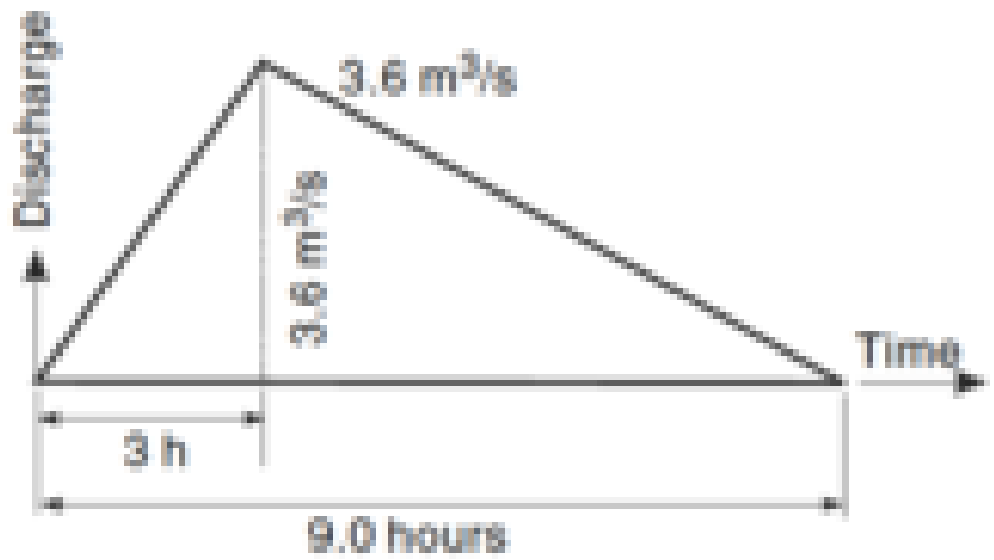
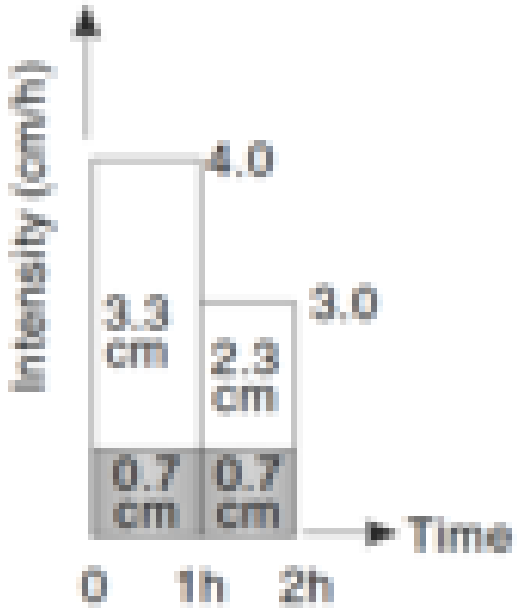


Fig. 6.23 *6-hour triangular UH of Example 6.16*



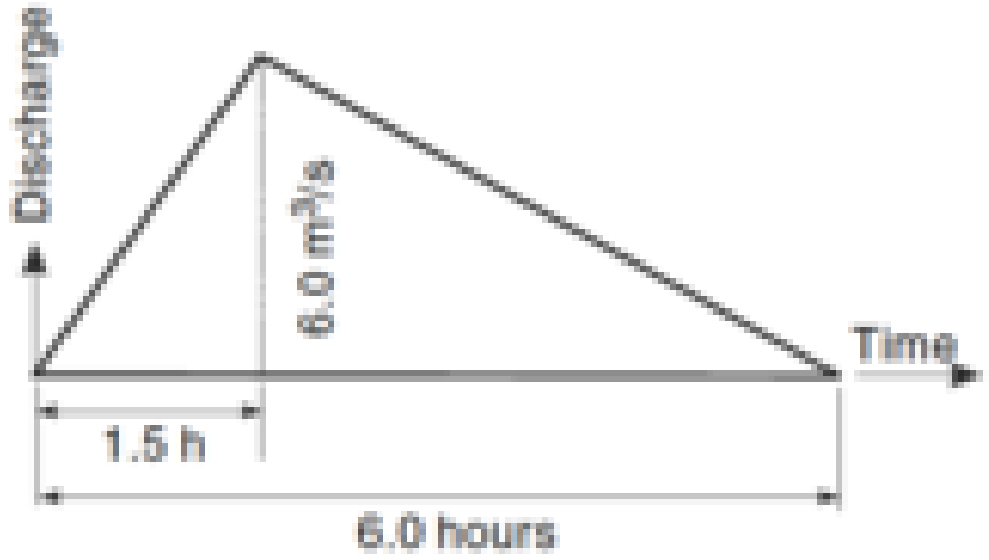
1-h Unit Hydrograph



Effective Rainfall Hyetograph

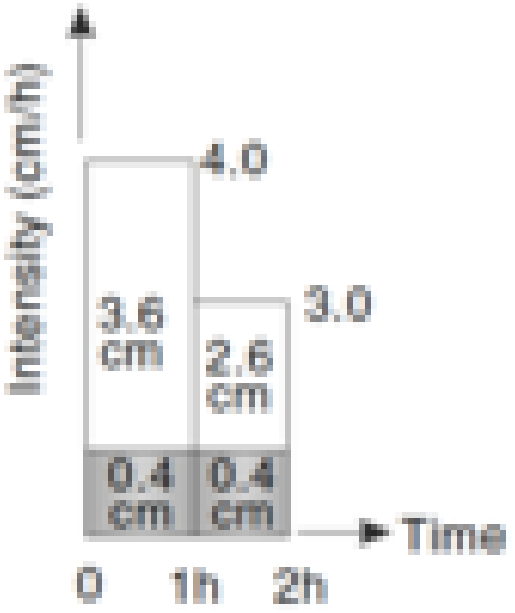
(a) Before Urbanisation

Fig. 6.24(a) ***ERH and 1-h UH before urbanisation***



1-h Unit Hydrograph

(b) After Urbanisation



Effective Rainfall Hyetograph

Fig. 6.24(b) *ERH and 1-h UH after urbanisation*

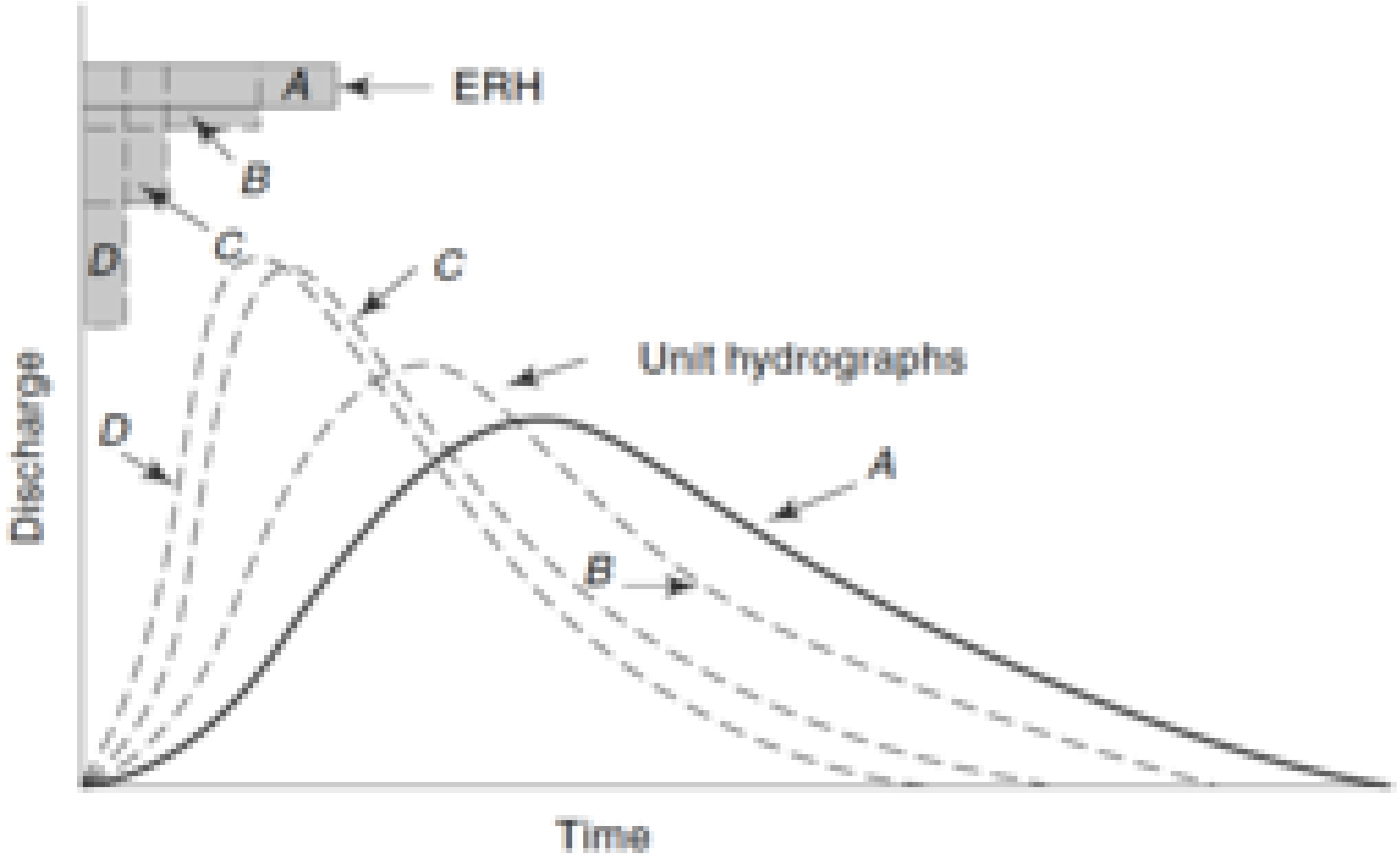


Fig. 6.25 *Unit Hydrographs of Different Durations*

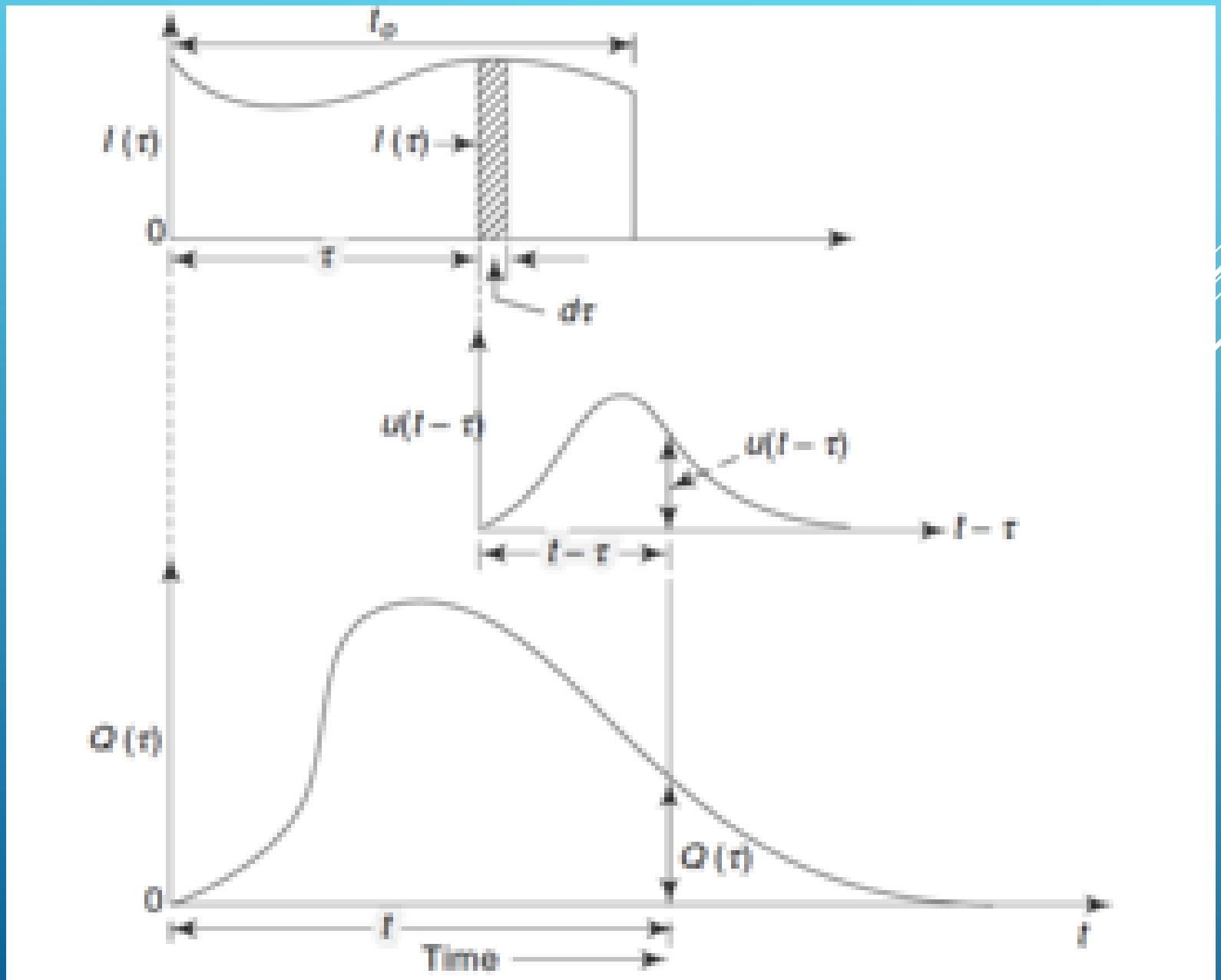


Fig. 6.26 *Convolution of I (τ) and IUH*

Lecture on Engineering Hydrology

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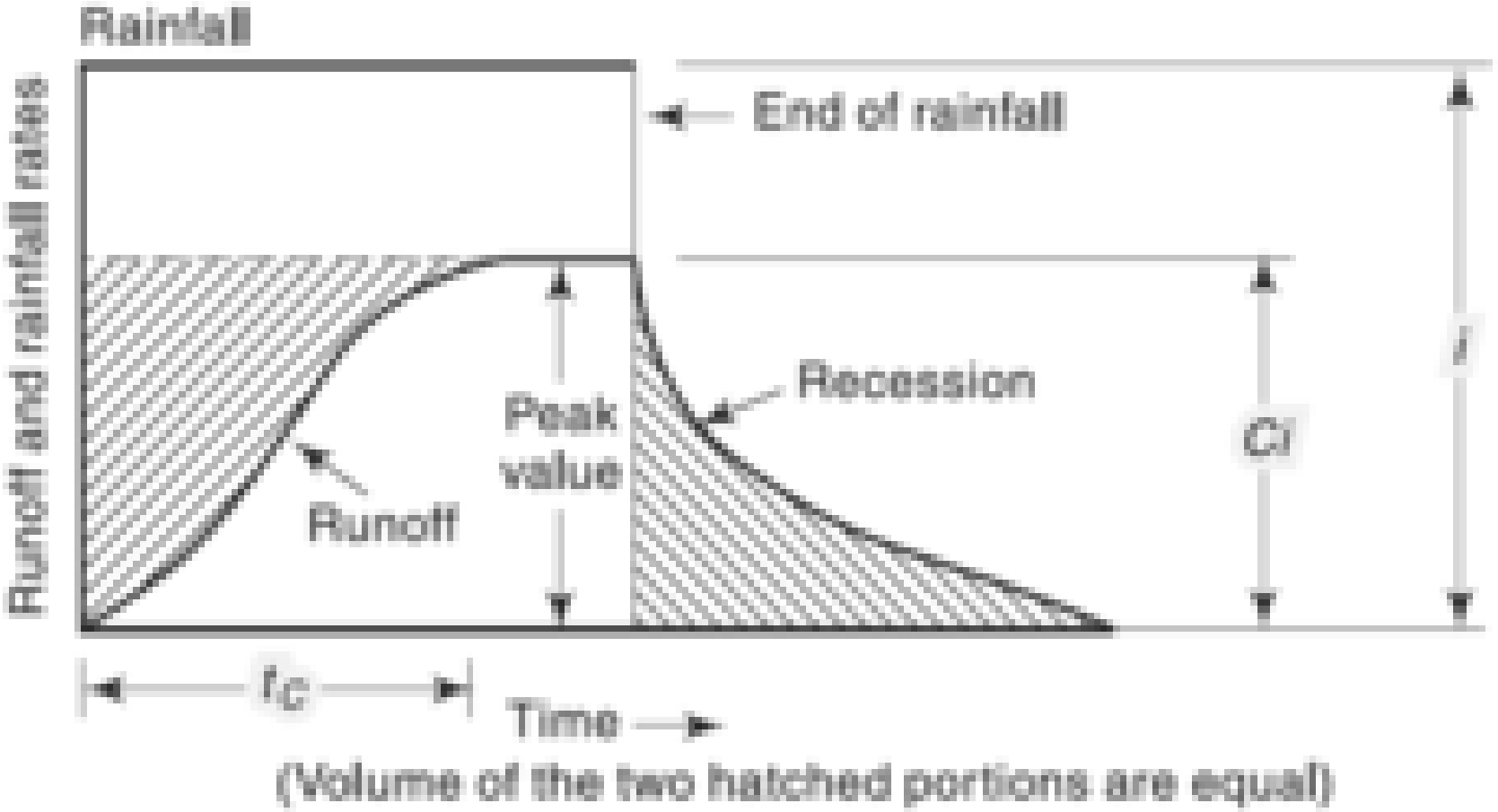

Fig. 7.1 ***Runoff Hydrograph due to Uniform Rainfall***

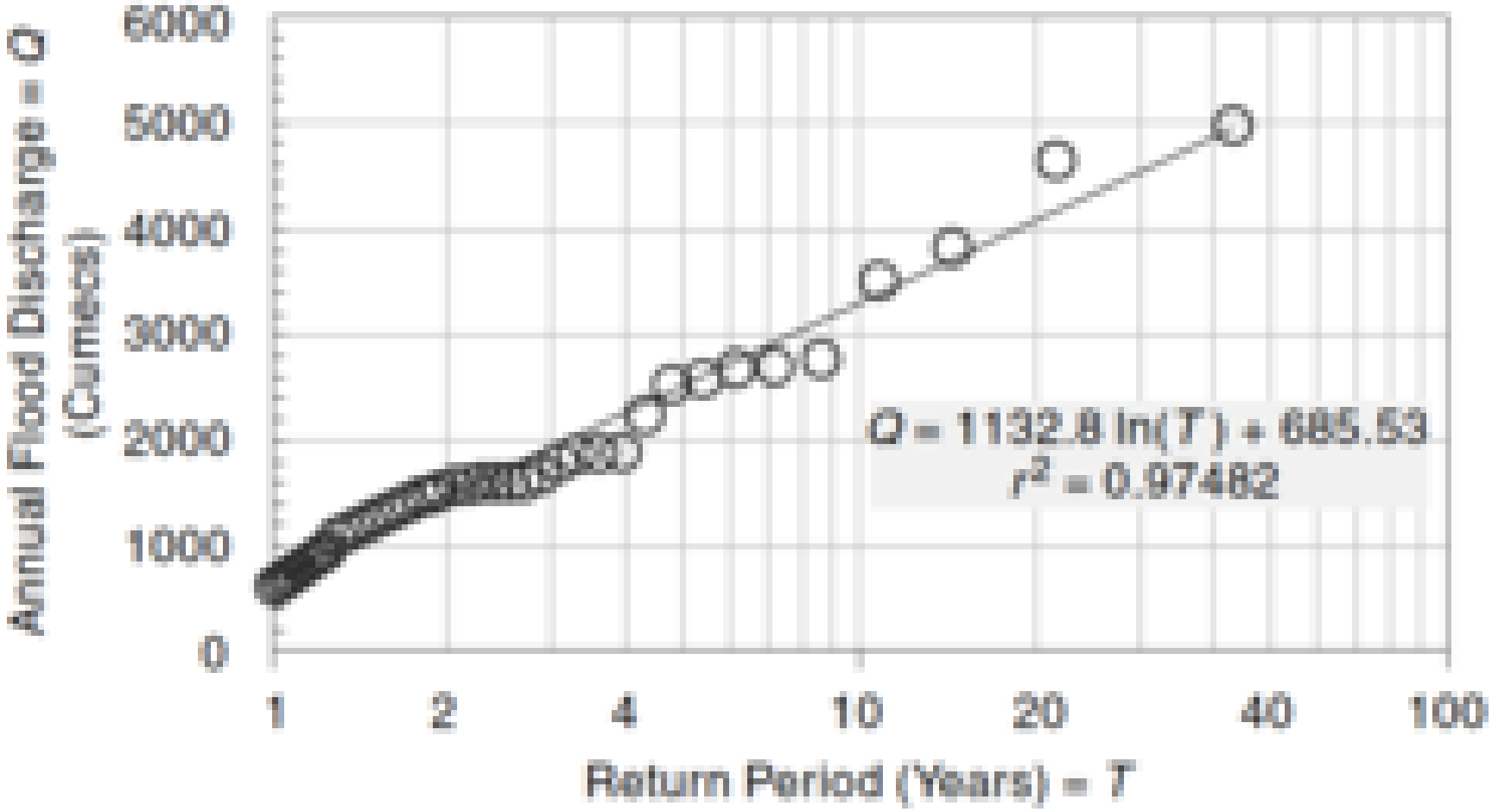

Fig. 7.2 *Flood Frequency Plot—Example 7.3*

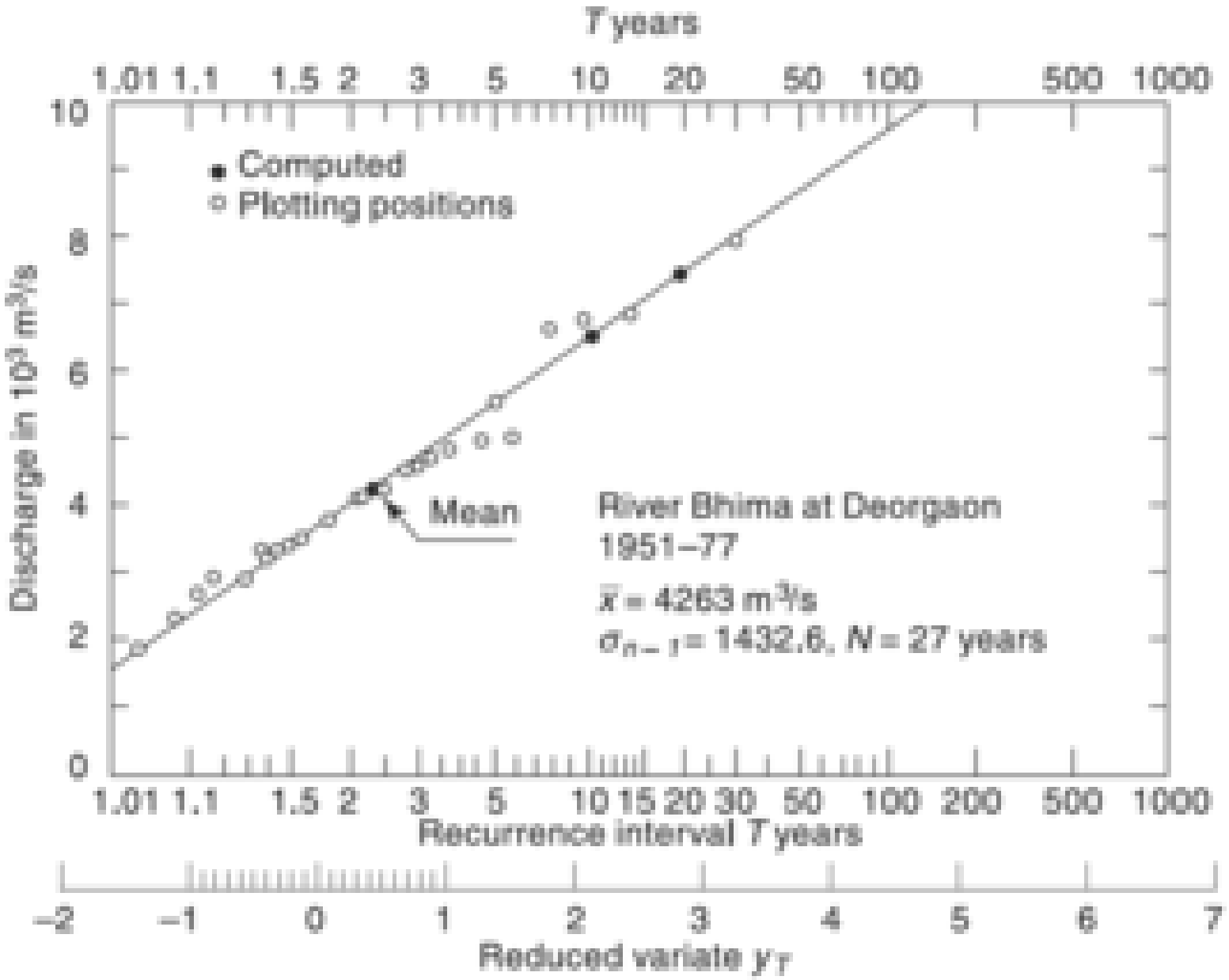

Fig. 7.3 *Flood Probability Analysis by Gumbel's Distribution*

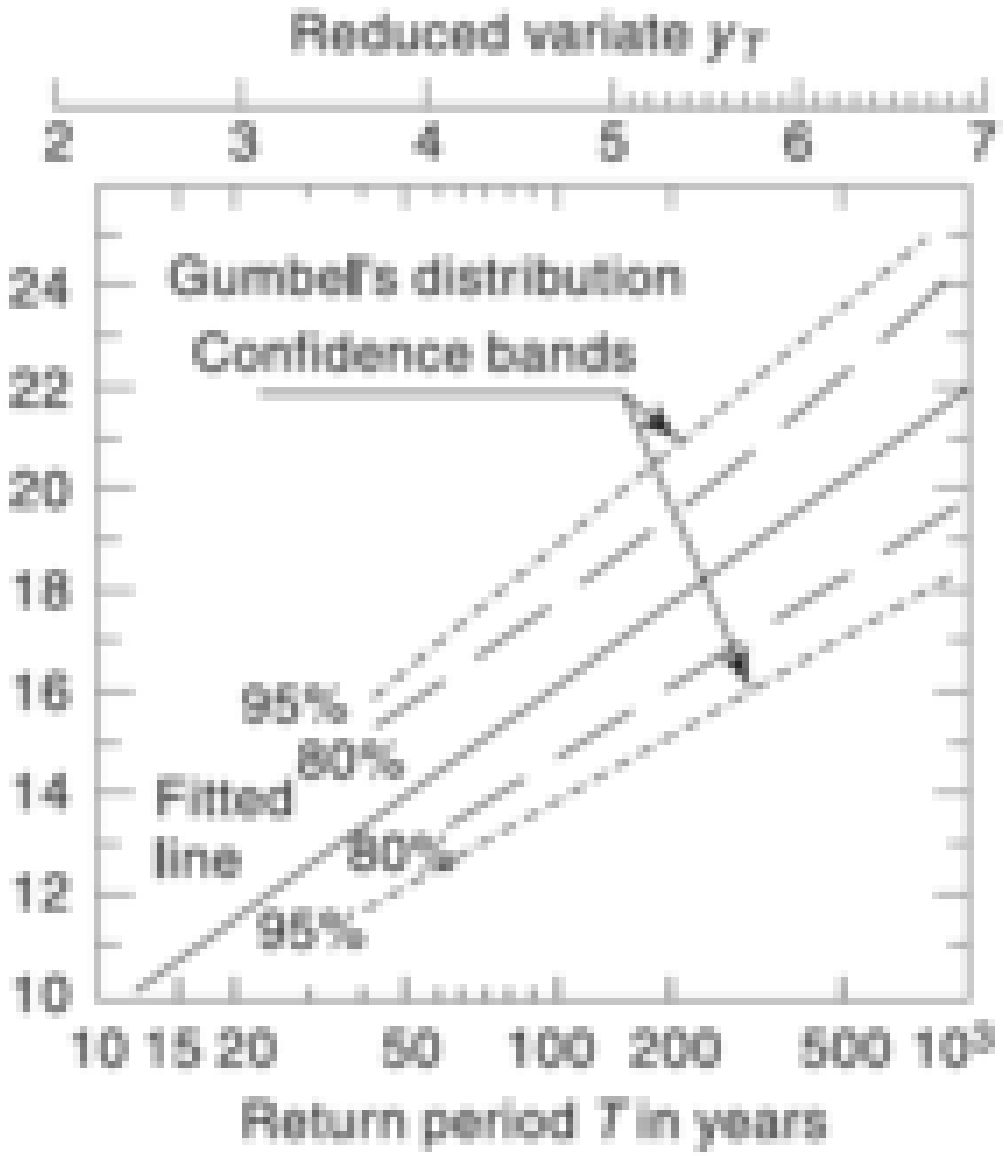

Fig. 7.4 *Confidence Bands for Gumbels Distribution—Example 7.8*

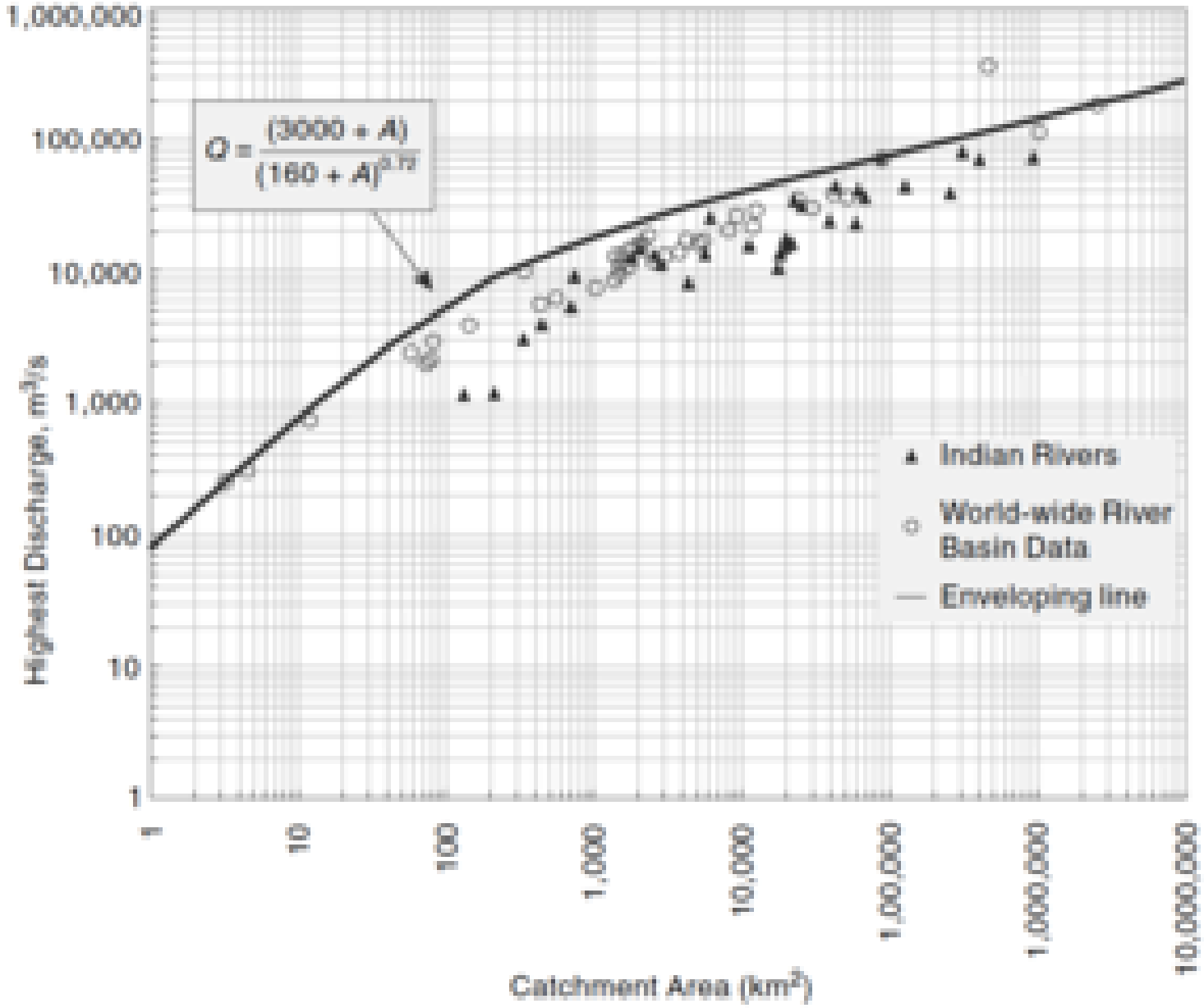

Fig. 7.5 ***Enveloping Line for Worldwide River Basin Data on Highest Floods (Data from Ref. 9)***

LECTURE ON ENGINEERING HYDROLOGY

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11-11-2020

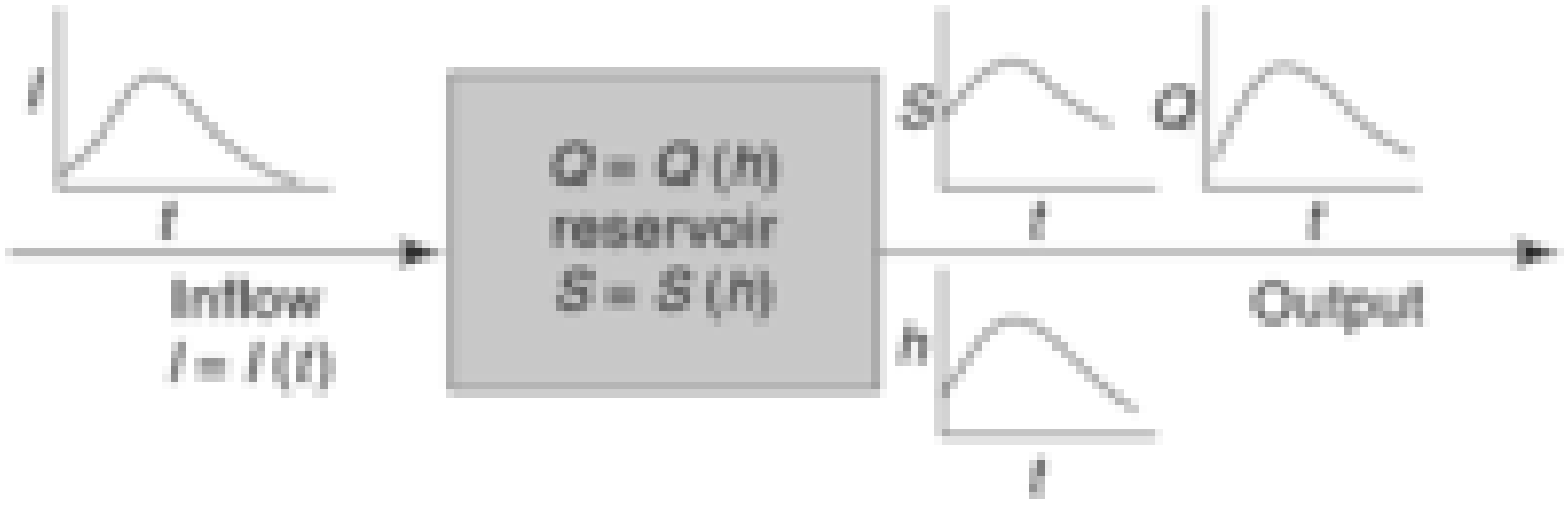

Fig. 8.1 *Storage Routing (Schematic)*

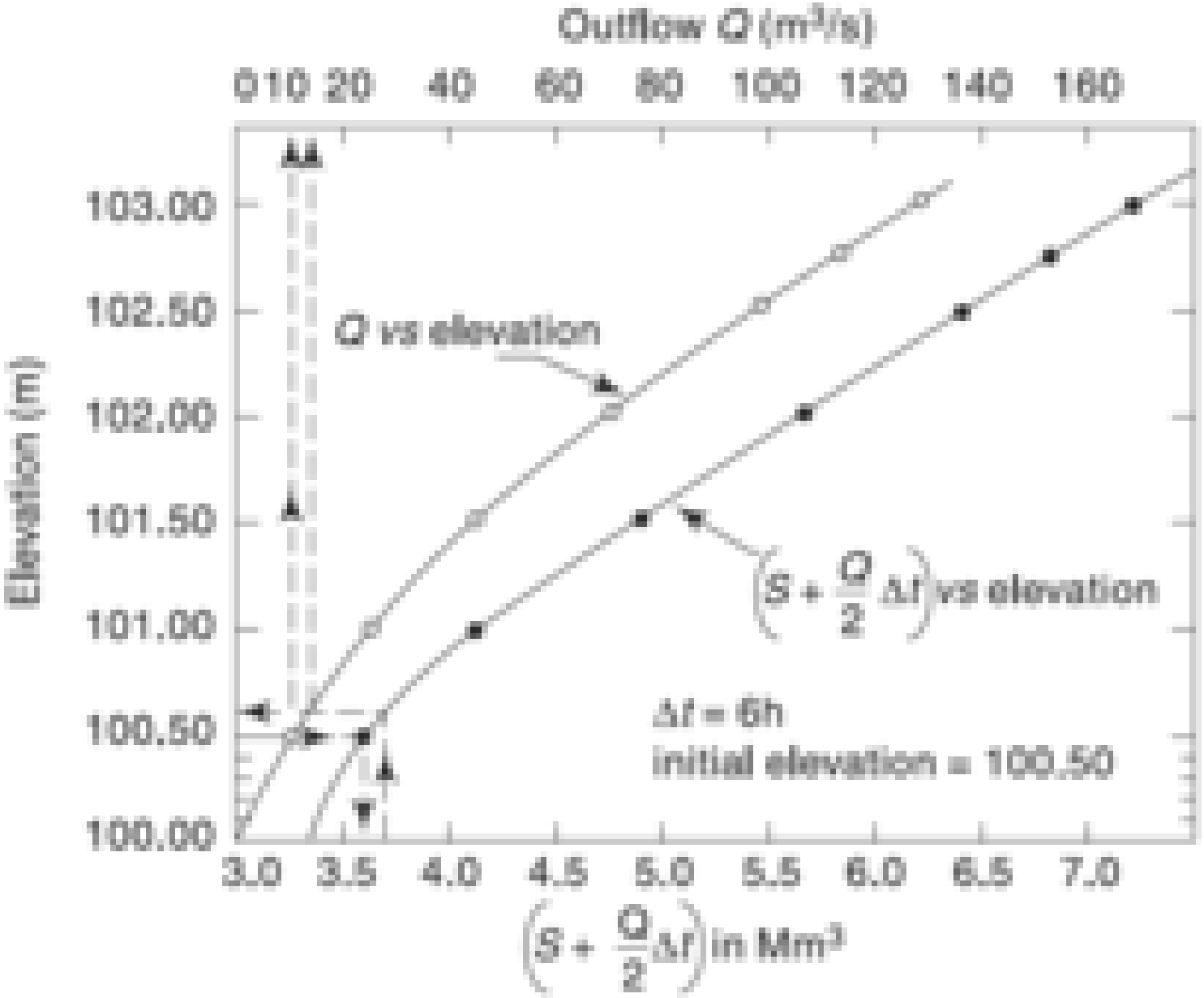

Fig. 8.2 *Modified Pul's Method of Storage Routing*

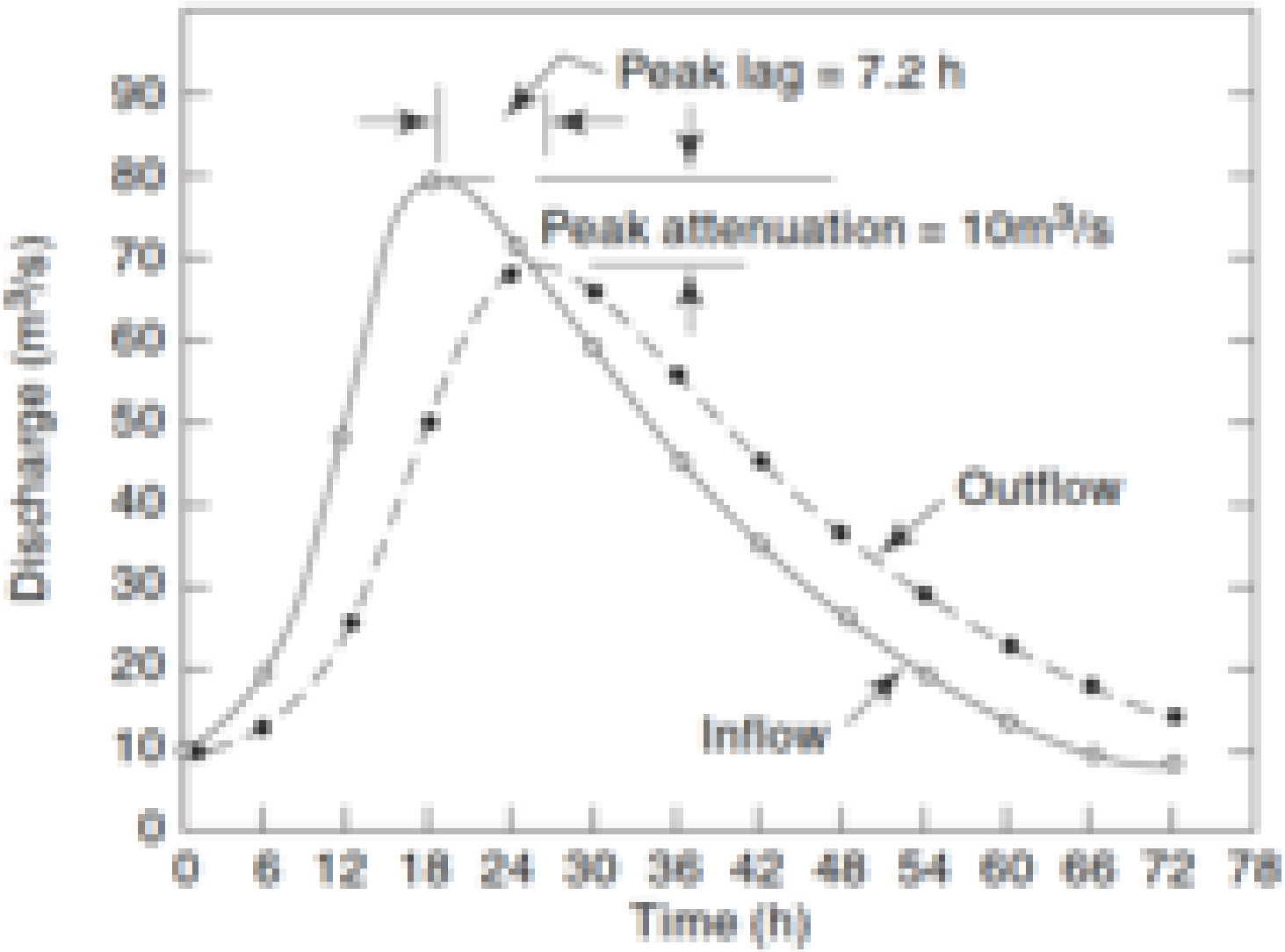

Fig. 8.3 *Variation of Inflow and Outflow Discharges—Example 8.1*

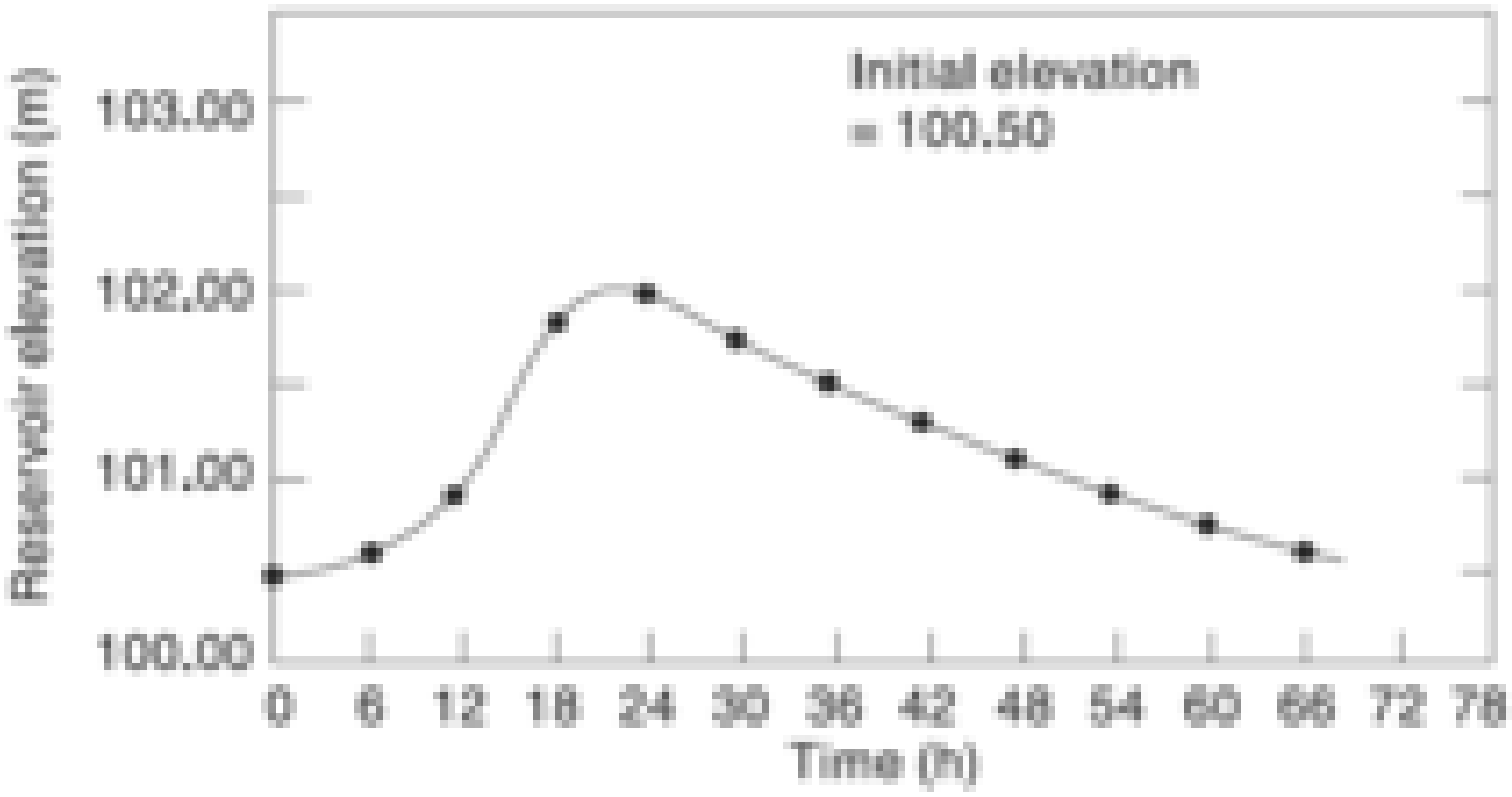

Fig. 8.4 *Variation of Reservoir Elevation with Time—Example 8.1*

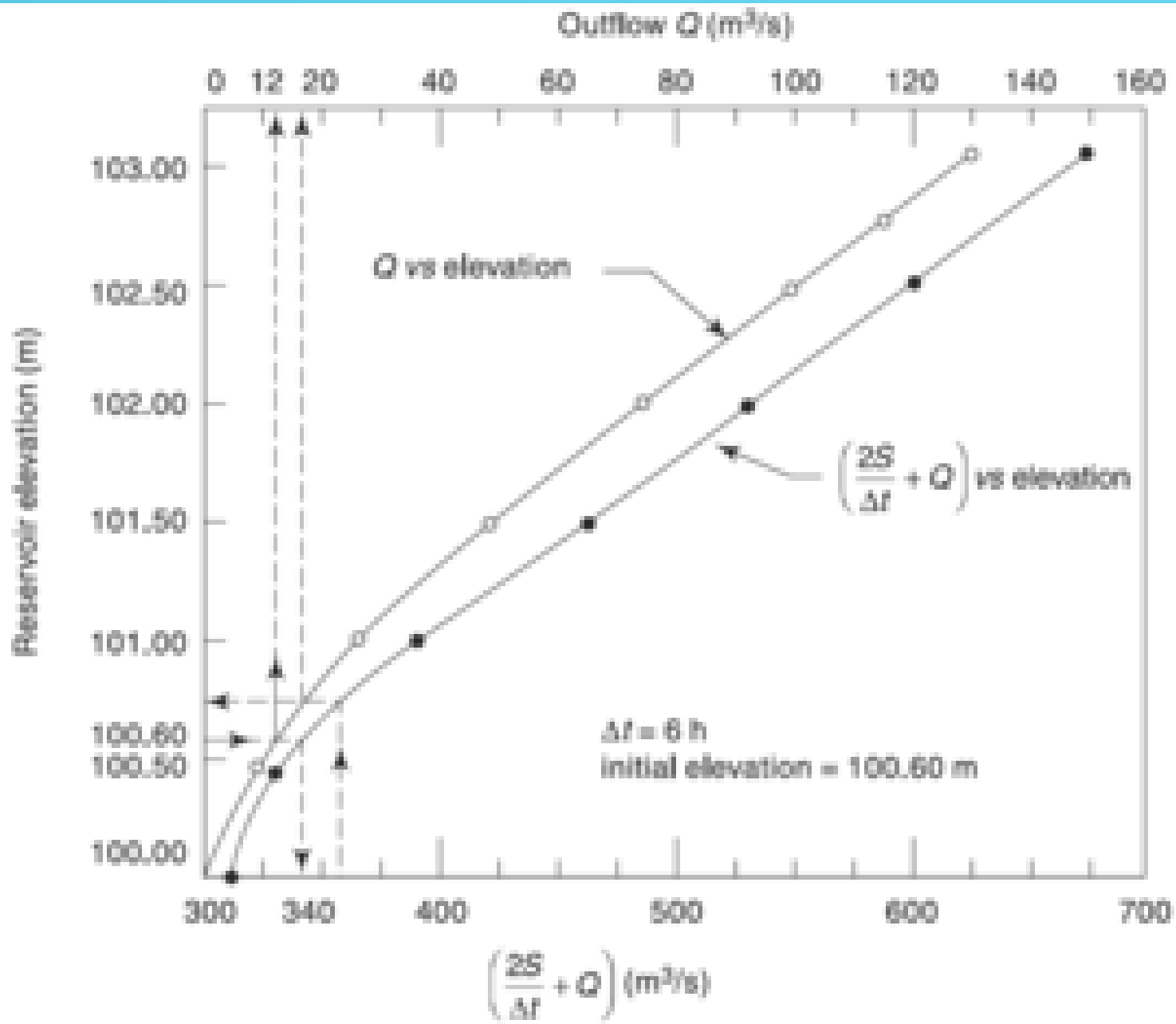

Fig. 8.5 *Goodrich Method of Storage Routing—Example 8.2*

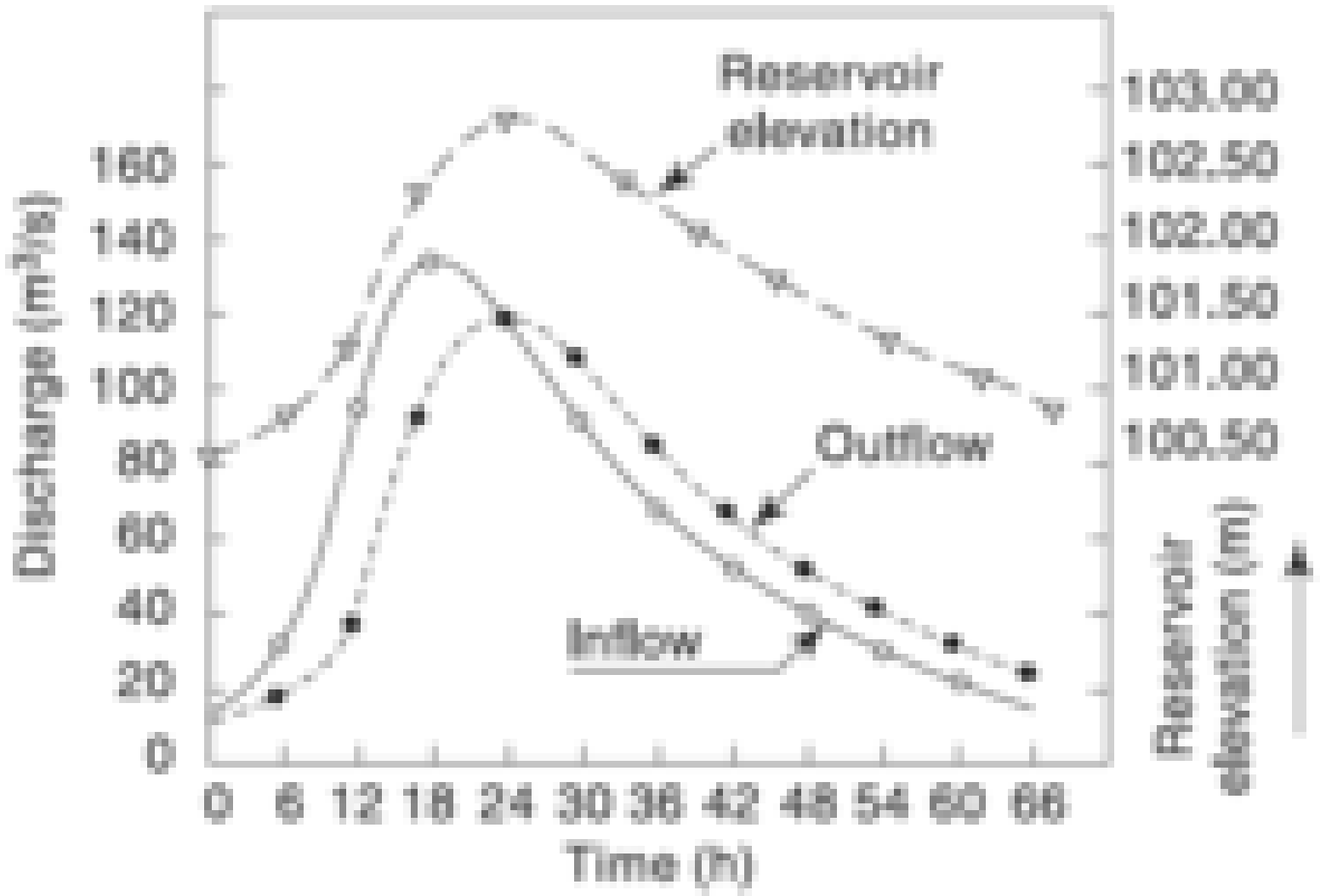

Fig. 8.6 ***Results of Reservoir Routing—Example 8.2***

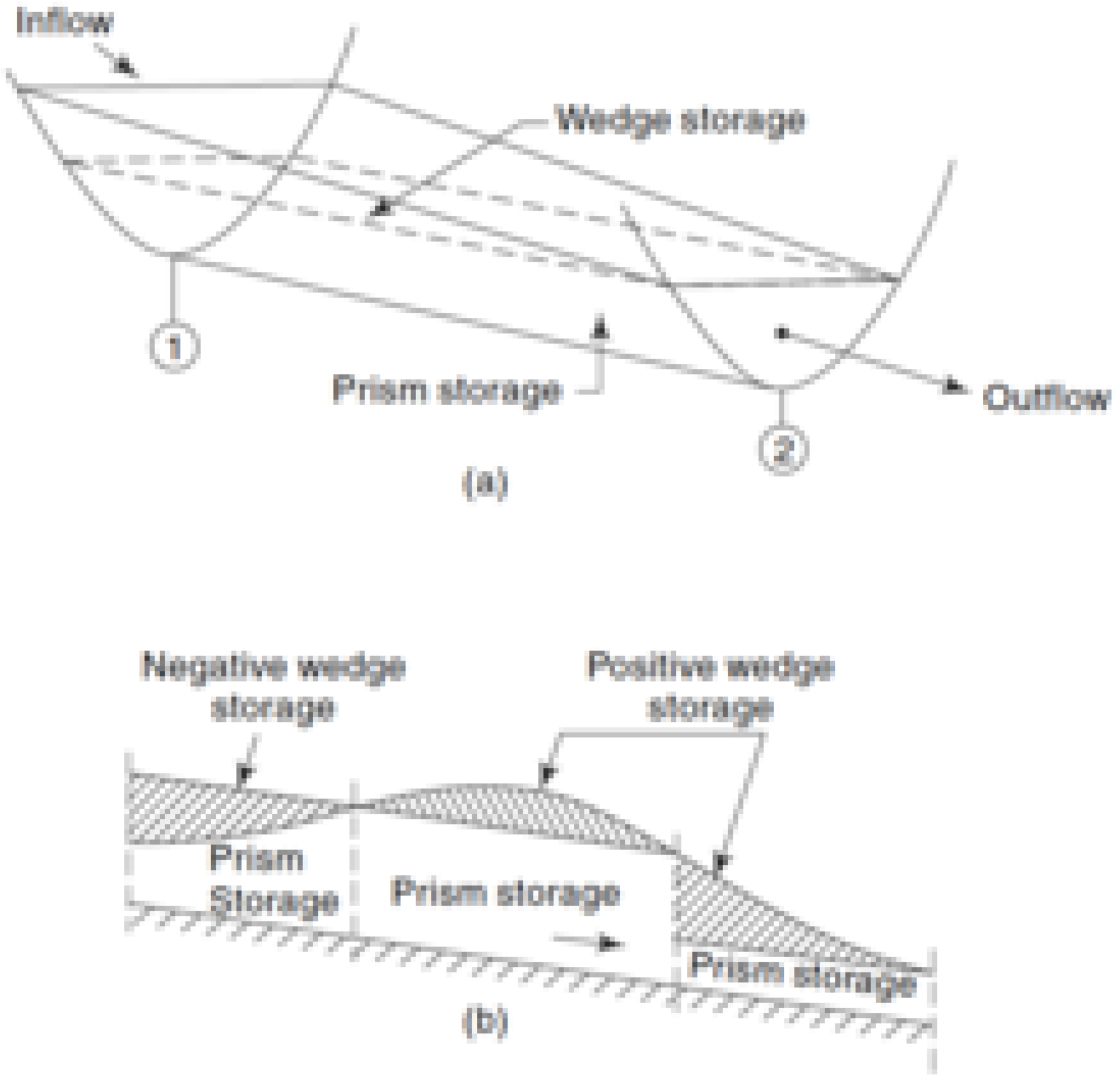

Fig. 8.7 *Storage in a Channel Reach*

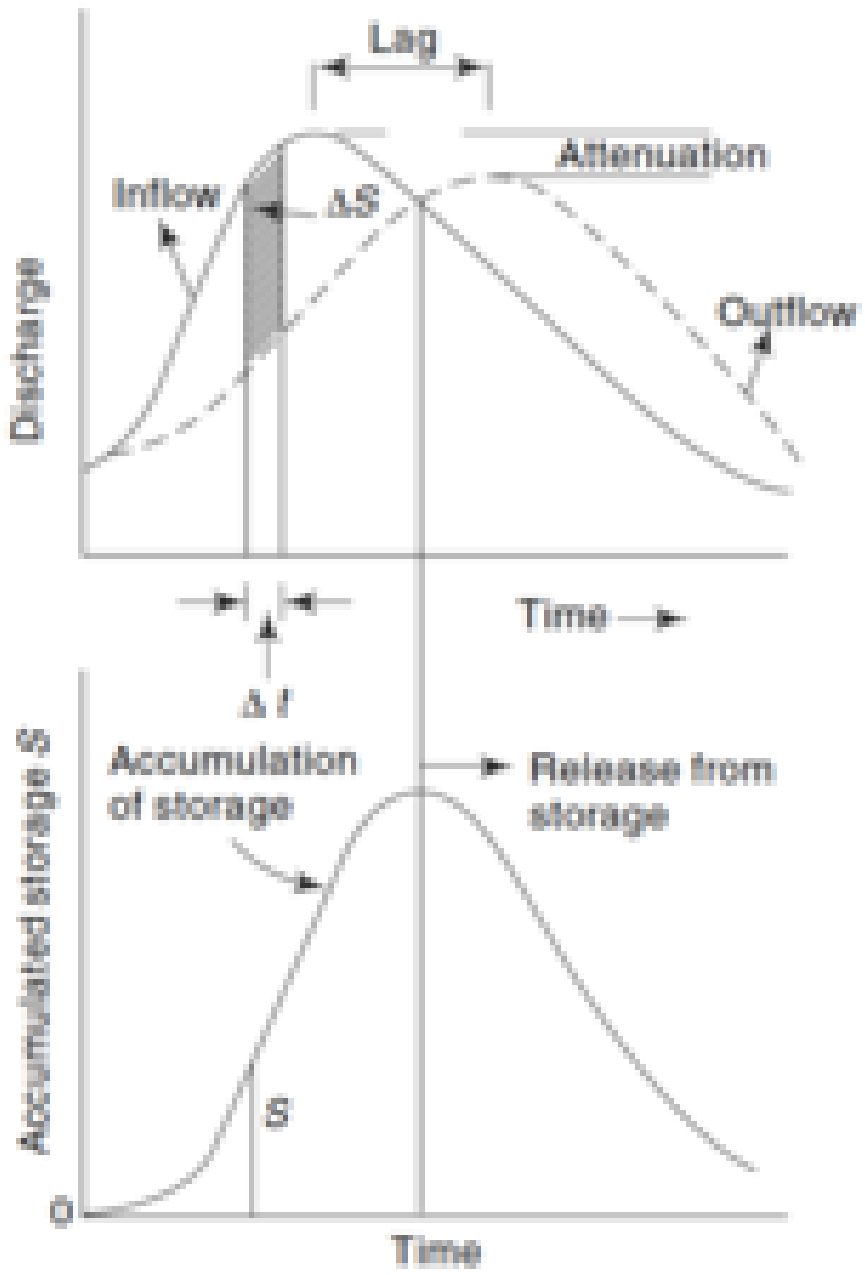

Fig. 8.8 *Hydrographs and Storage in Channel Routing*

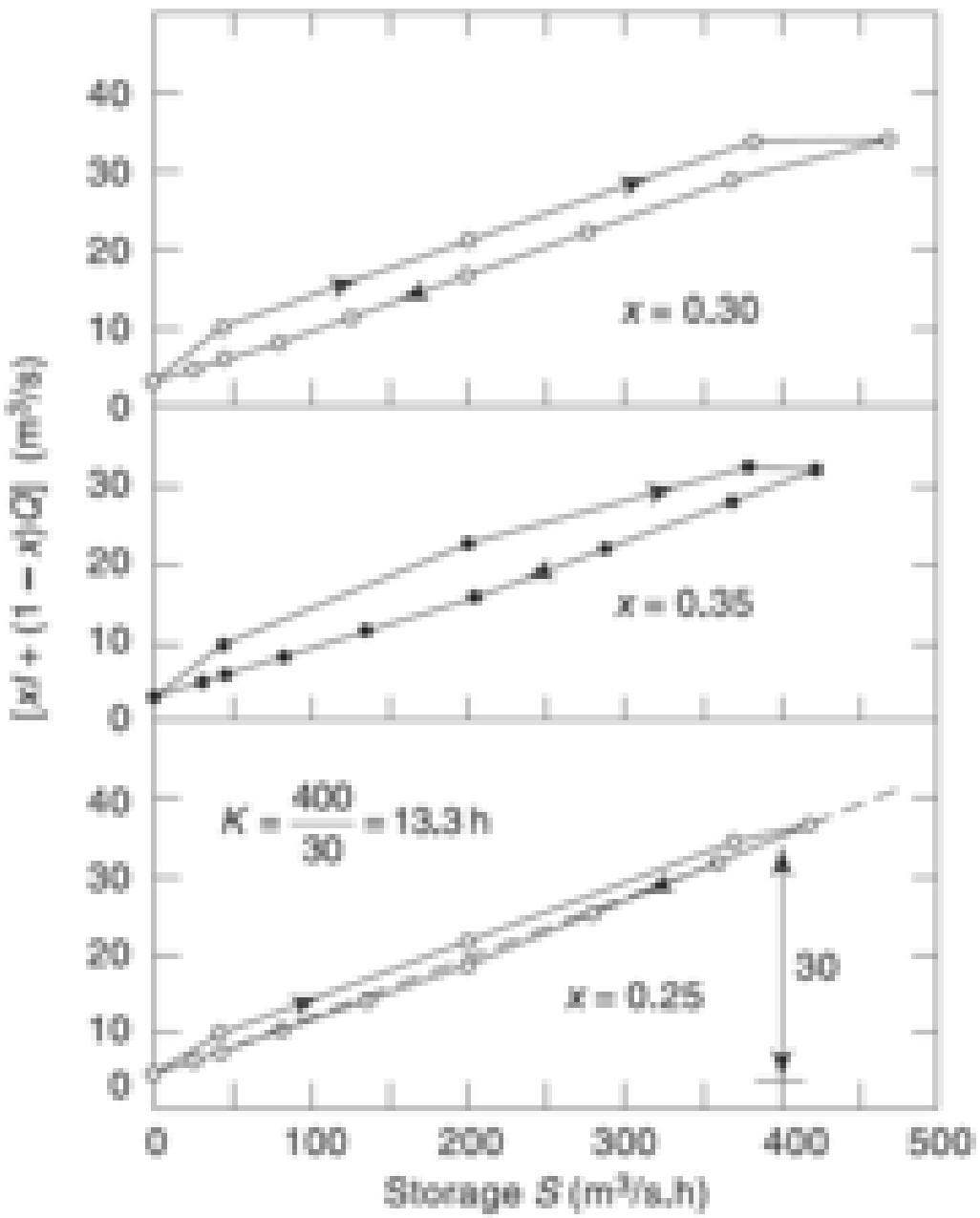

Fig. 8.9 *Determination of K and x for a channel reach—Example 8.4*

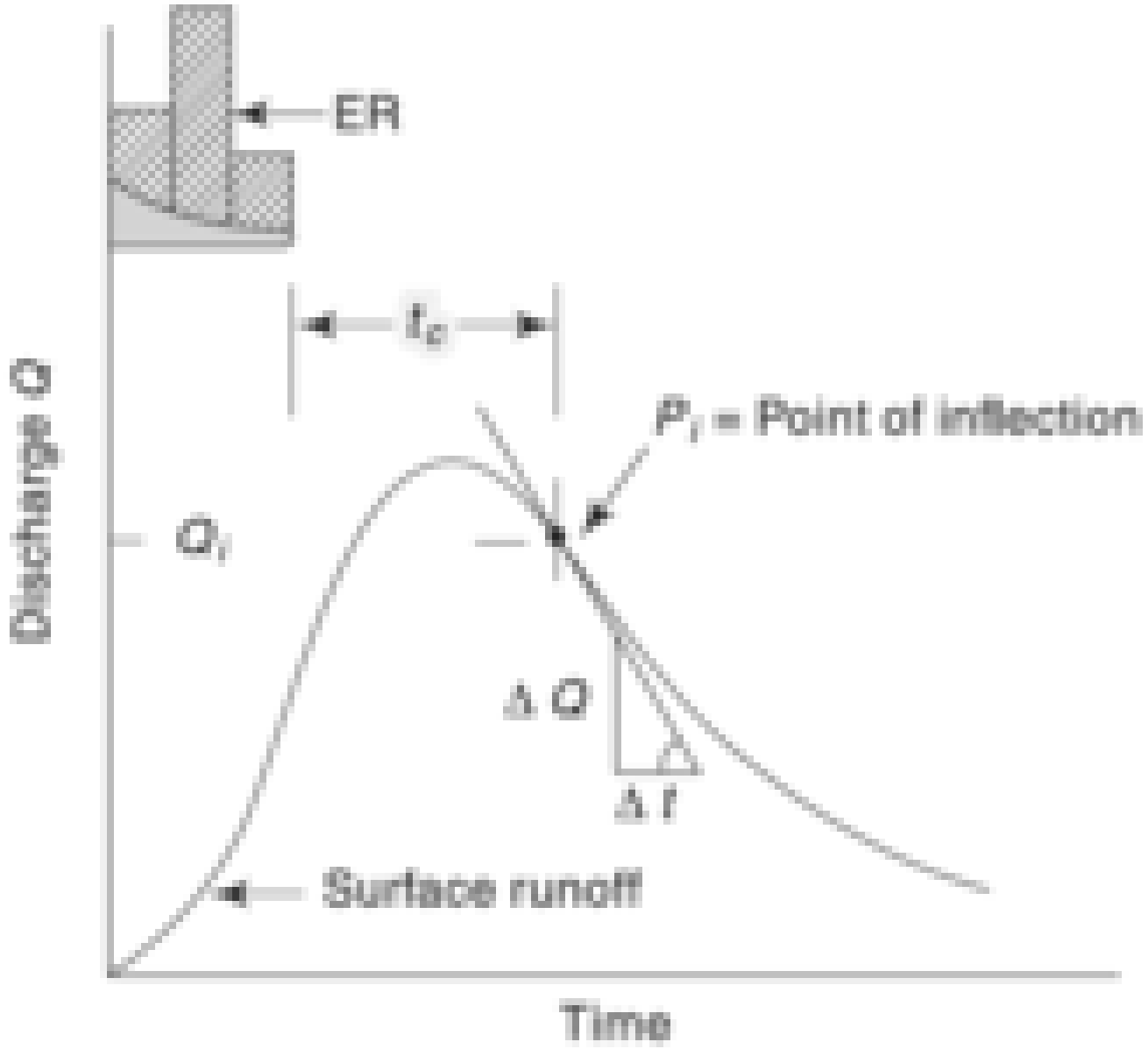

Fig. 8.10 *Surface Runoff of a Catchment*

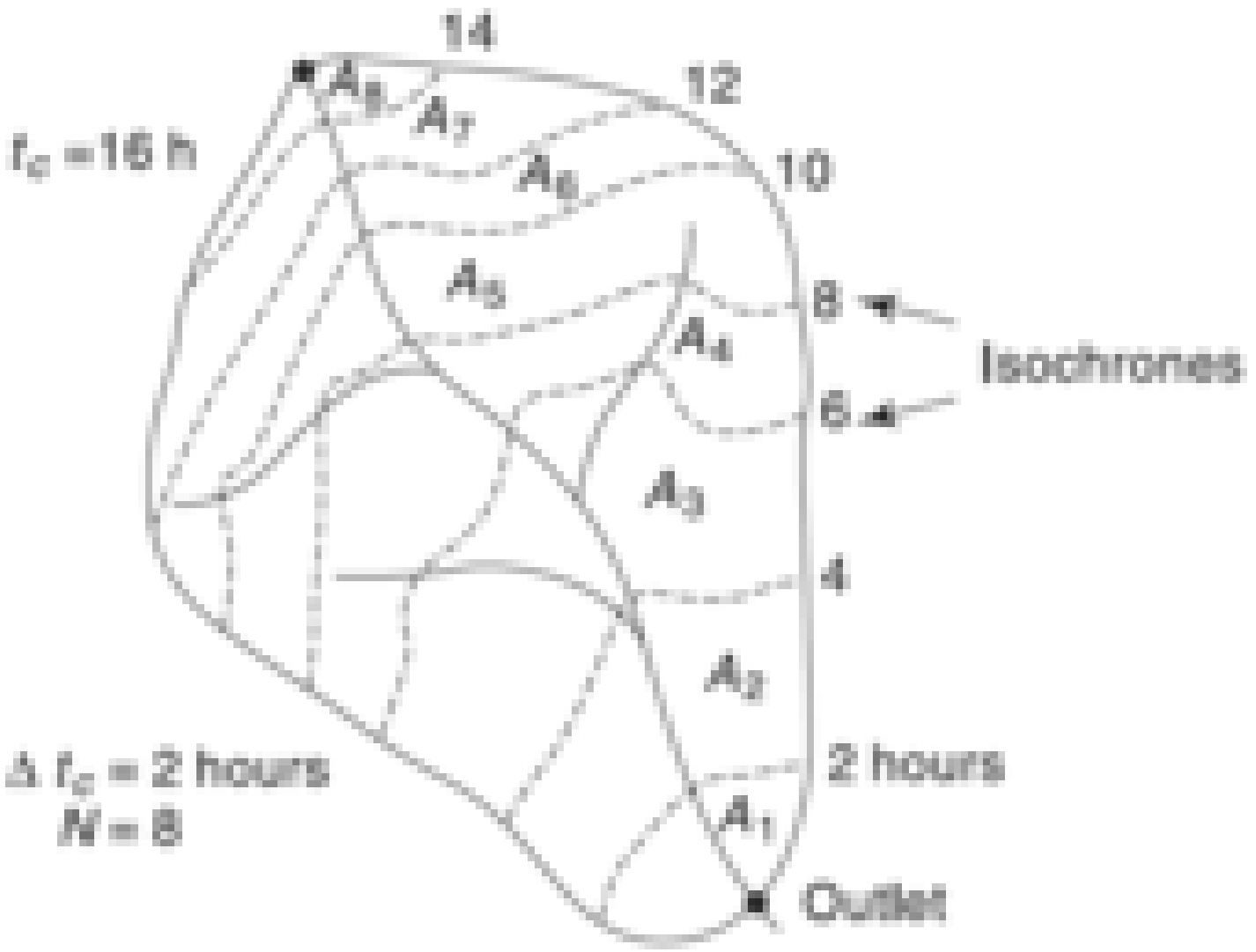

Fig. 8.11 *Isochrones in a Catchment*

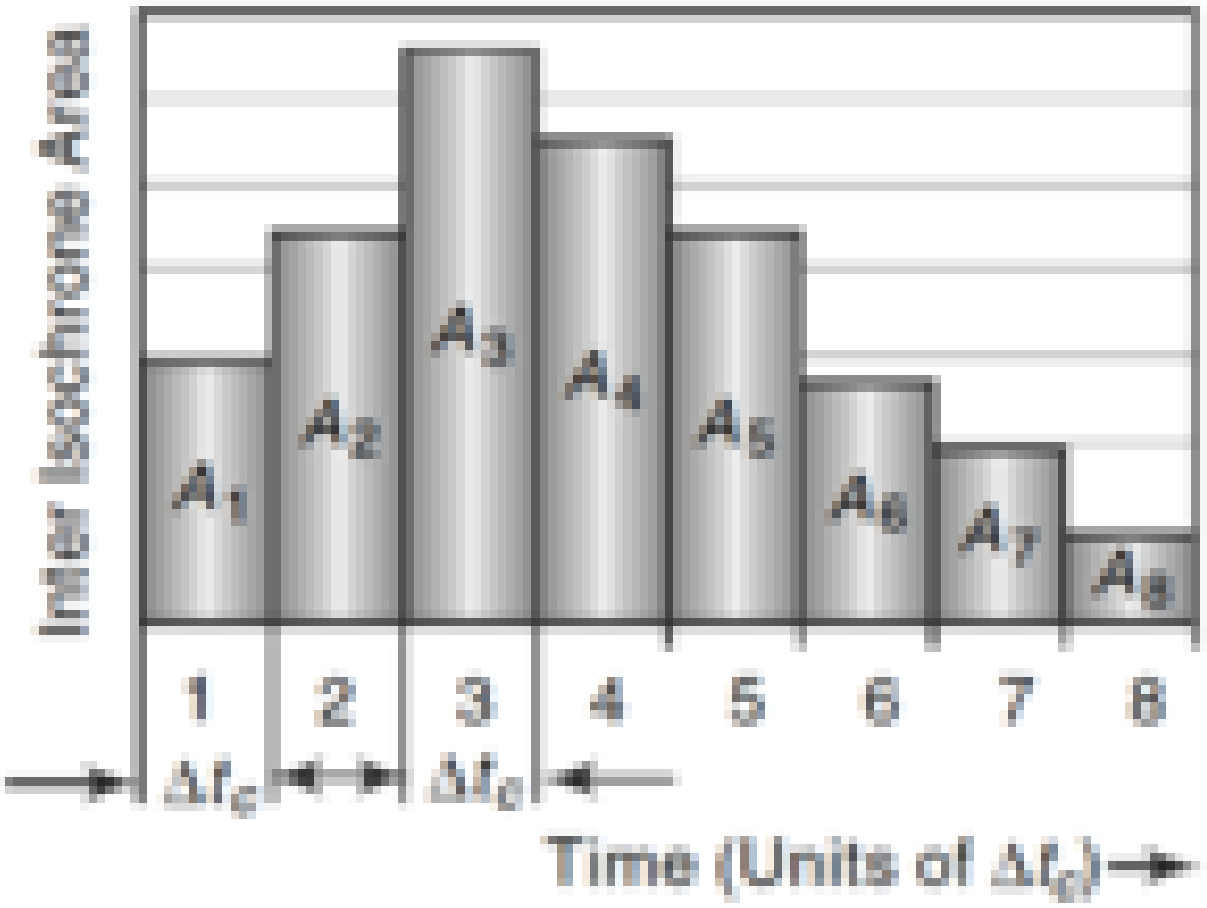

Fig. 8.12 *Time-area Histogram*

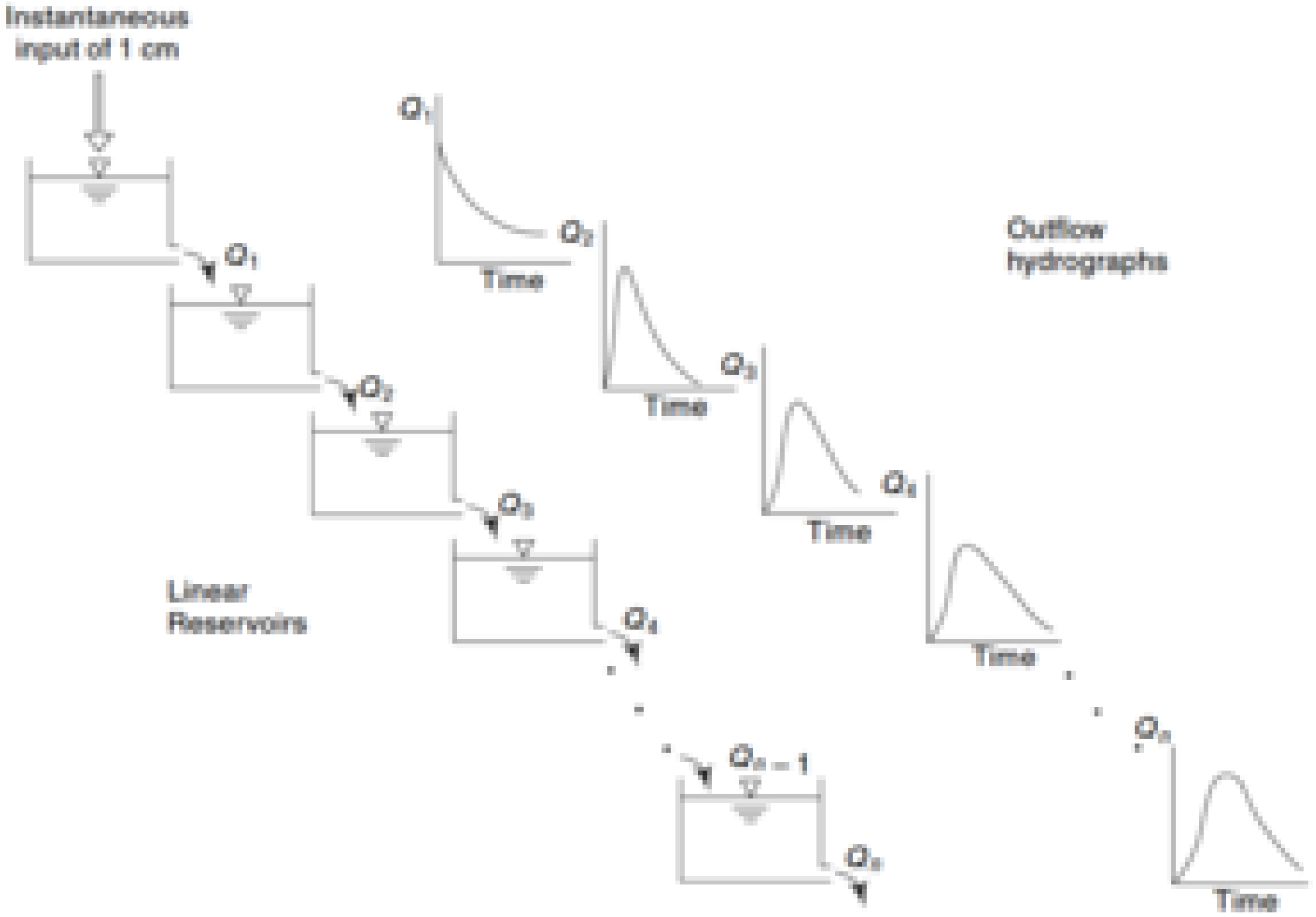

Fig. 8.13 *Nash Model: Cascade of Linear Reservoirs*

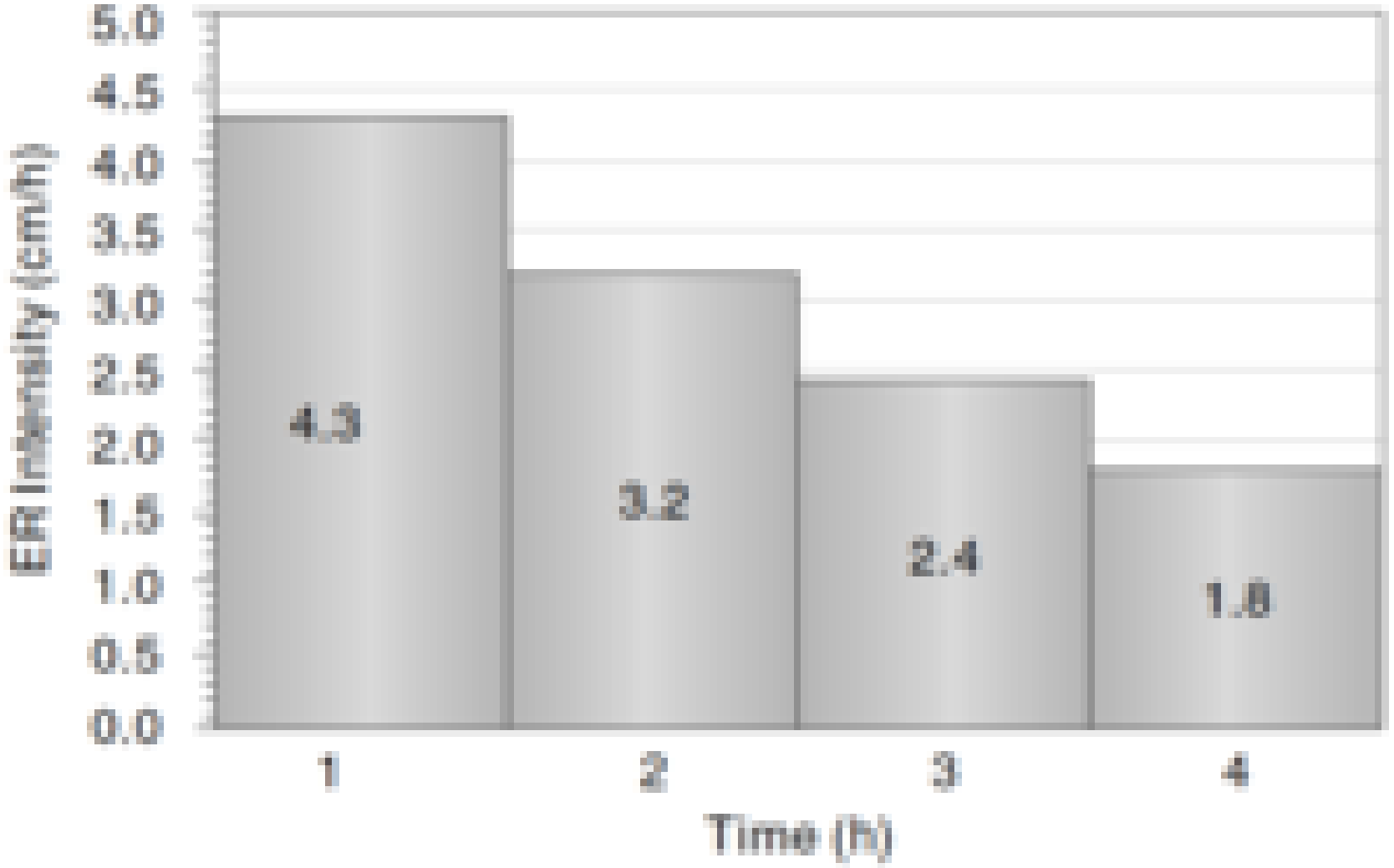

Fig. 8.14(a) ***Excess Rainfall Hyetograph of Example 8.7***

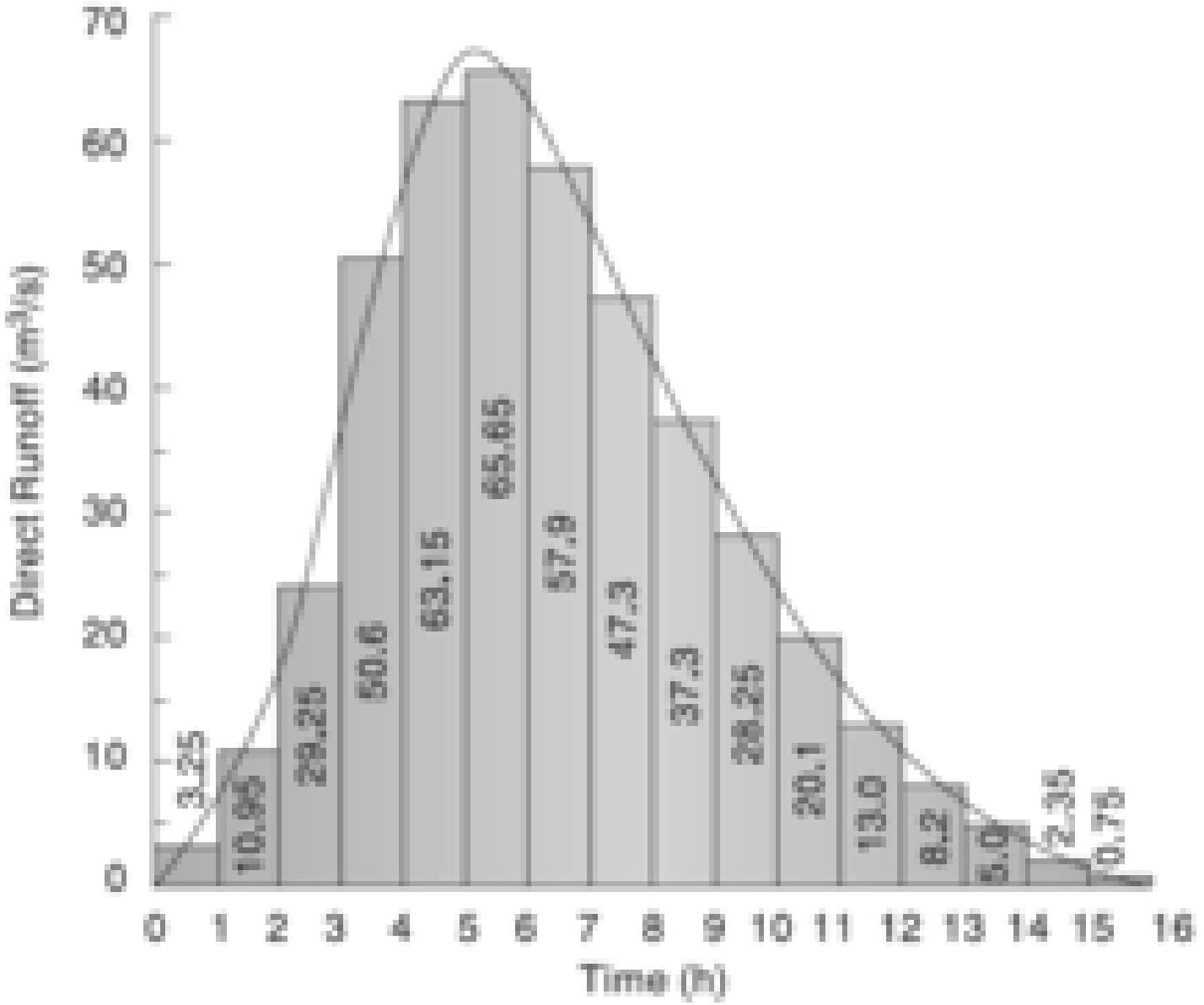

Fig. 8.14(b) *Direct Runoff Hydrograph of Example 8.7*

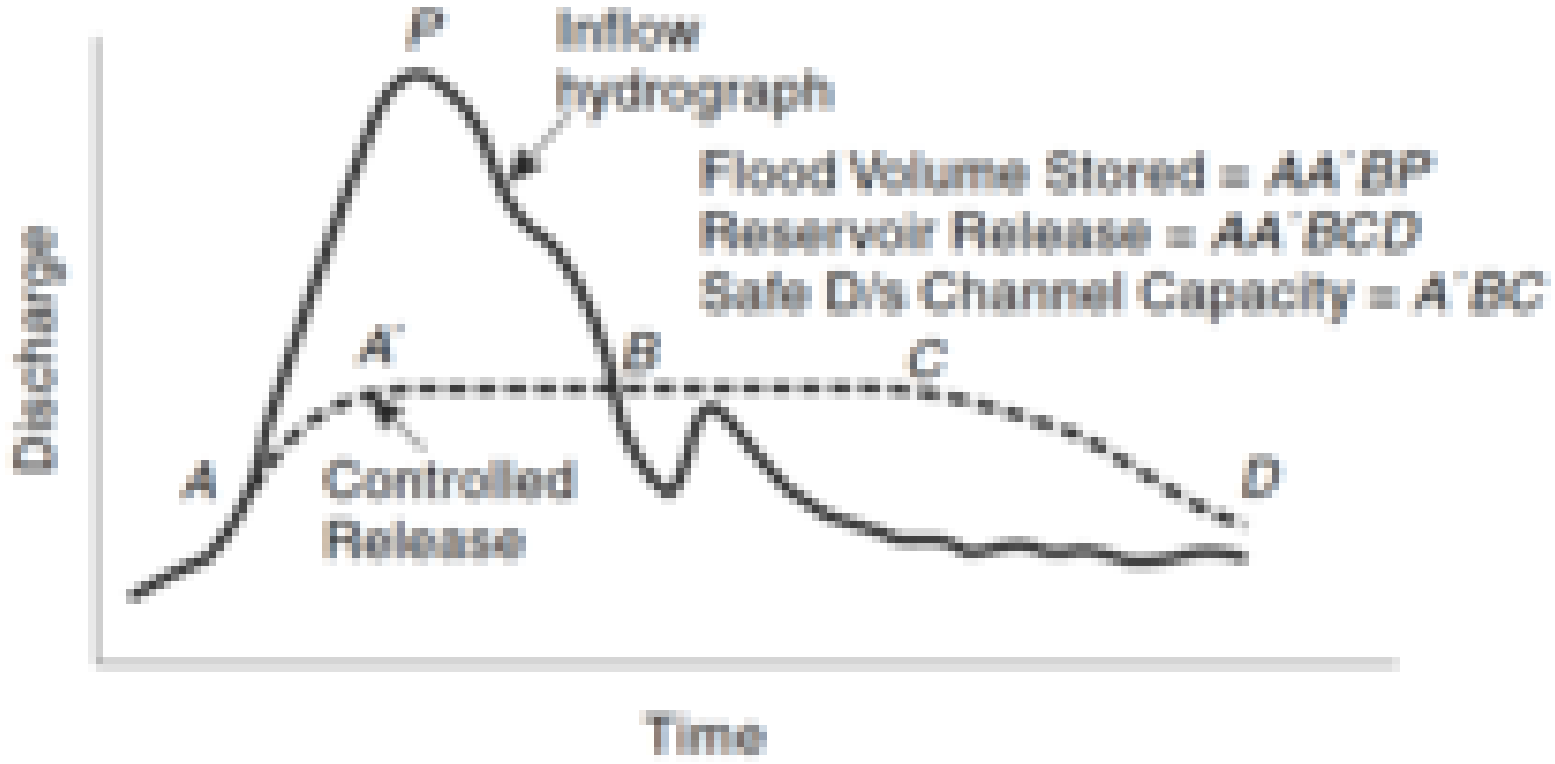

Fig. 8.15 *Flood Control Operation of a Reservoir*

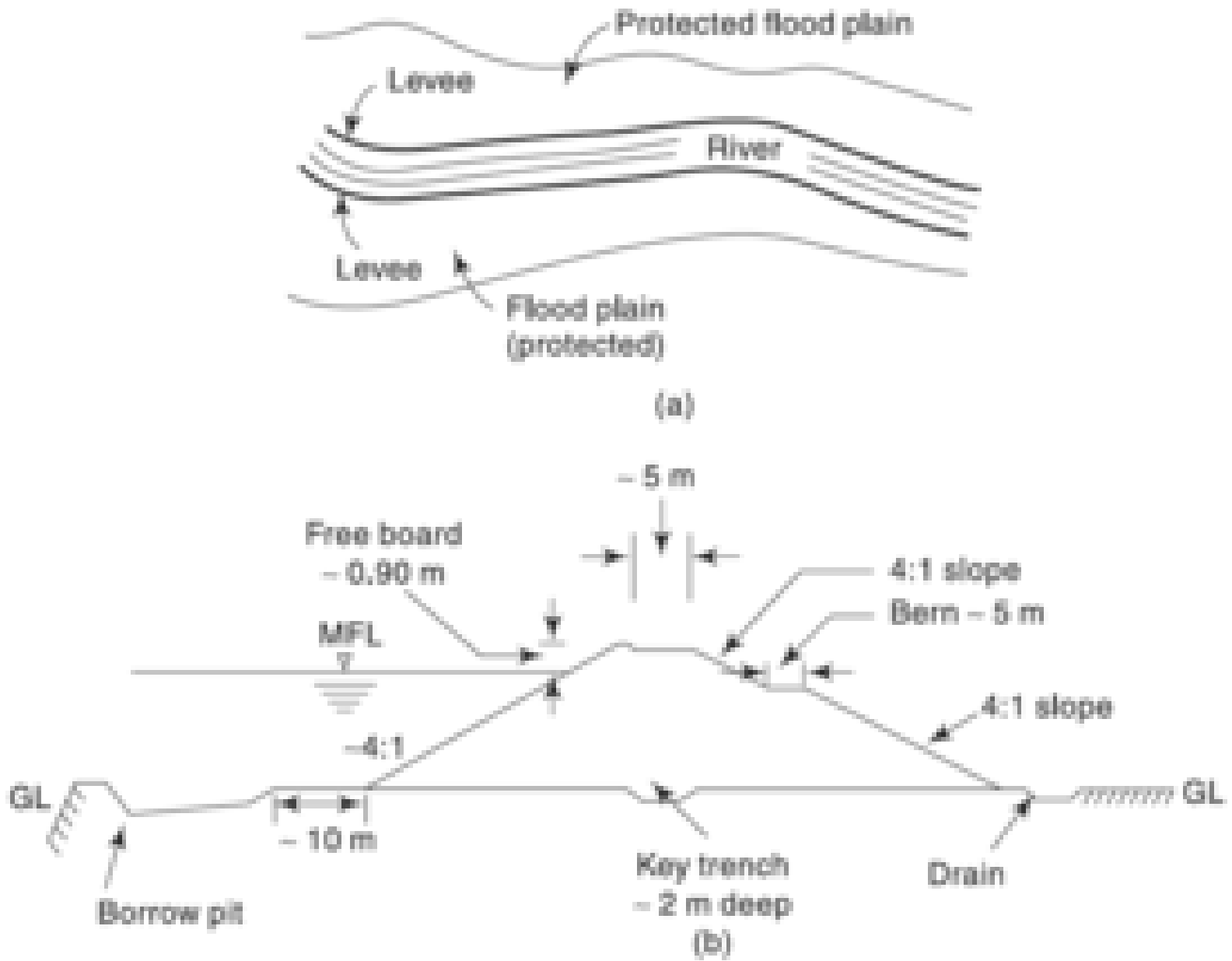

Fig. 8.16 *A typical levee: (a) Plan (schematic) (b) Cross section*

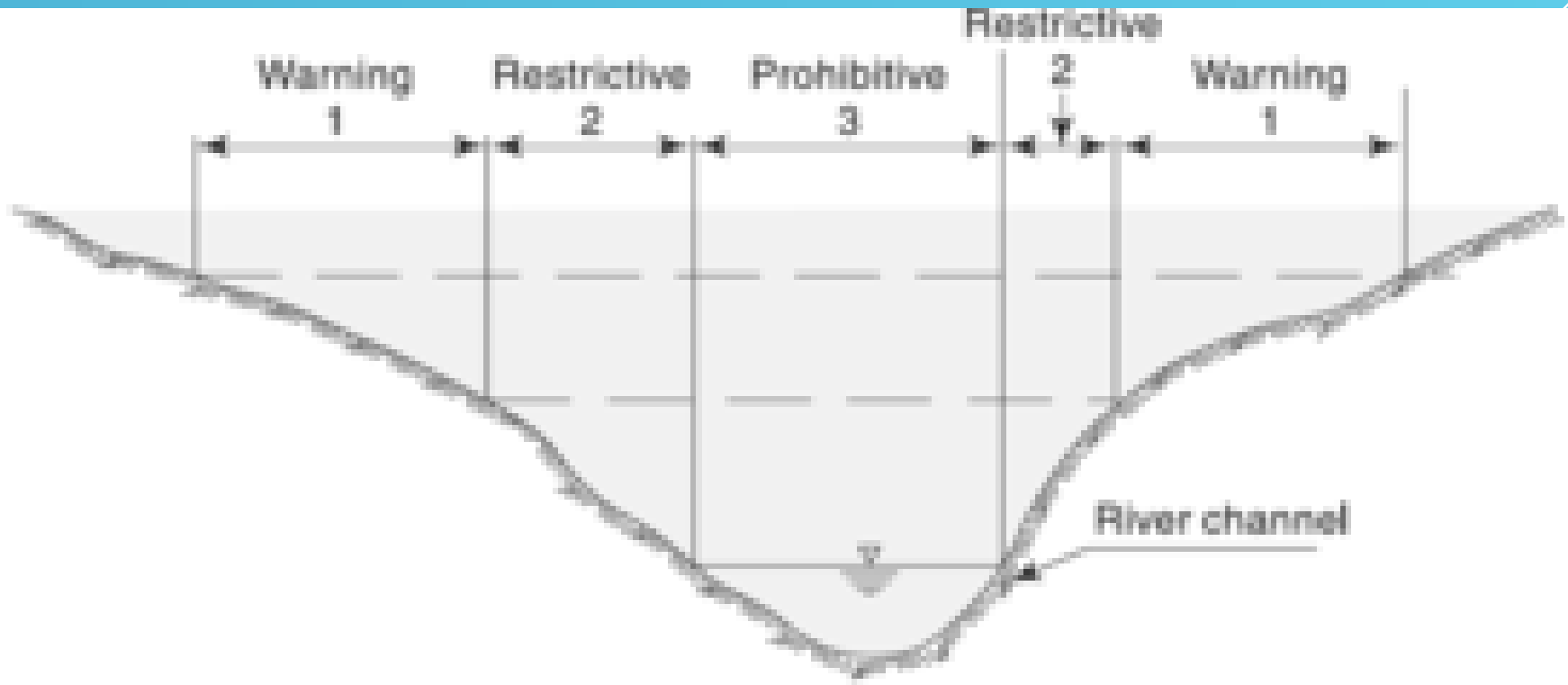

Fig. 8.17 *Conceptual Zoning of a Flood Plain*

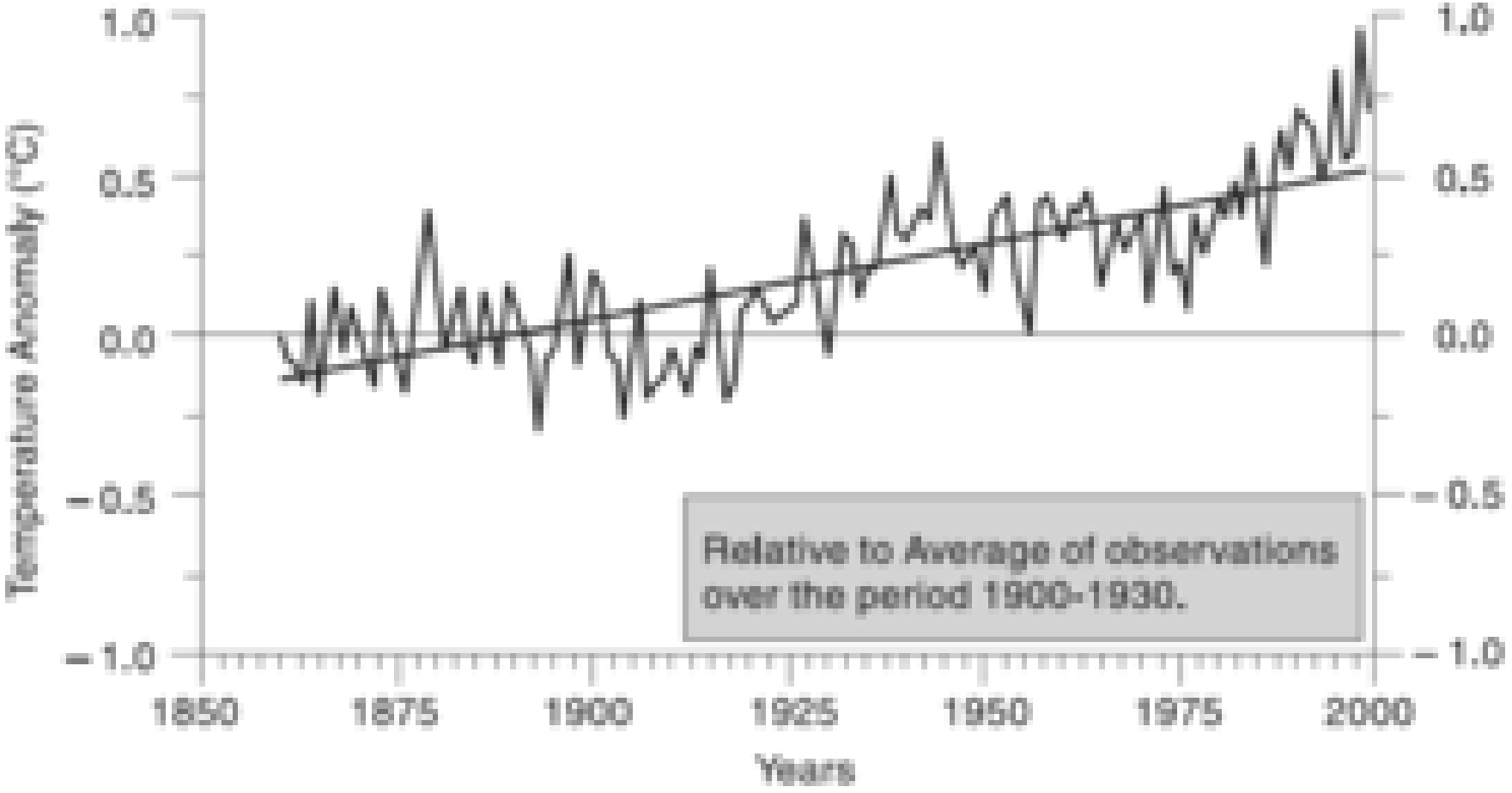

Fig. 8.18 *Observed Rise in Global Mean Temperature (Ref. 13.)*

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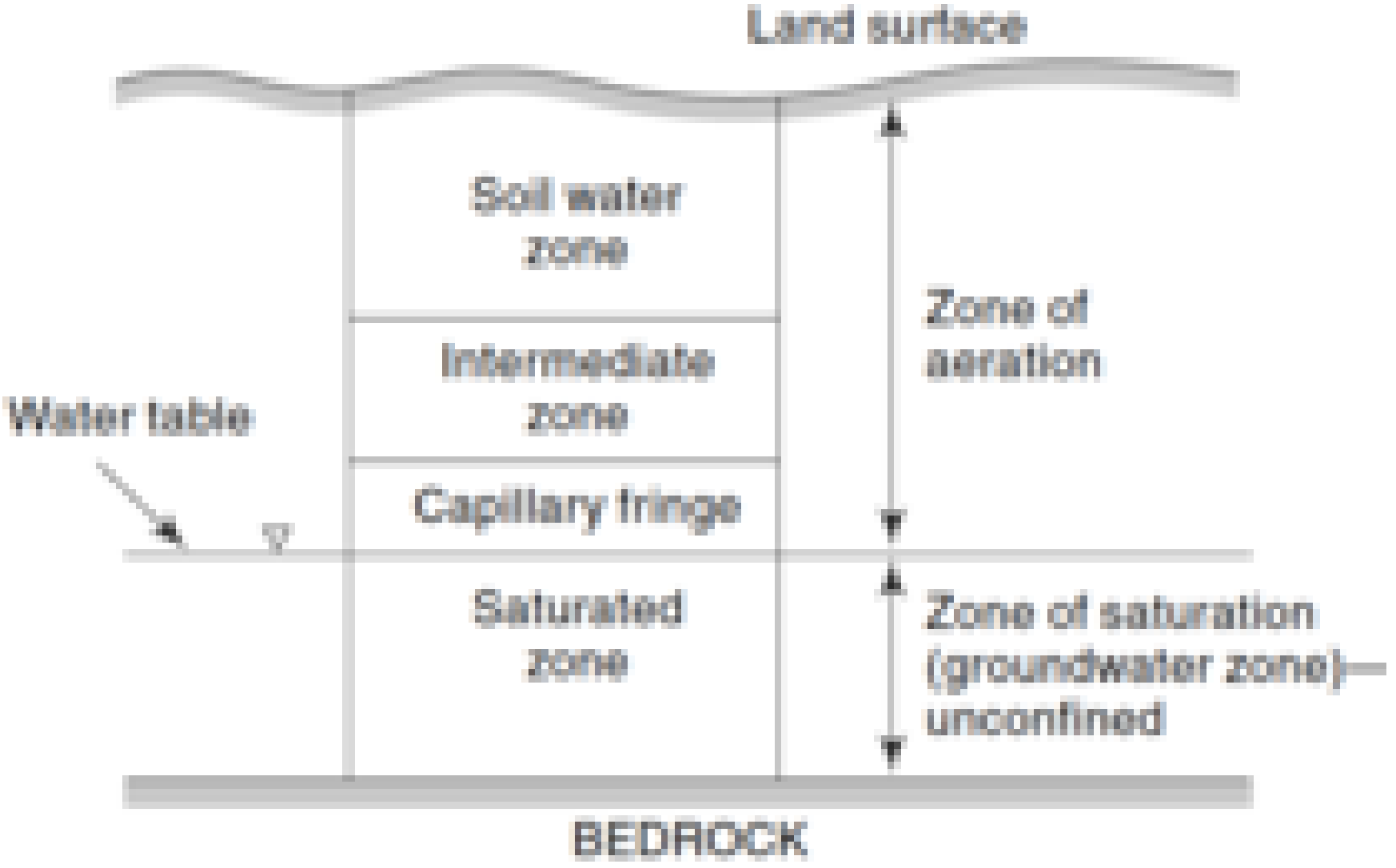

Fig. 9.1 *Classification of Subsurface Water*

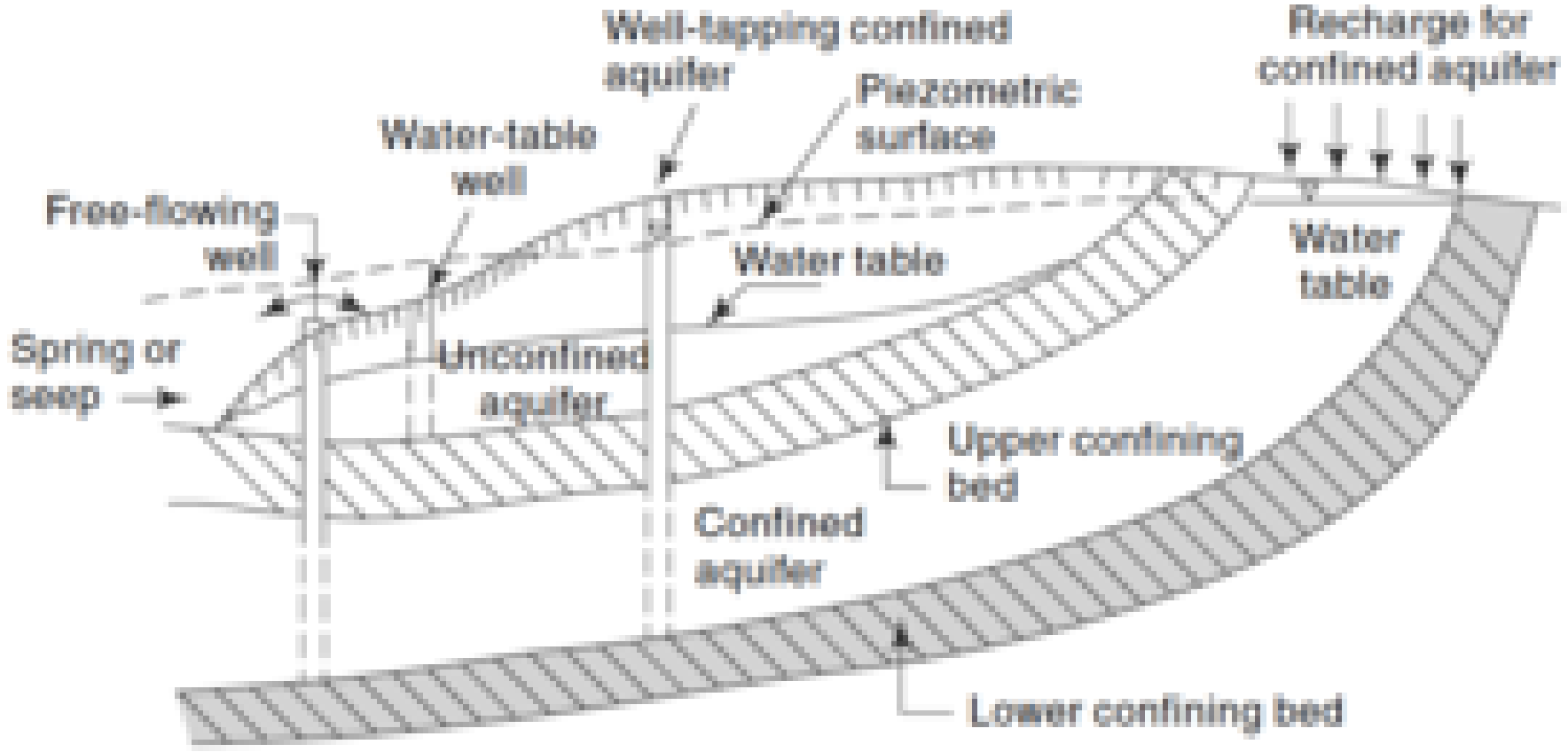

Fig. 9.2 *Confined and Unconfined Aquifers*

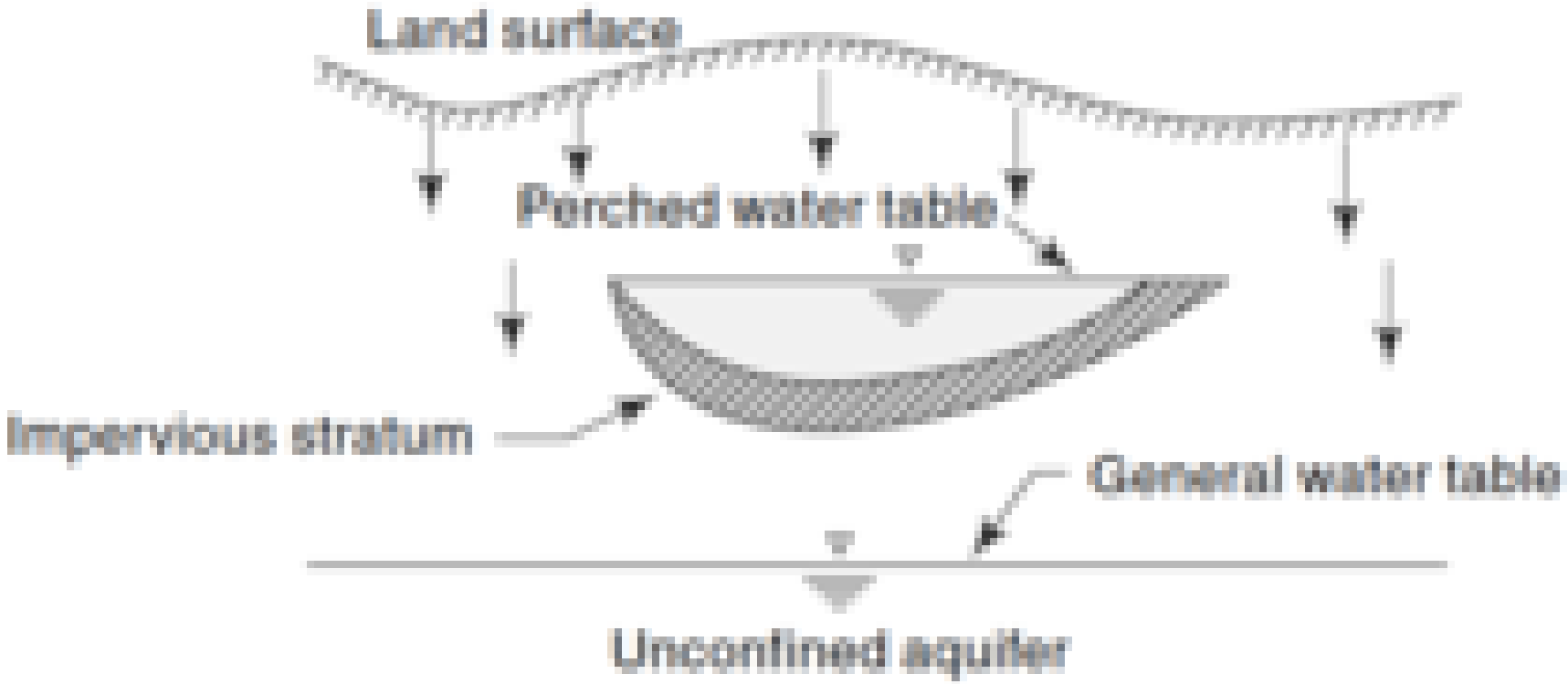

Fig. 9.3 ***Perched Water Table***

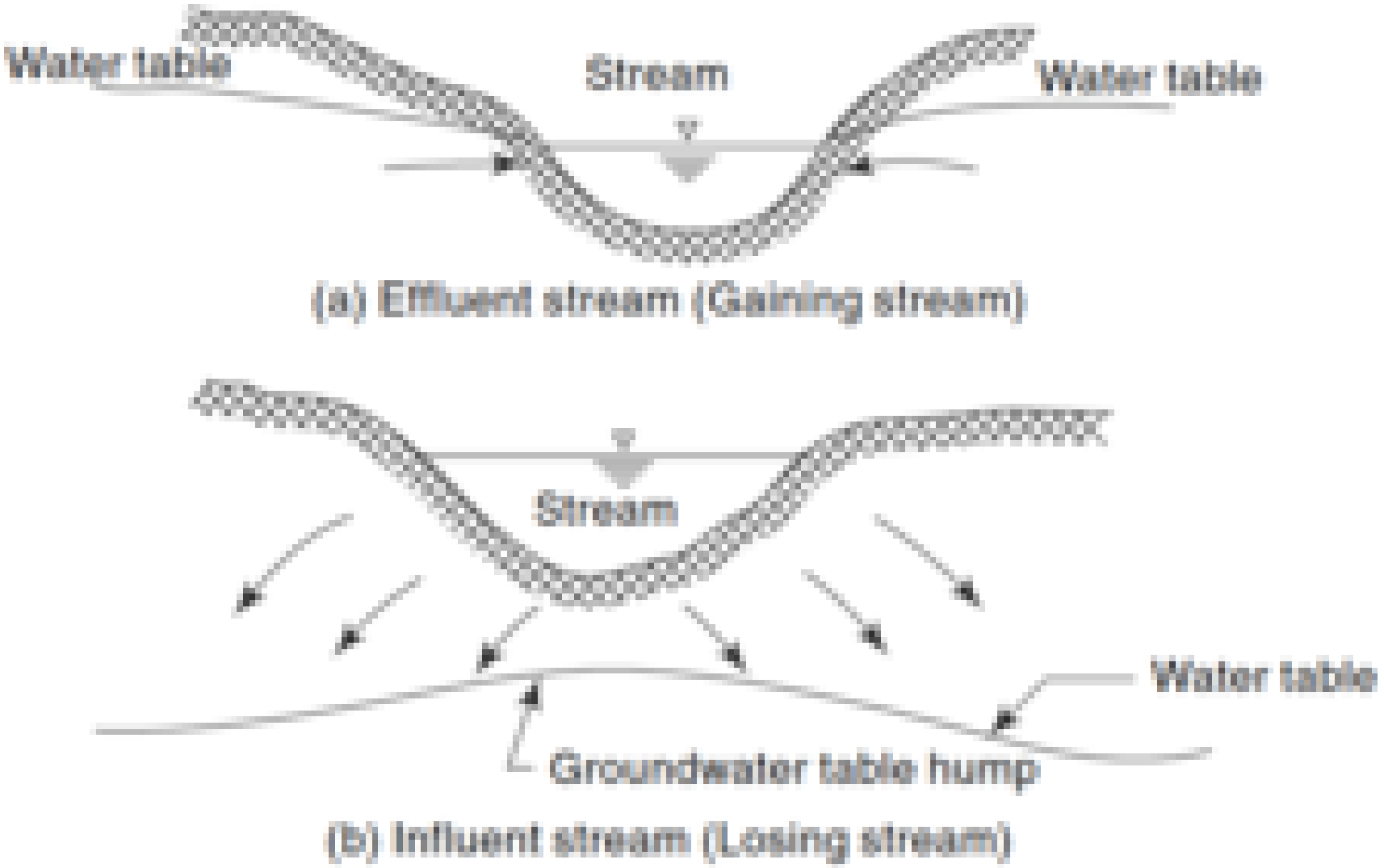

Fig. 9.4 ***Effluent and Influent Streams***

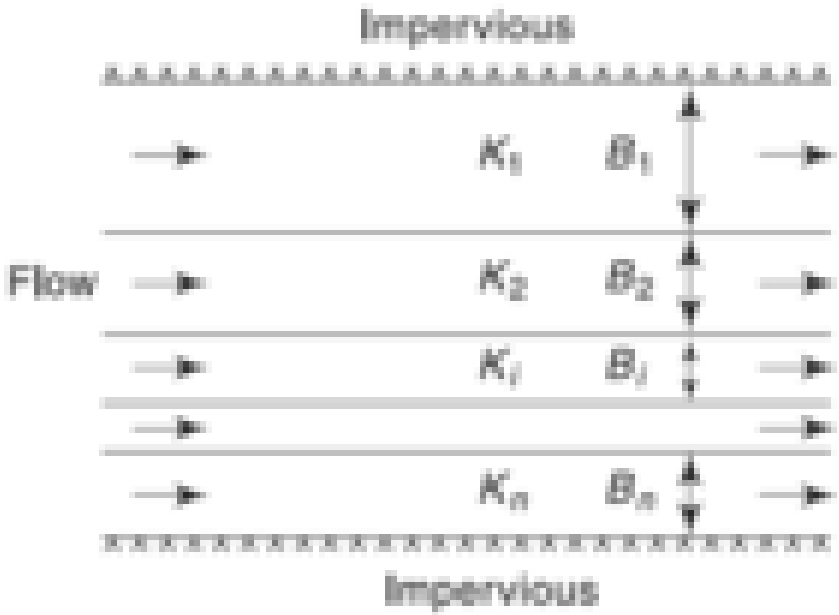

Fig. 9.5(a) *Flow Parallel to Stratification*

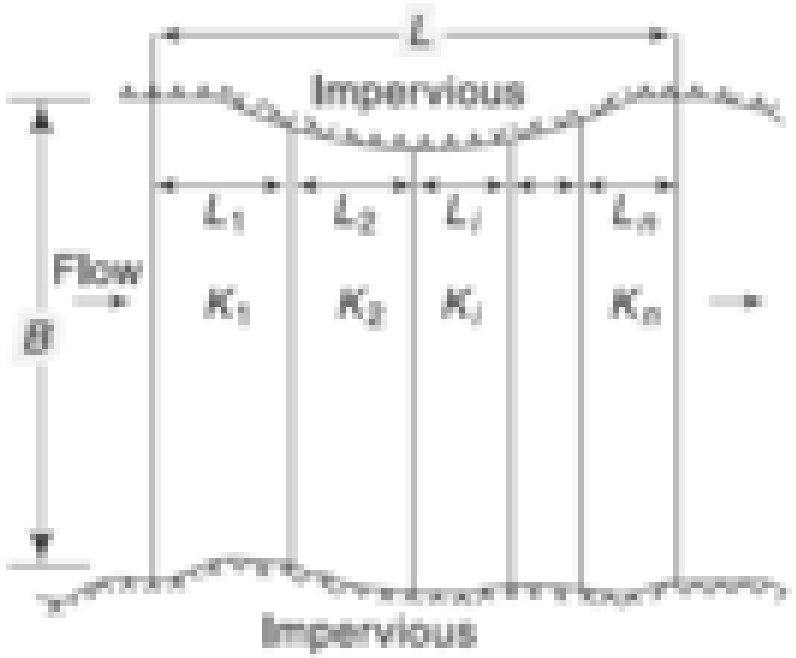

Fig. 9.5(b) *Flow Normal to Stratification*

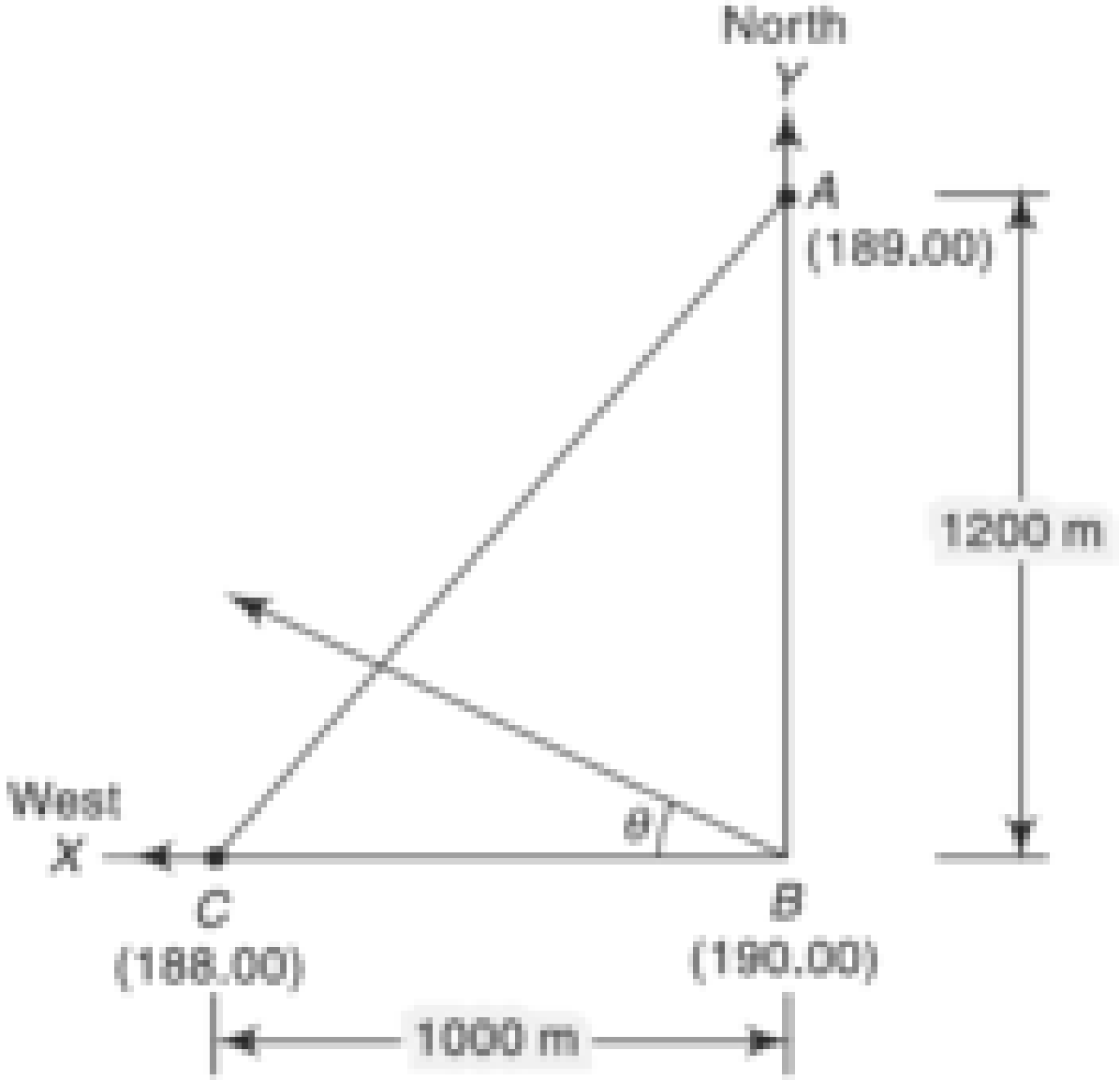

Fig. 9.6 *Layout of Wells—Example 9.3*

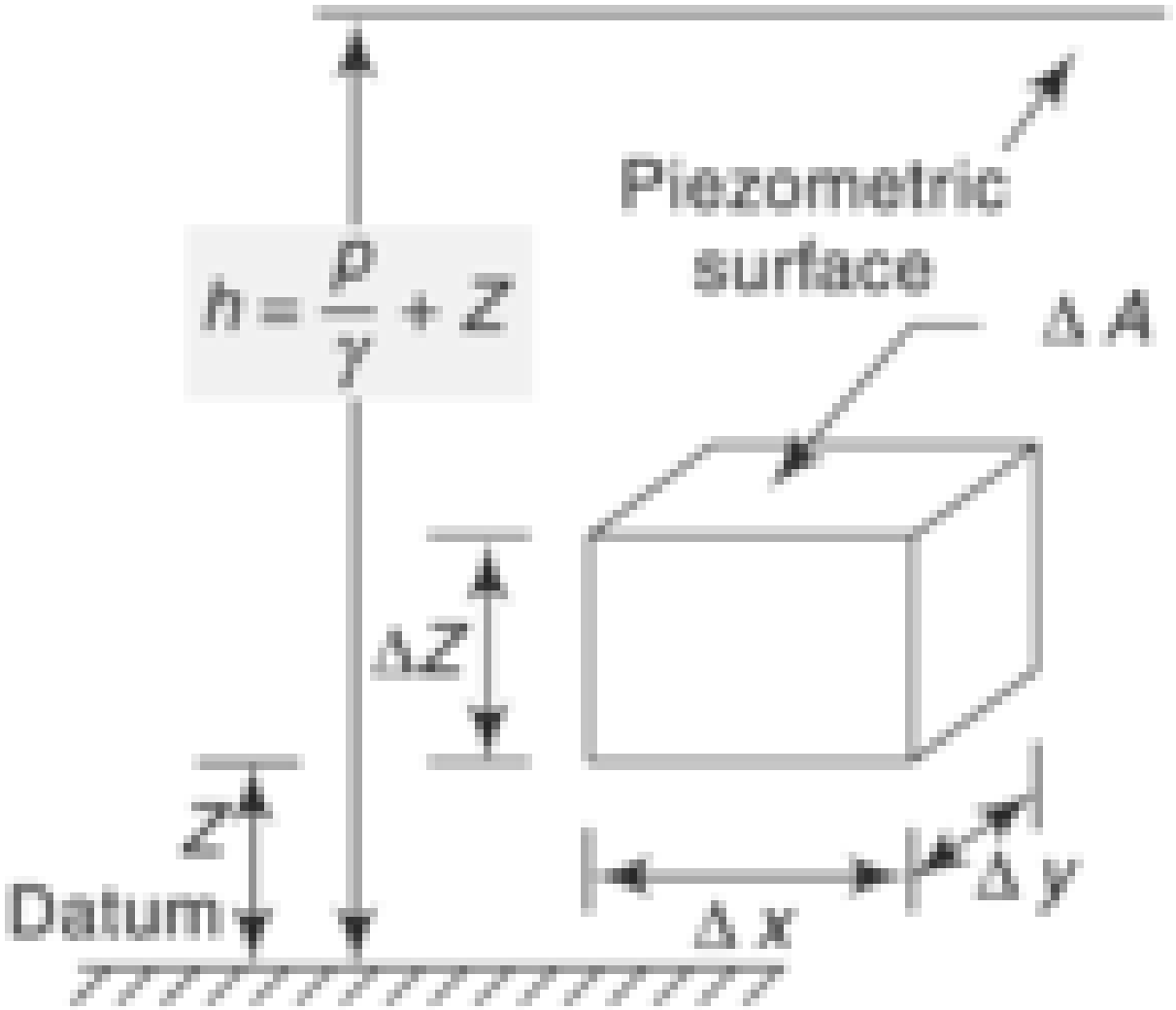

Fig. 9.7 *Volume Element of a Compressible Aquifer*

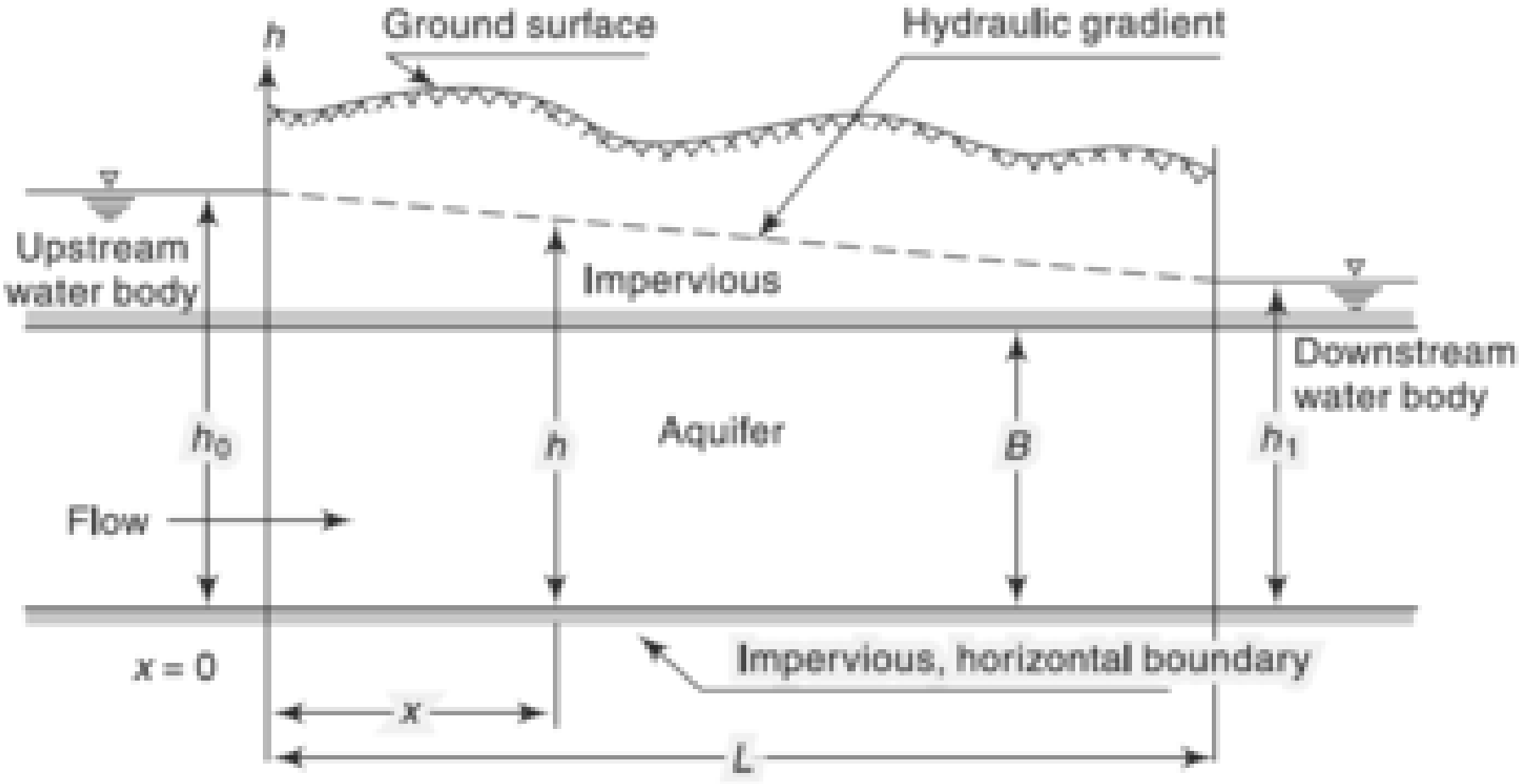

Fig. 9.8 *Confined Groundwater Flow between Two Water Bodies*

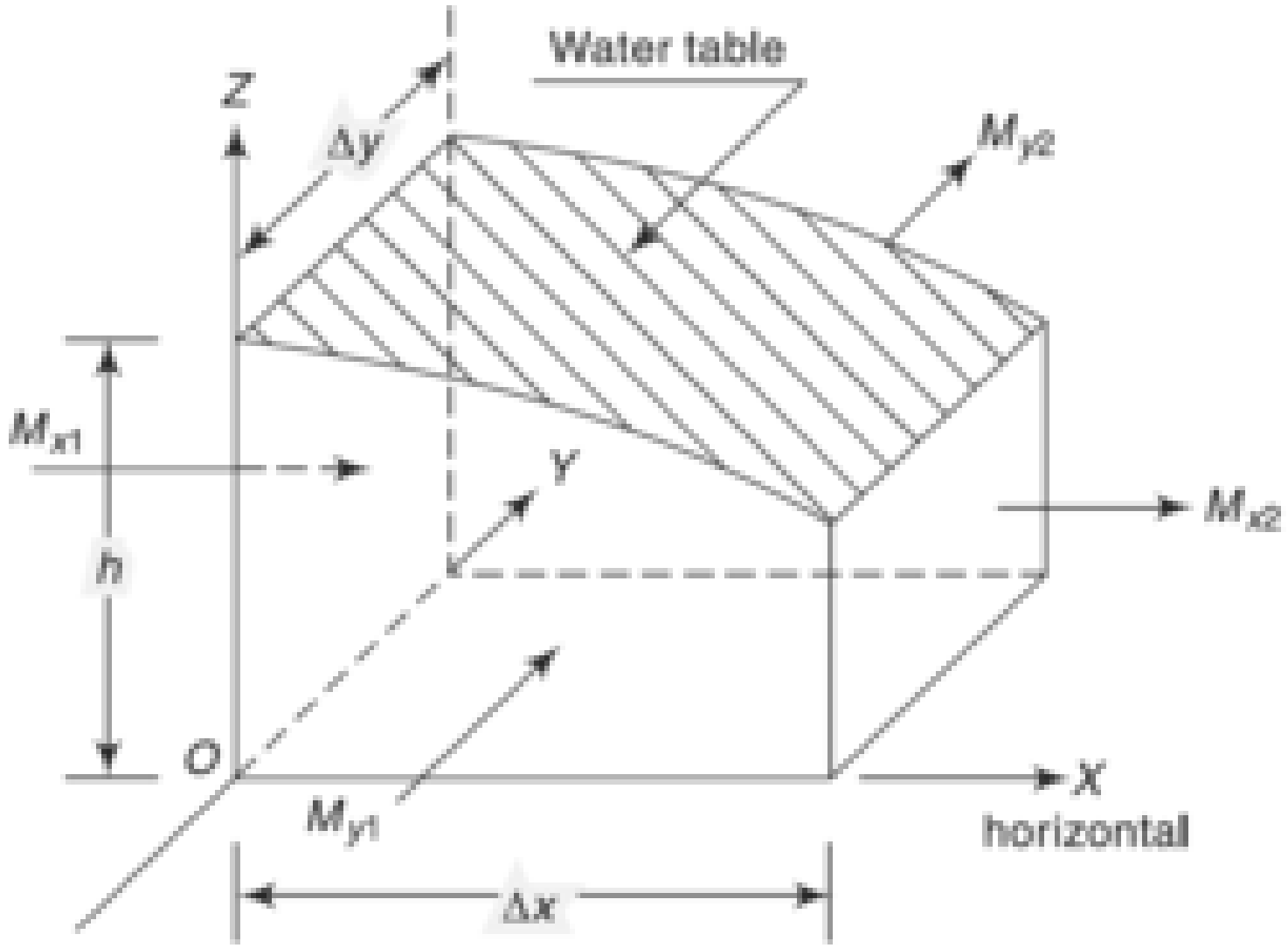

Fig. 9.9(a) ***Definition Sketch—Unconfined Ground-water***

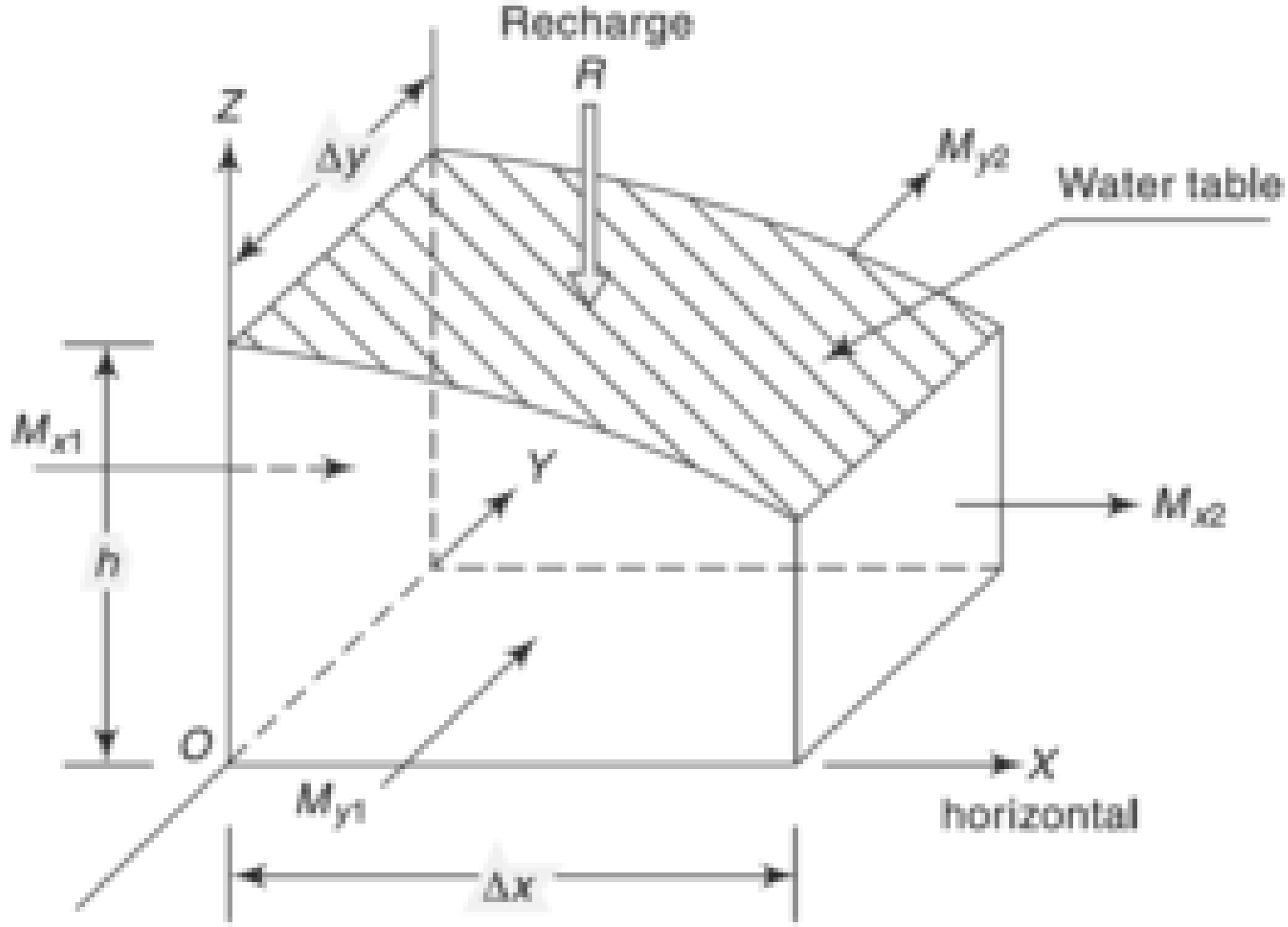

Fig. 9.9(b) ***Definition Sketch—Unconfined flow with Recharge***

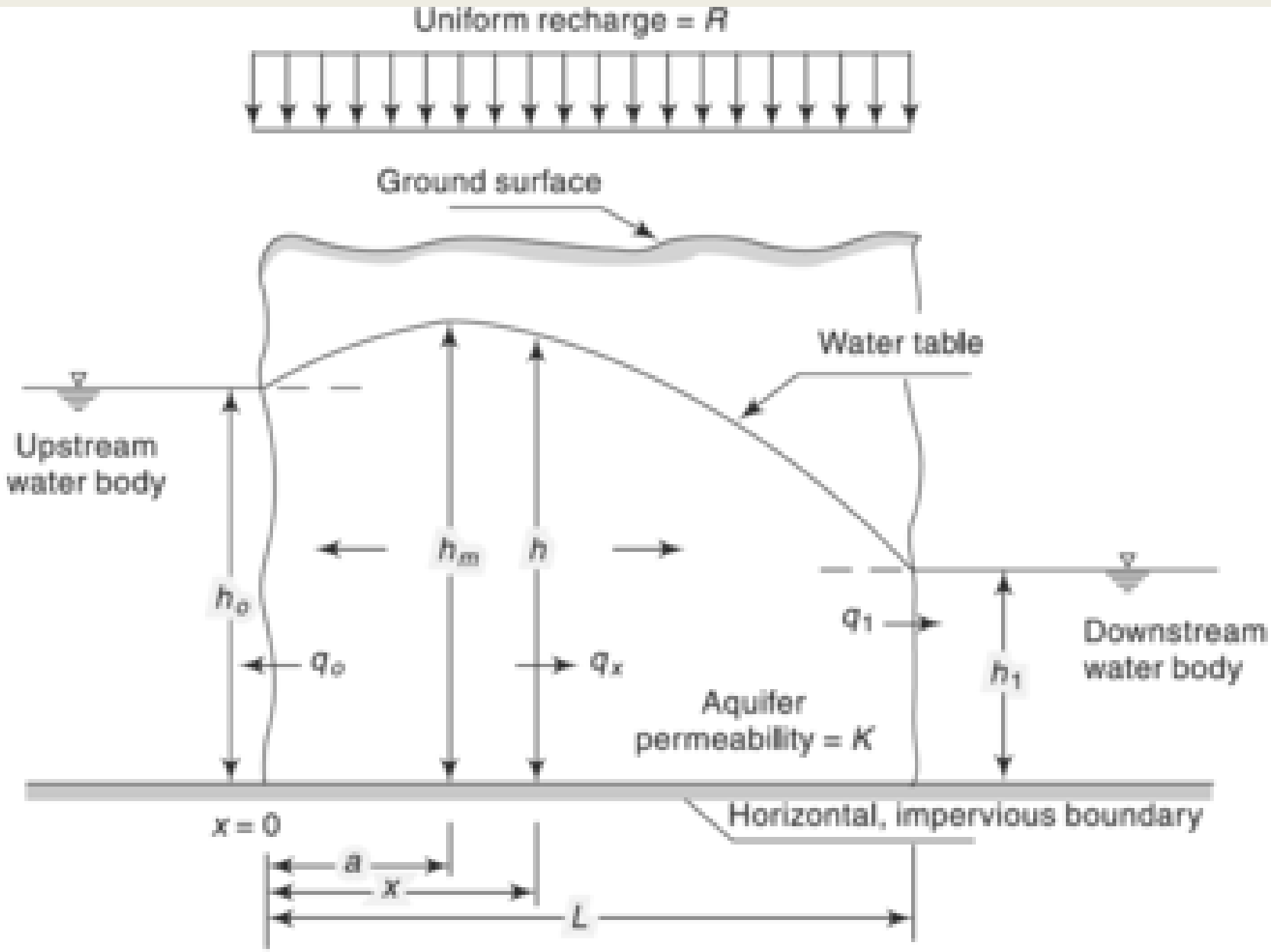

Fig. 9.10 *One-Dimensional Dupit Flow with Recharge*

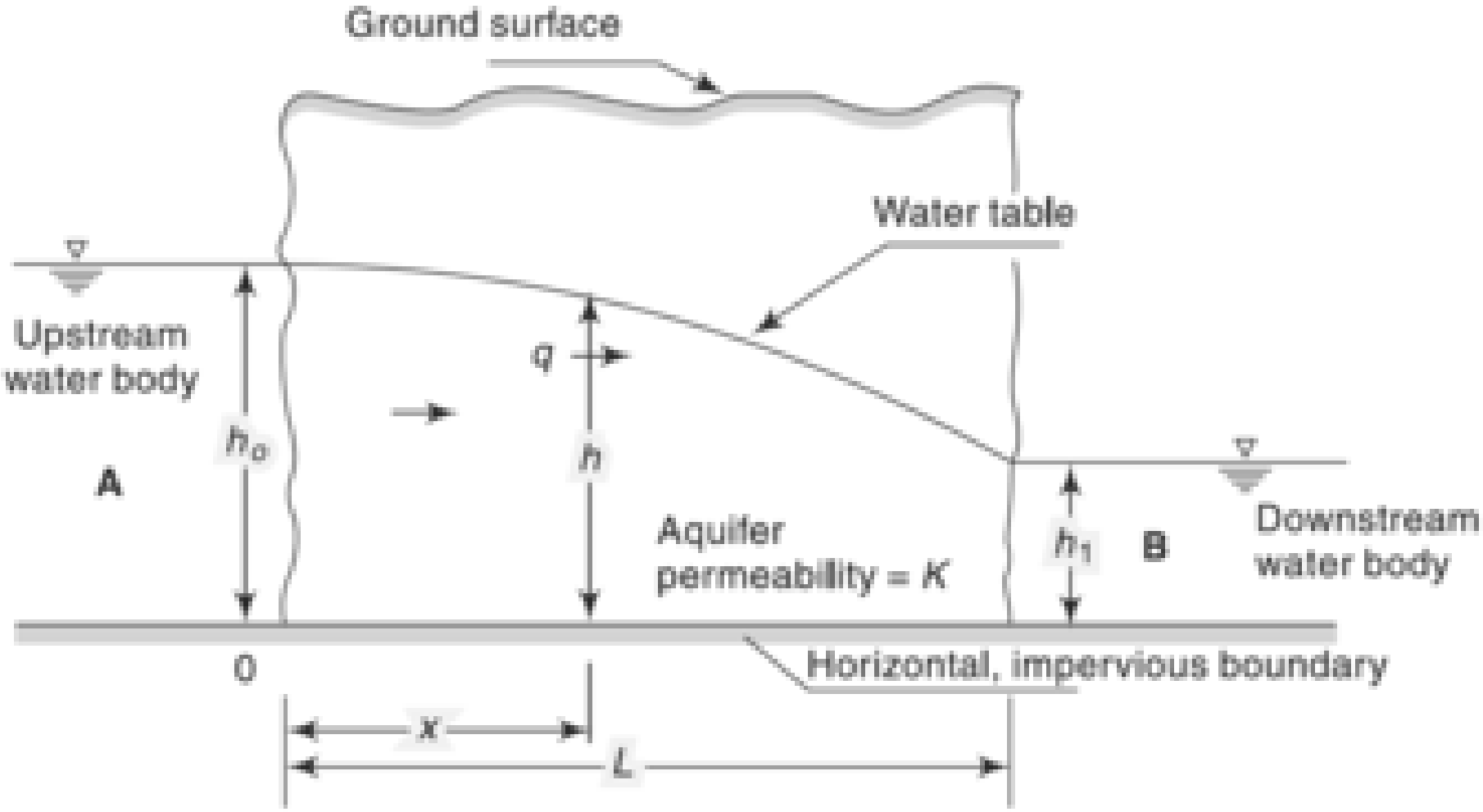

Fig. 9.11 ***One-Dimensional Unconfined Flow Without Recharge***

$$h^2 = \frac{R}{K}(L - x)\,x$$

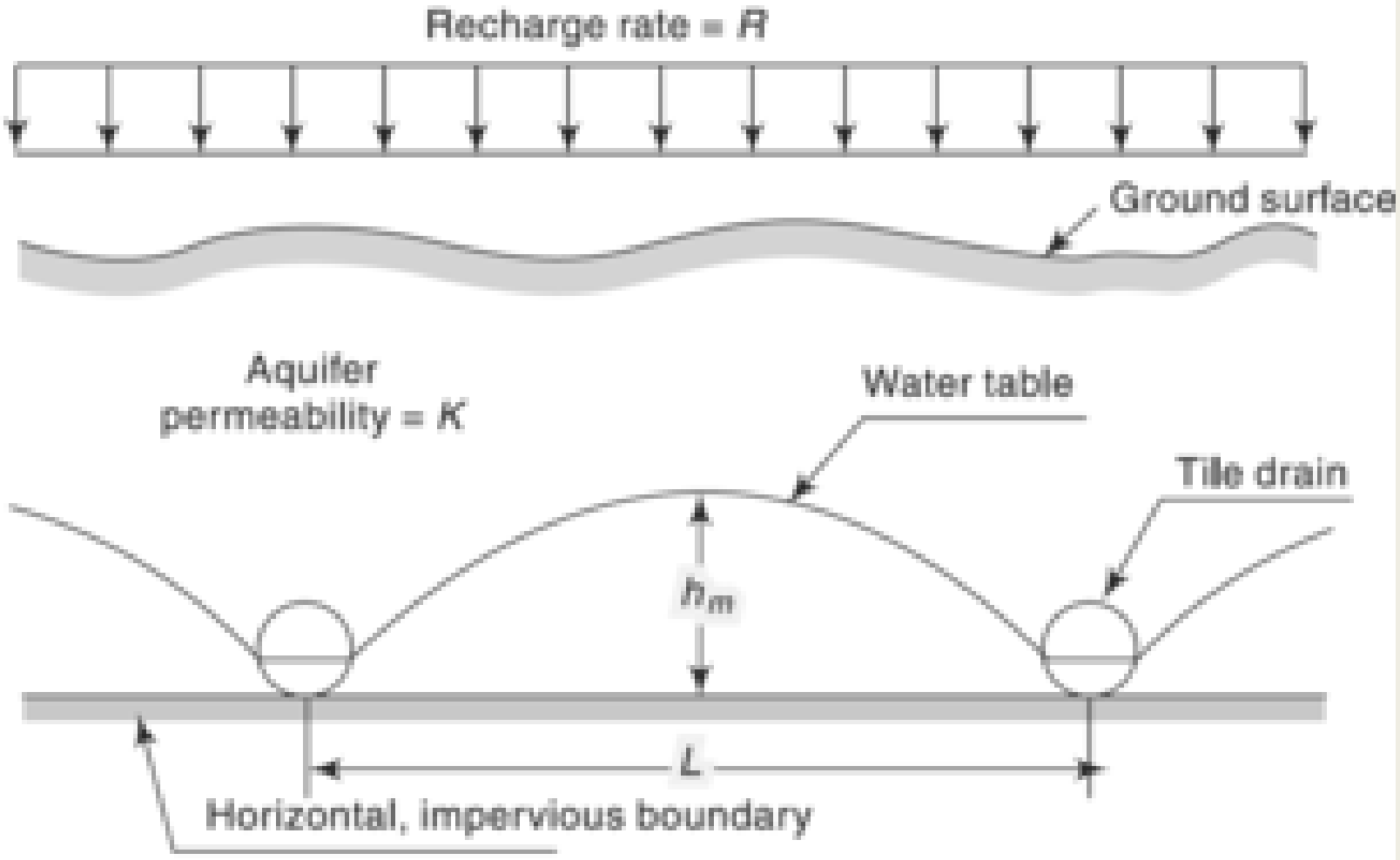

Fig. 9.12 *Tile Drains under a Constant Recharge Rate*

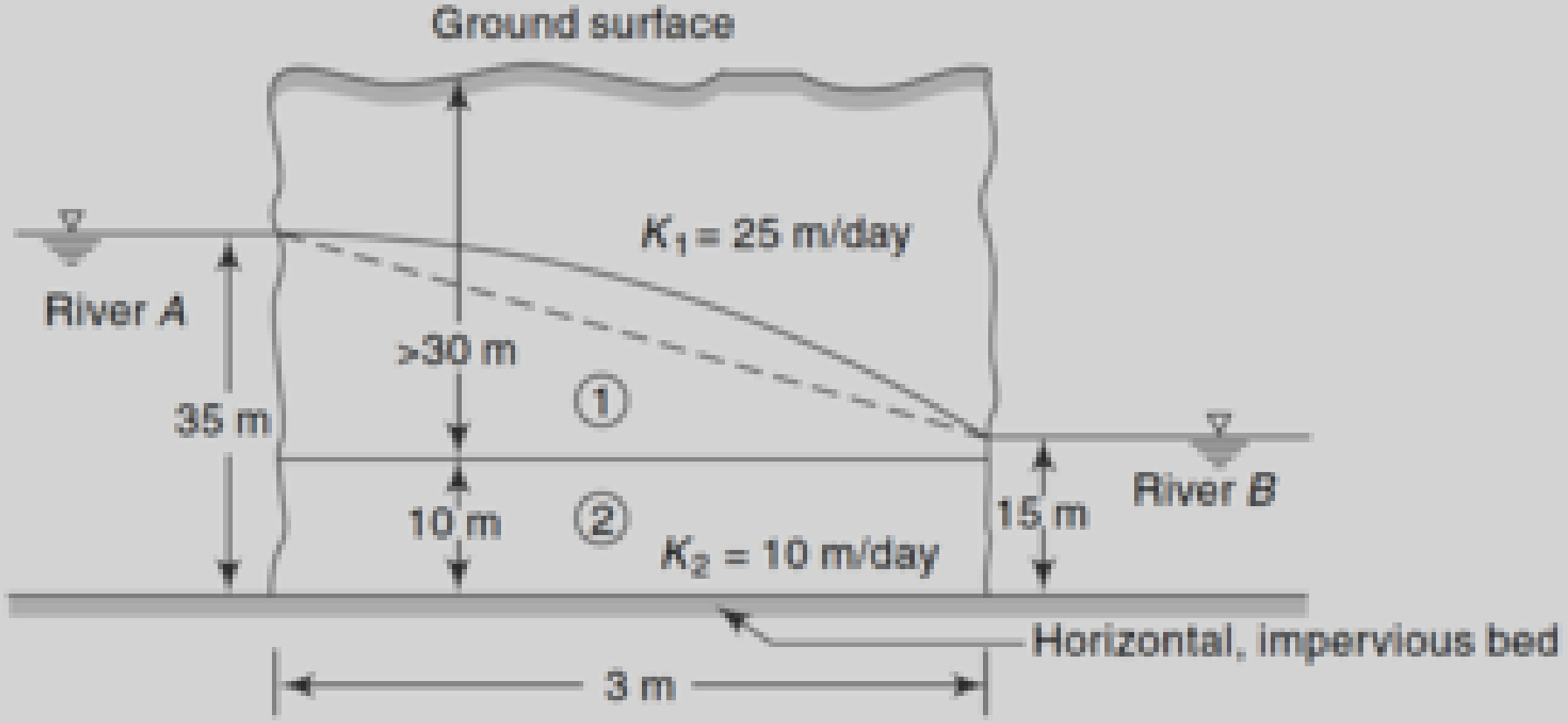

Fig. 9.13 *Schematic Layout of Example 9.4*

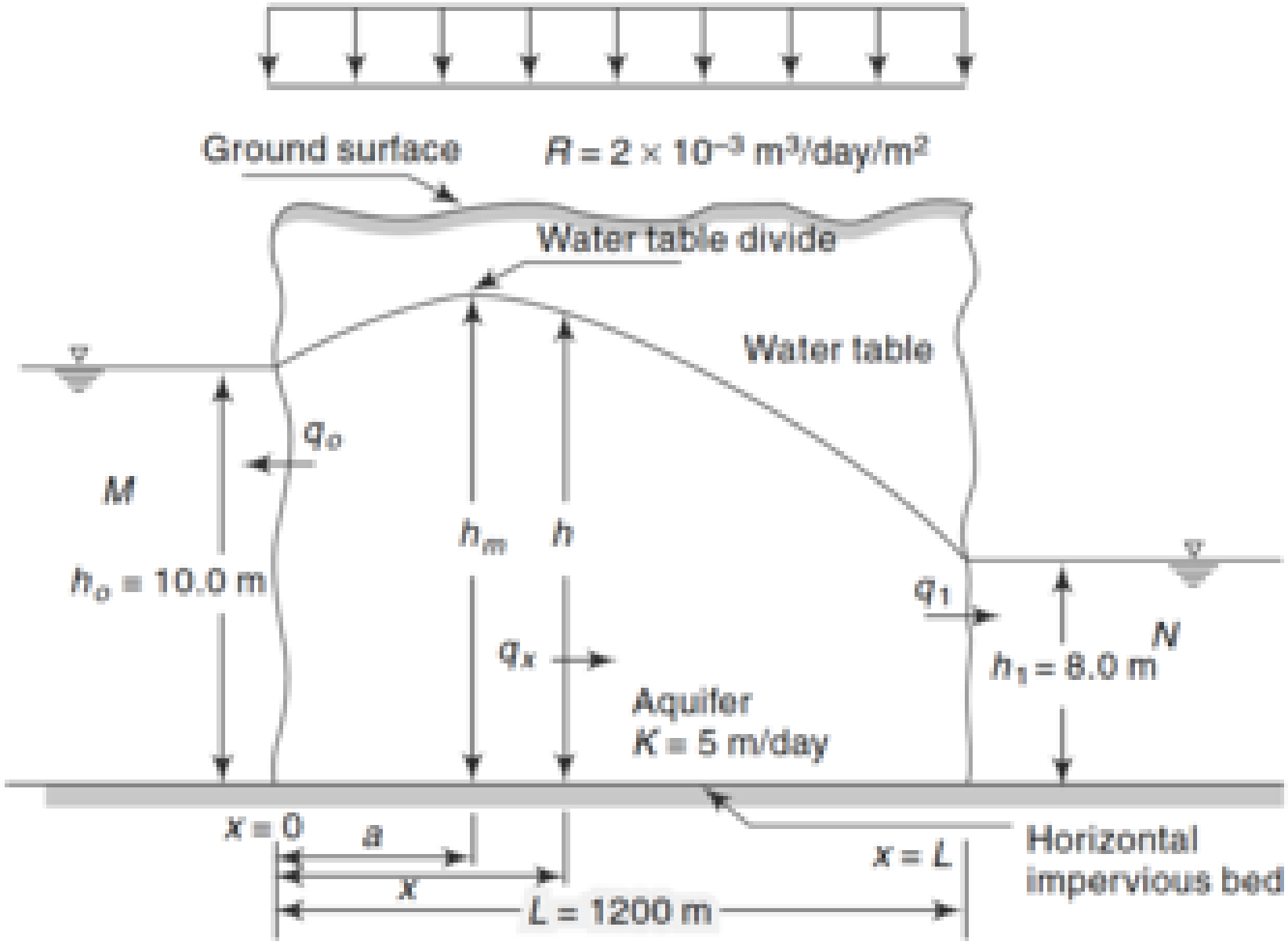

Fig. 9.14 *Schematic Layout—Example 9.5*

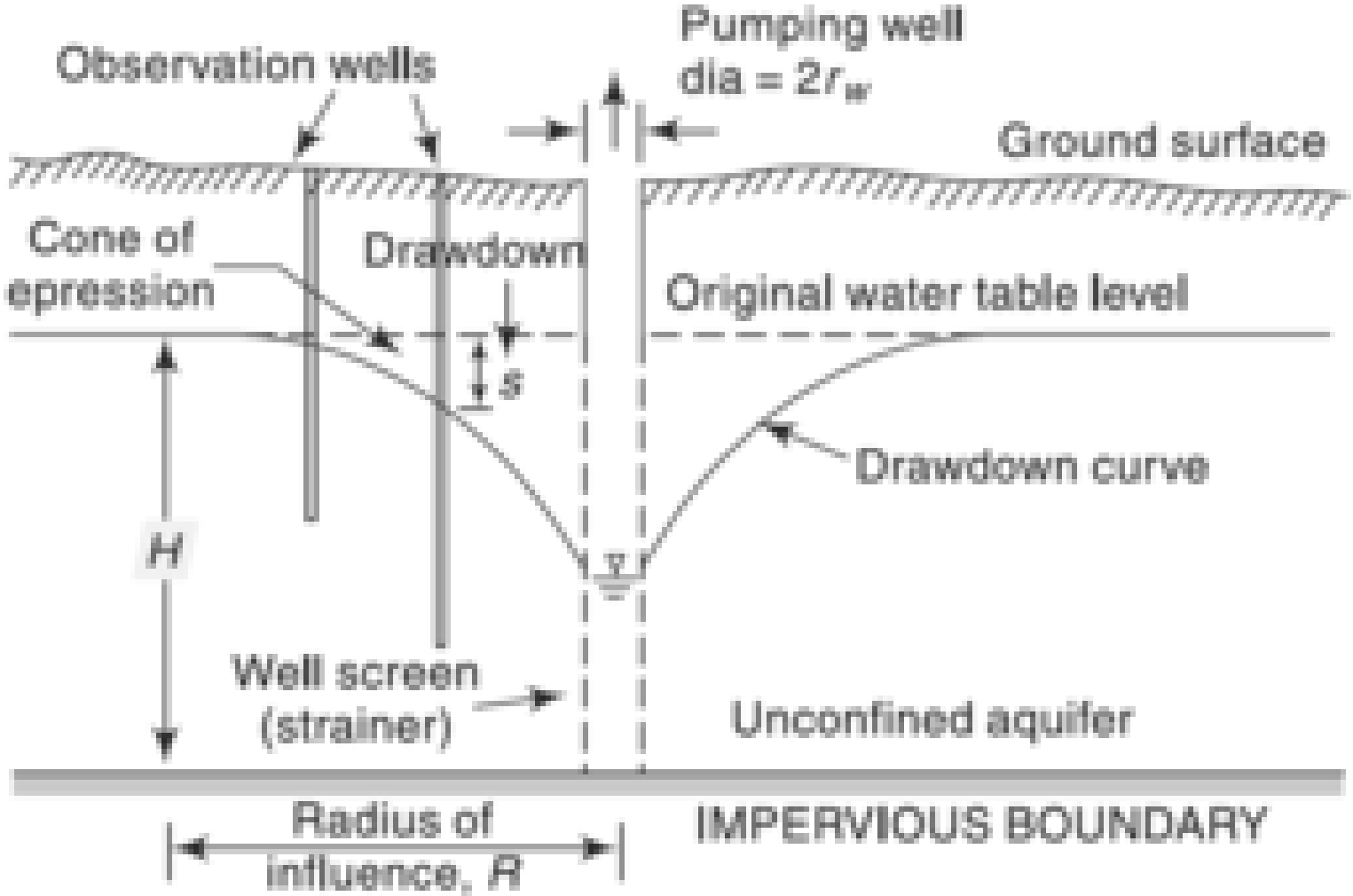

Fig. 9.15 ***Well Operating in an Unconfined Aquifer, (definition sketch)***

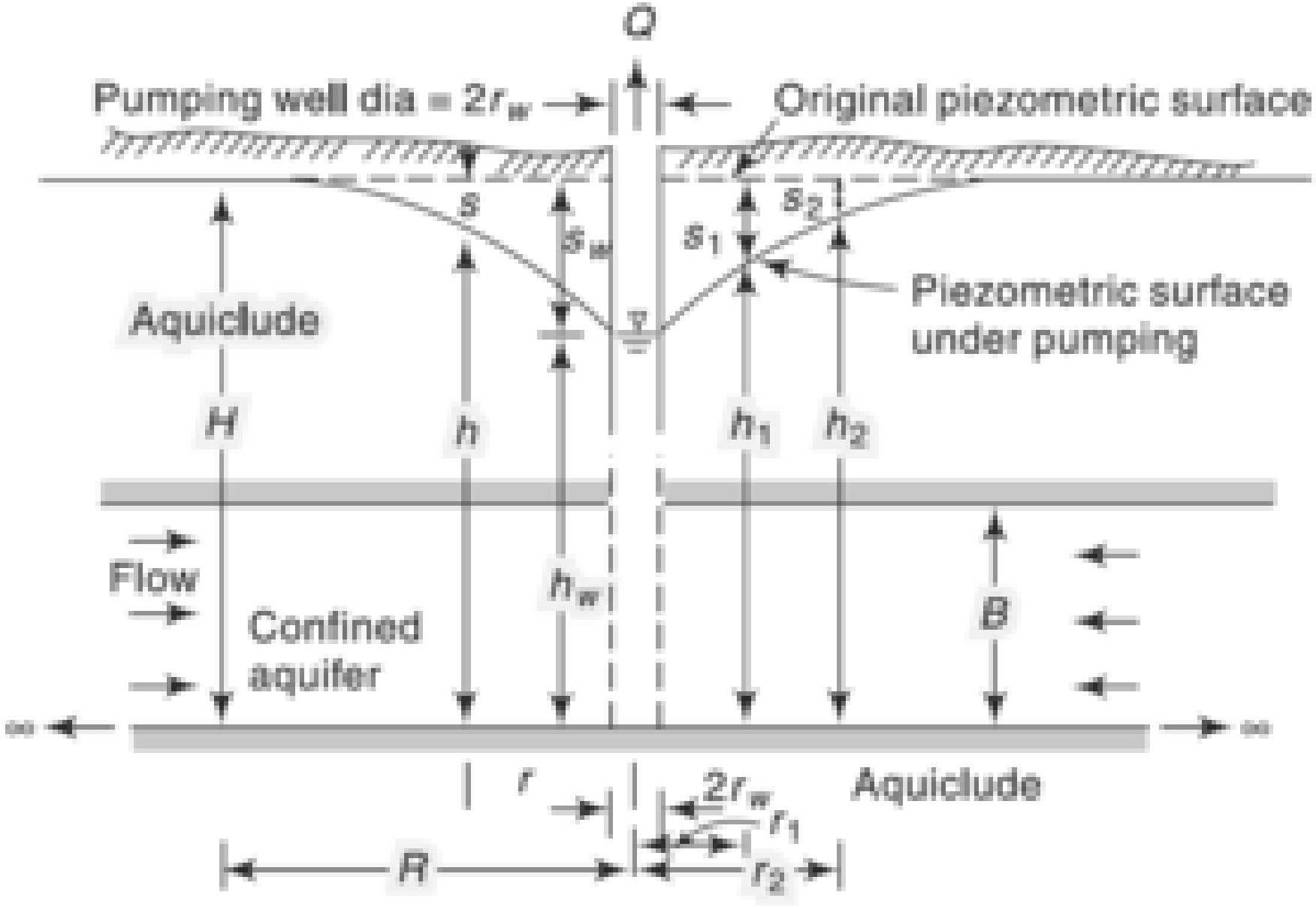

Fig. 9.16 *Well Operating in a Confined Aquifer*

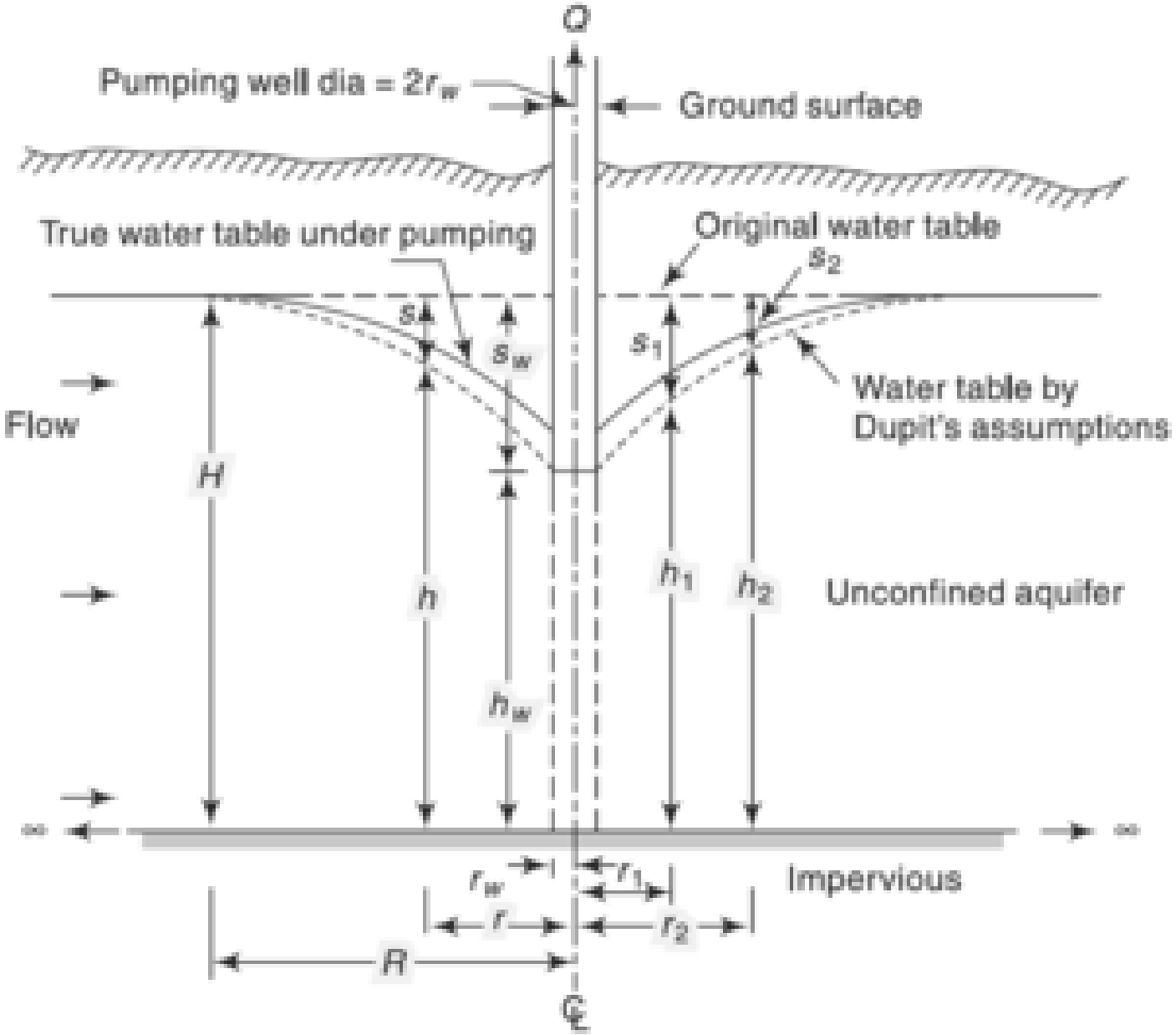

Fig. 9.17 ***Radial Flow to a Well in an Unconfined Aquifer***

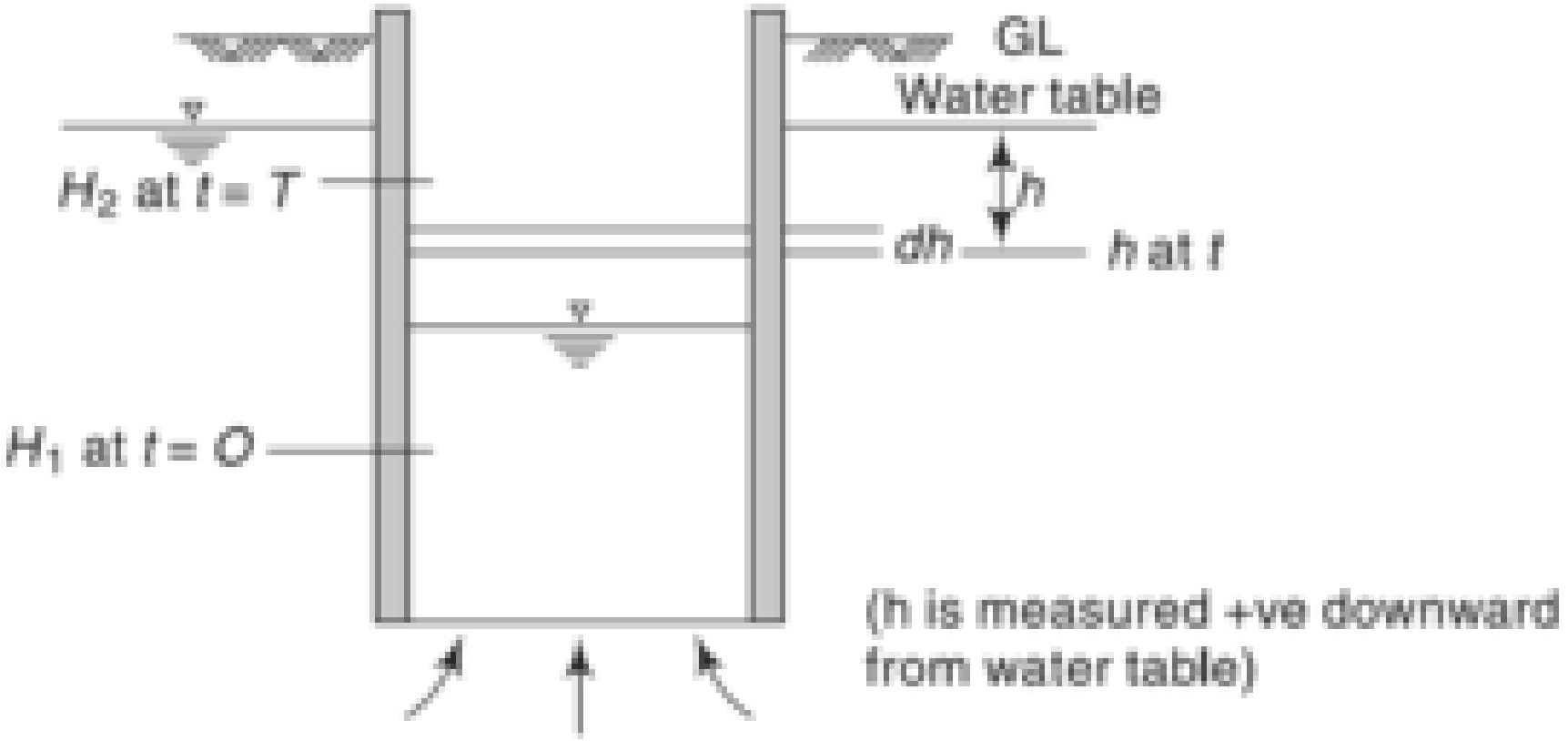

Fig. 9.18 ***Recuperation Test for Open well***

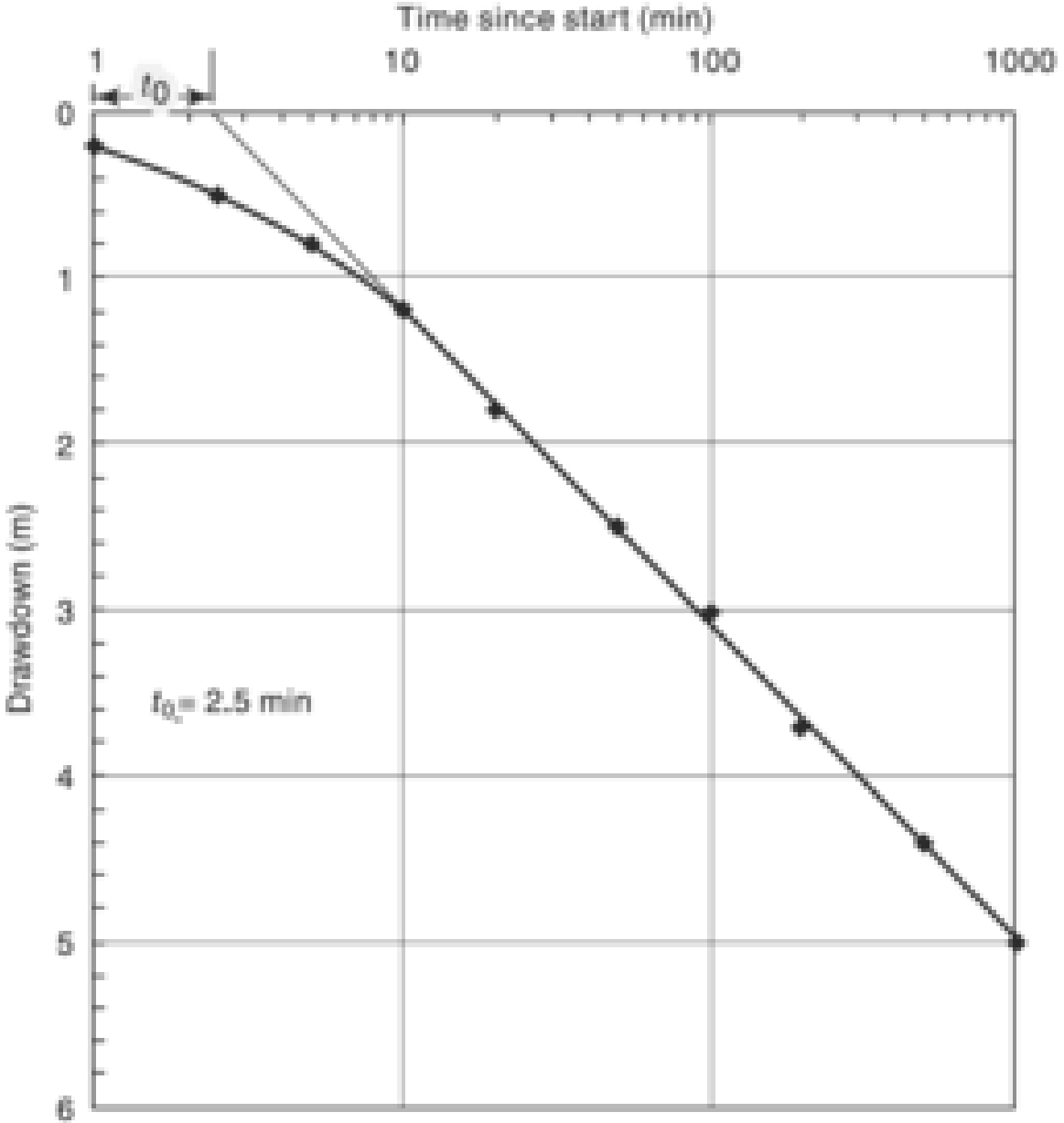

Fig. 9.19 *Time–Drawdown Plot—Example 9.12*

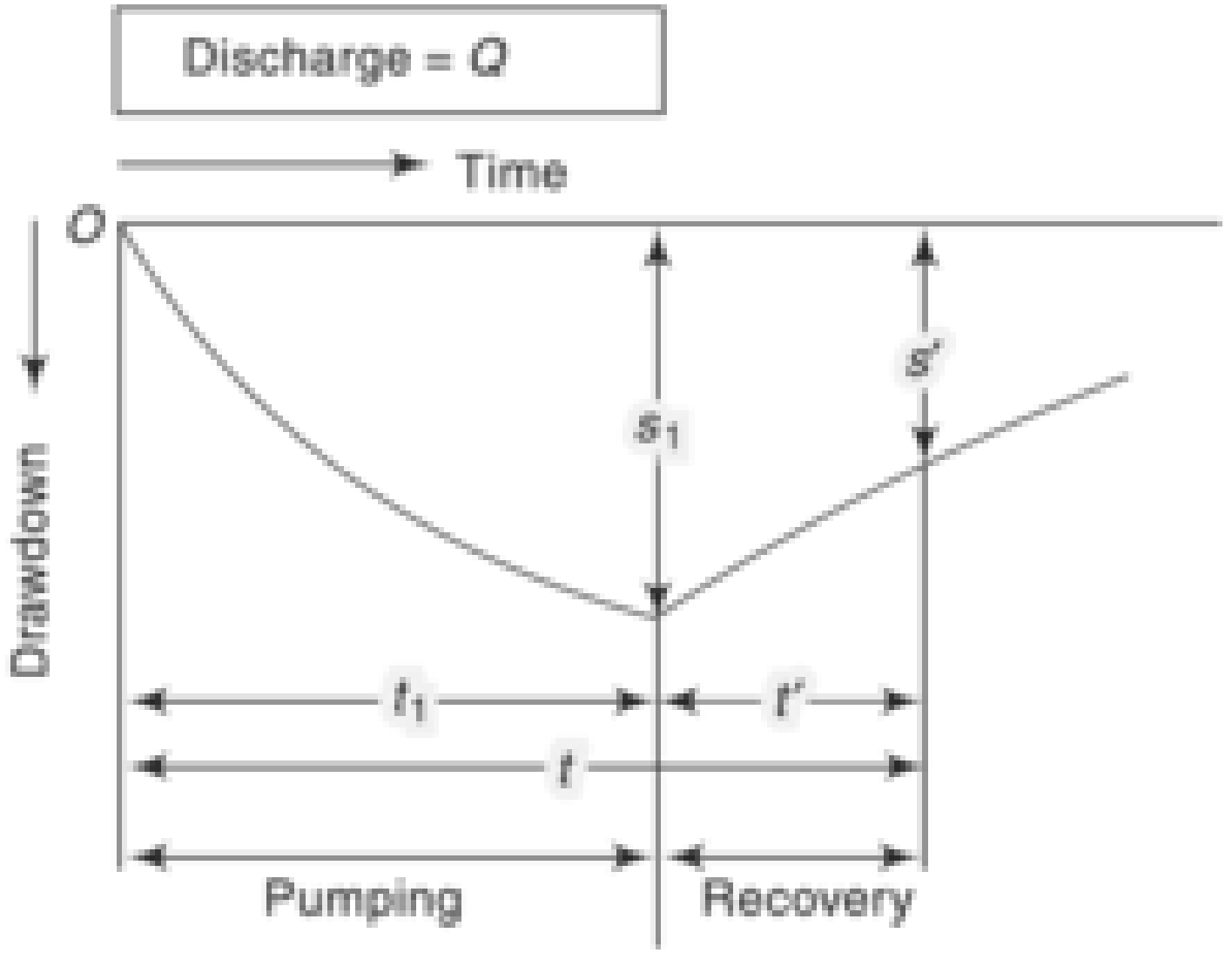

Fig. 9.20 ***Variation of Piezometric Head in Pumping and Recovery Head***

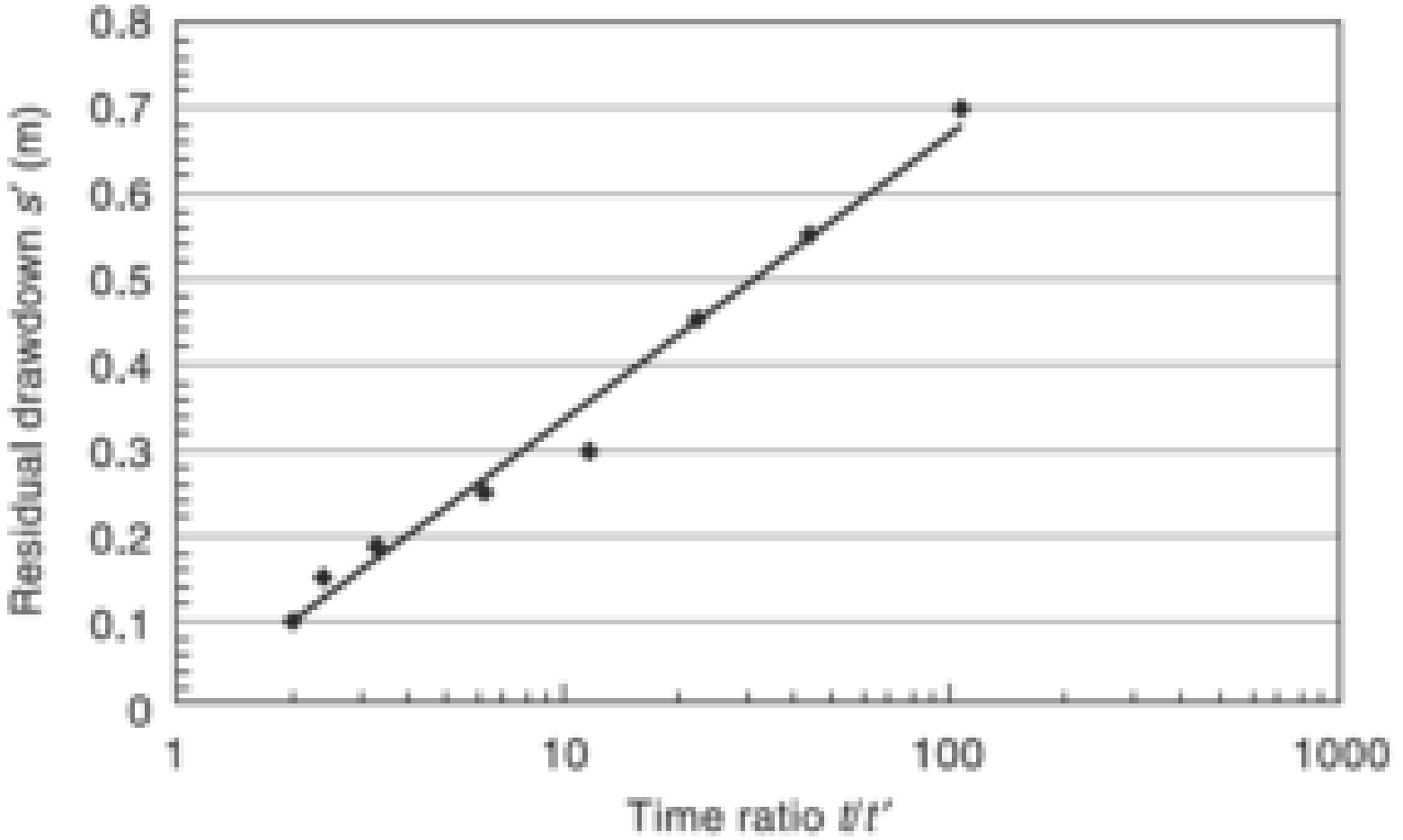

Fig. 9.21 *Plot of residual drawdown against time ratio (t/t′)—Example 9.12*

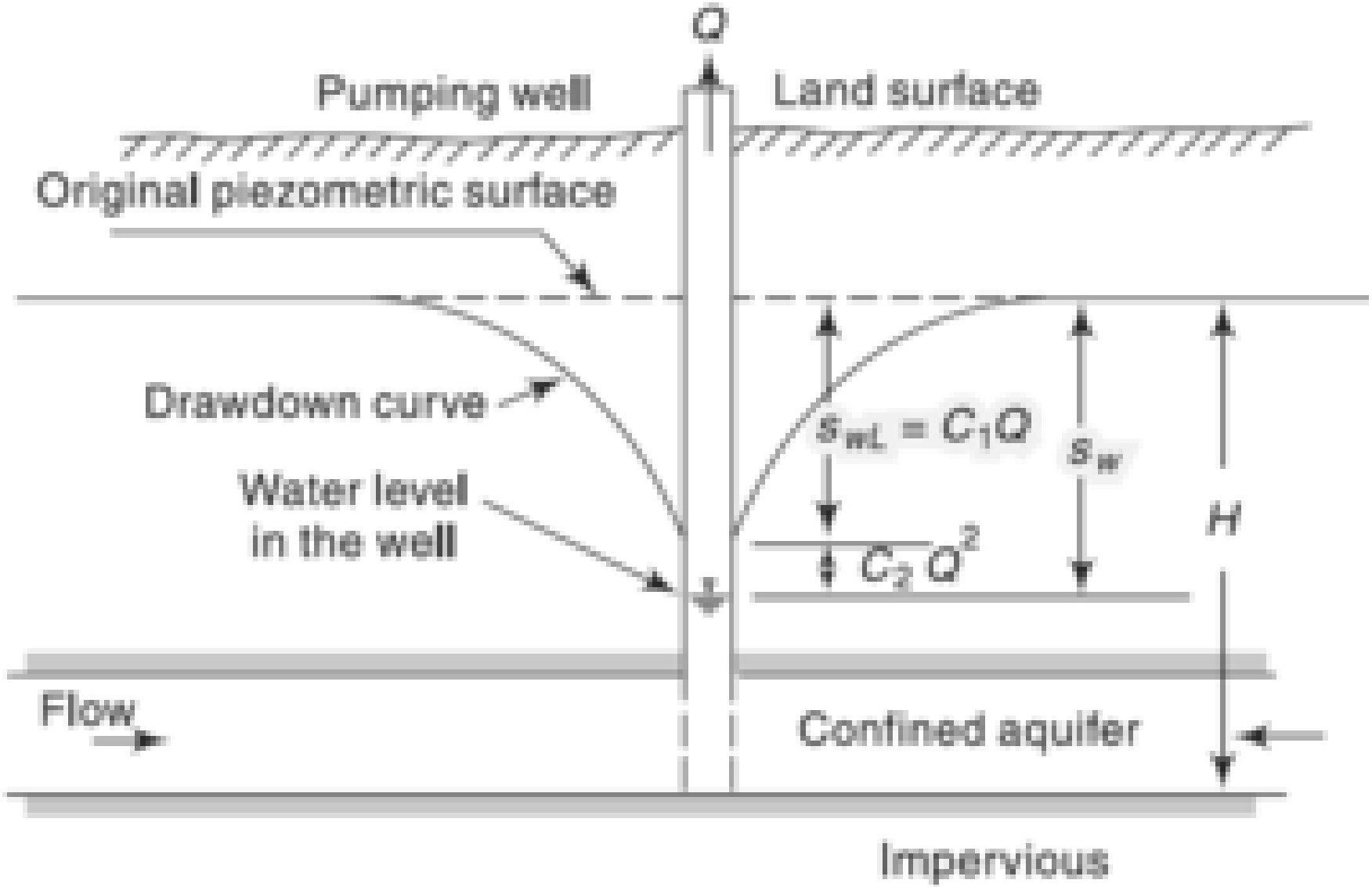

Fig. 9.22 *Definition Sketch for Well Loss*

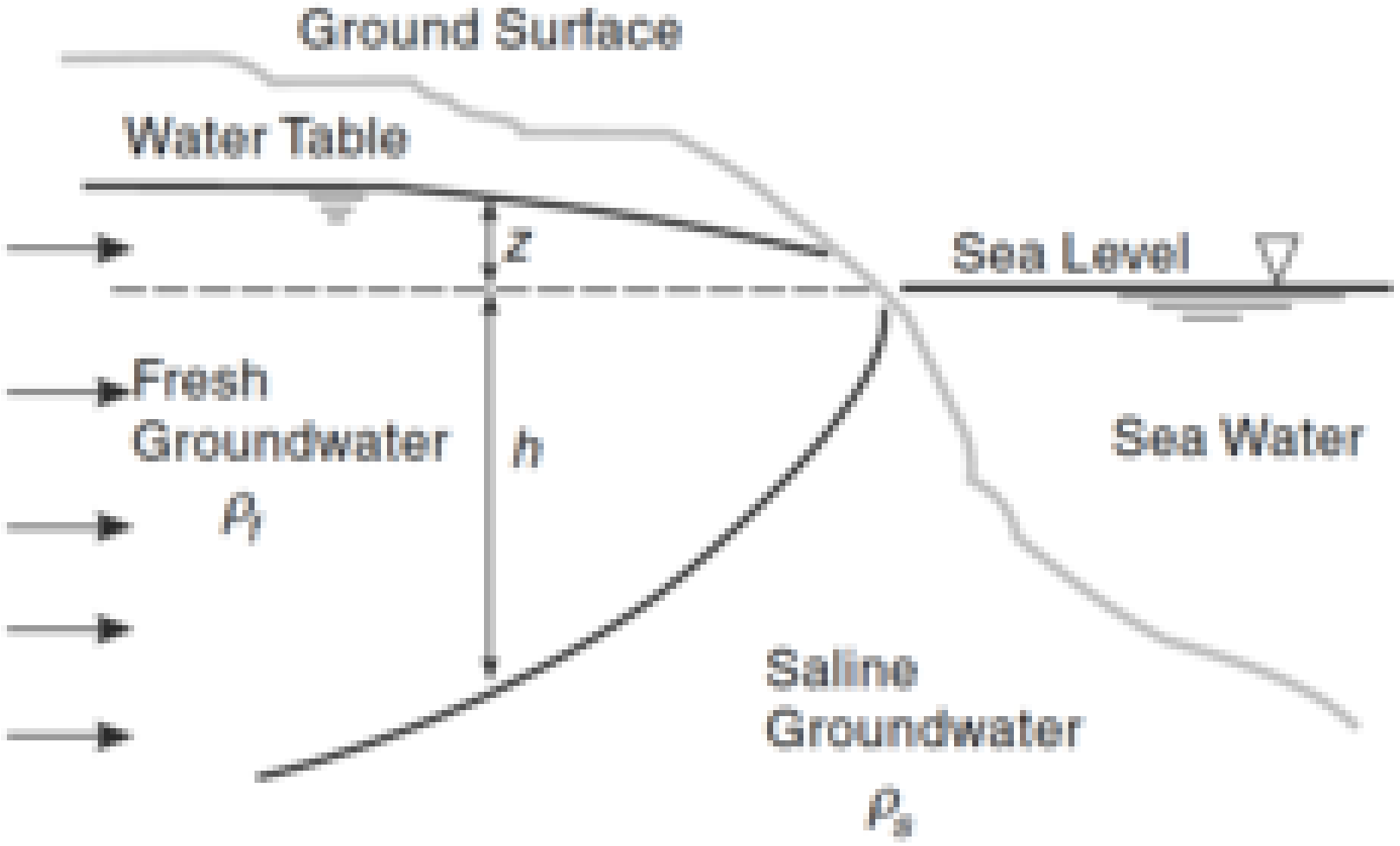

Fig. 9.23 *Interface Between Fresh and Saline Groundwater in a Coastal Unconfined Aquifer*

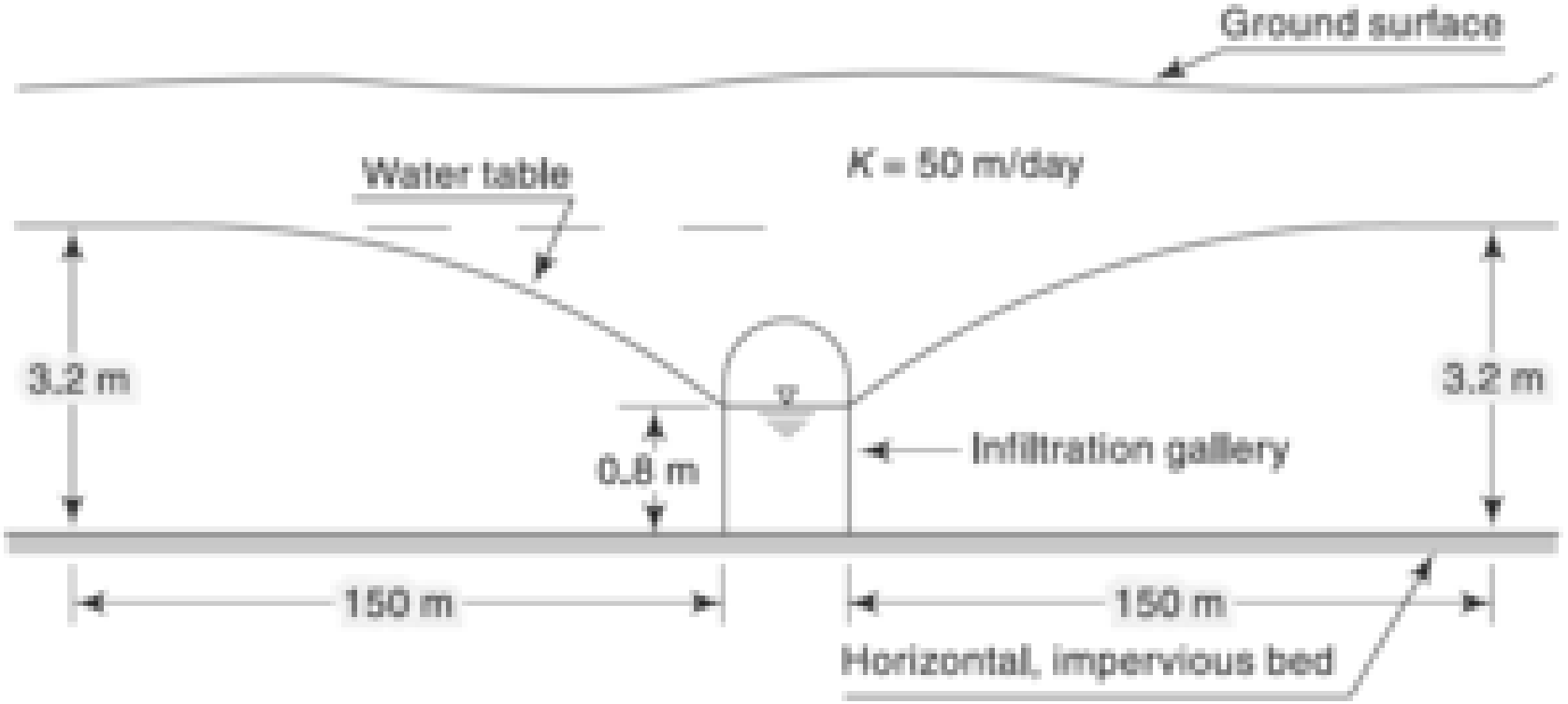

Fig. 9.24 *Schematic Layout of Problem 9.9*

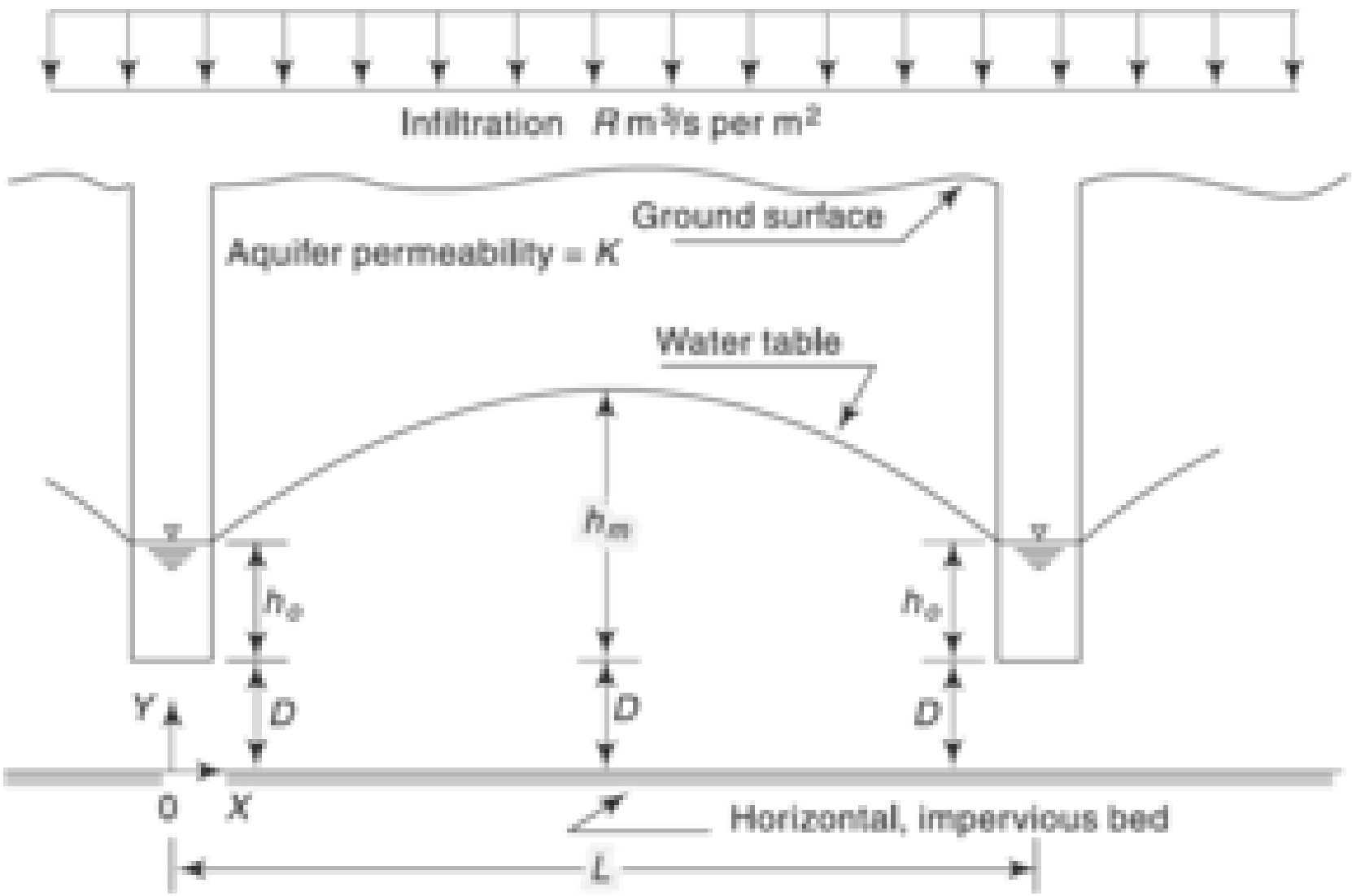

Fig. 9.25 *Seepage to Open Ditches—Problem 9.10*

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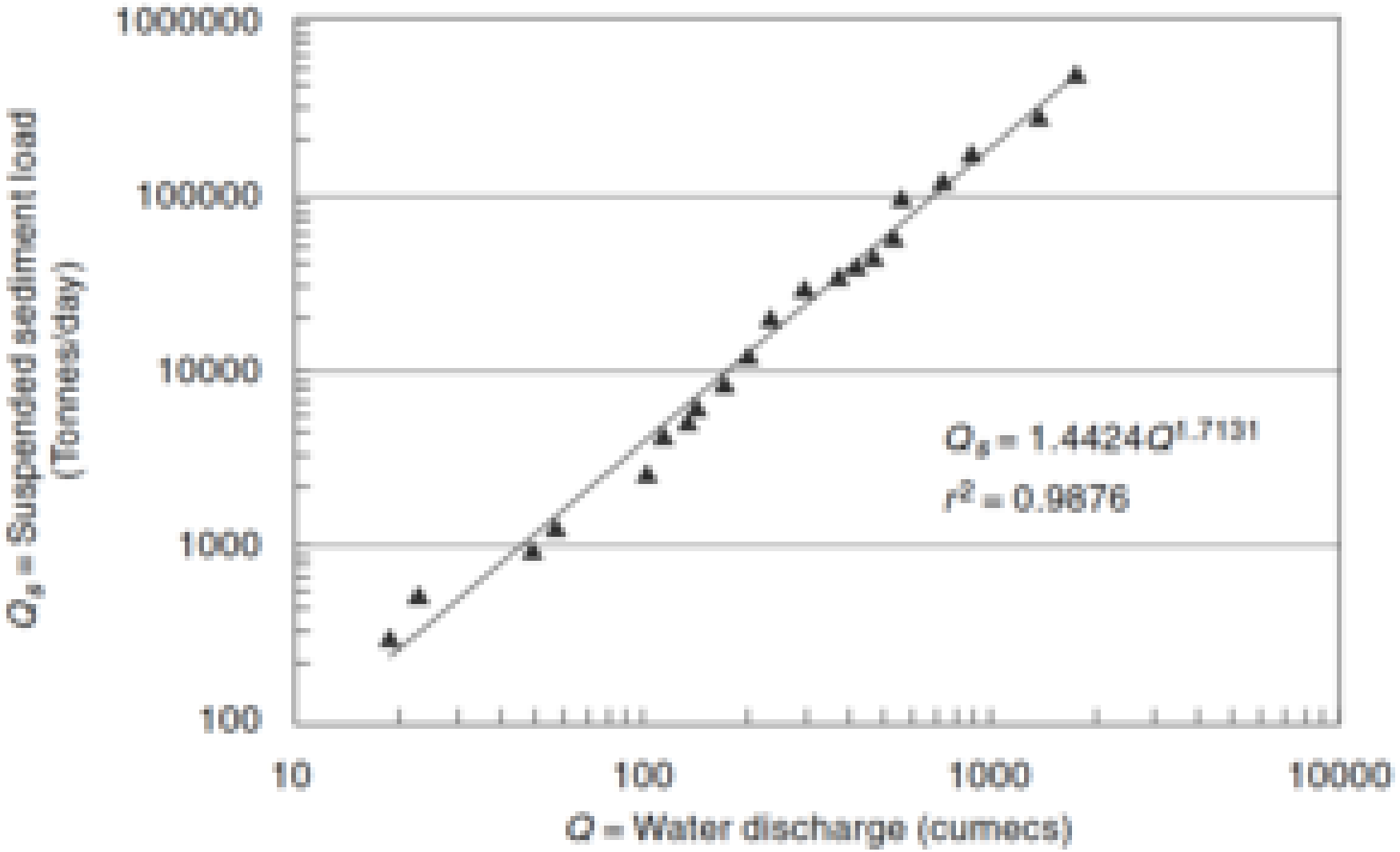

Fig. 10.1 *Sediment rating curve (Schematic)*

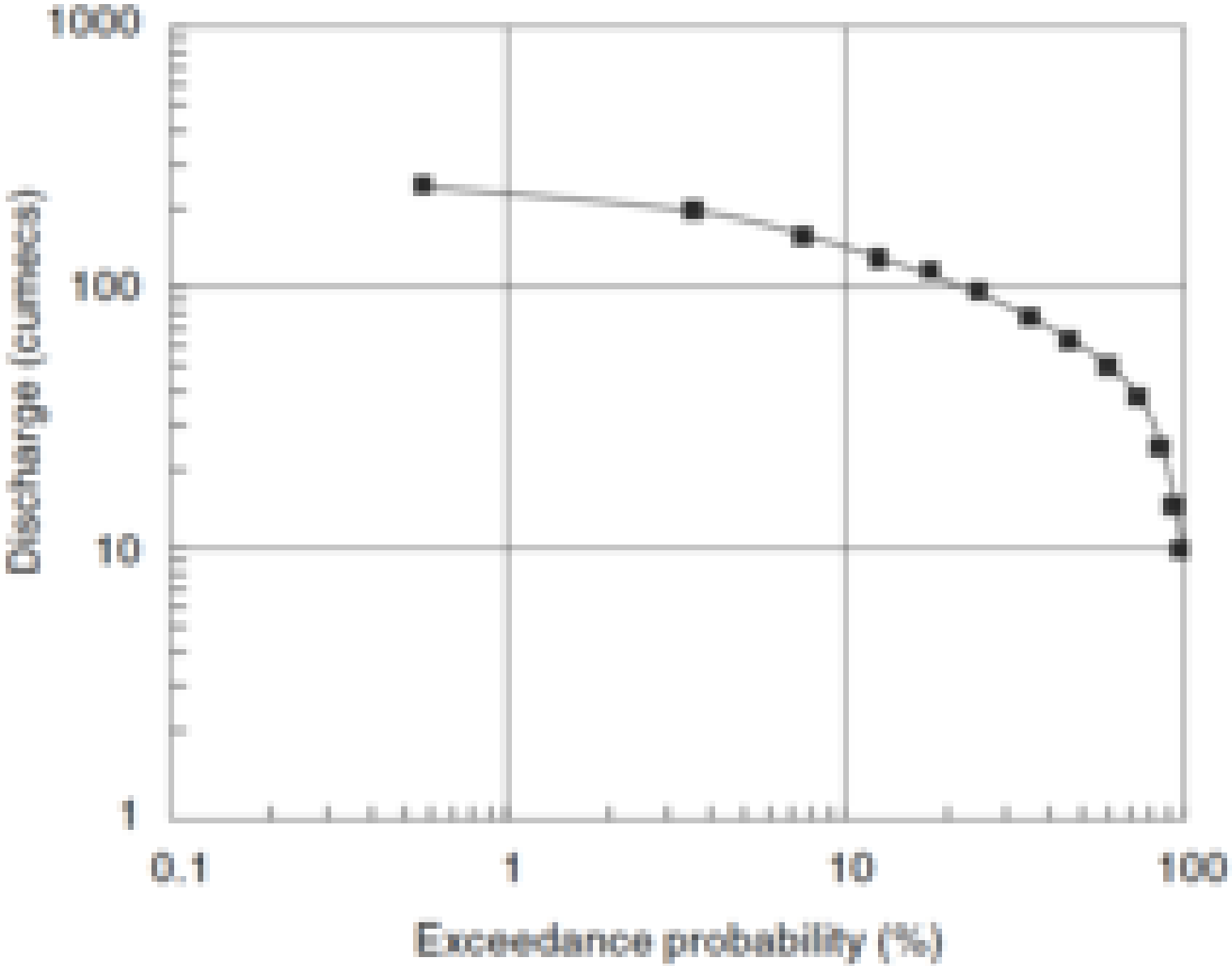

Fig. 10.2 ***Flow Duration Curve—Example 10.1***

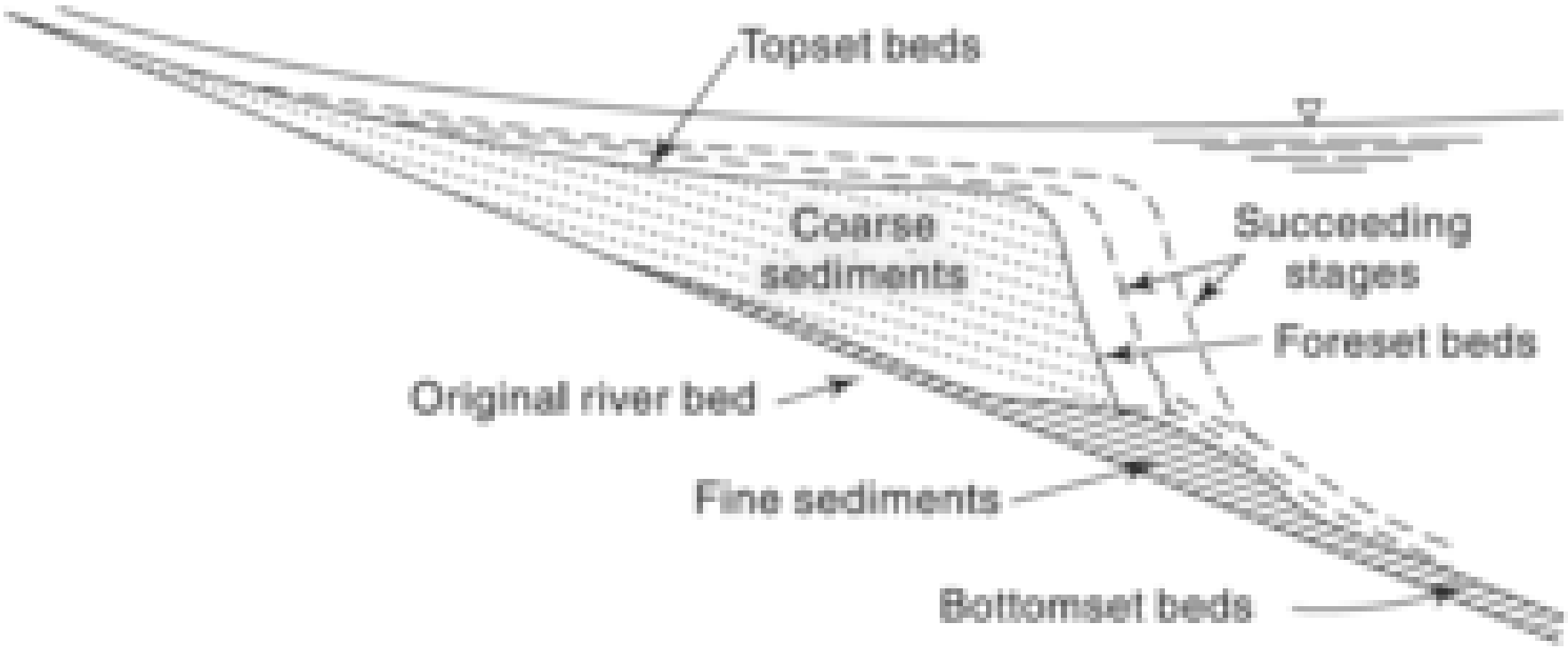

Fig. 10.3 *Schematic Representation of Reservoir Delta*

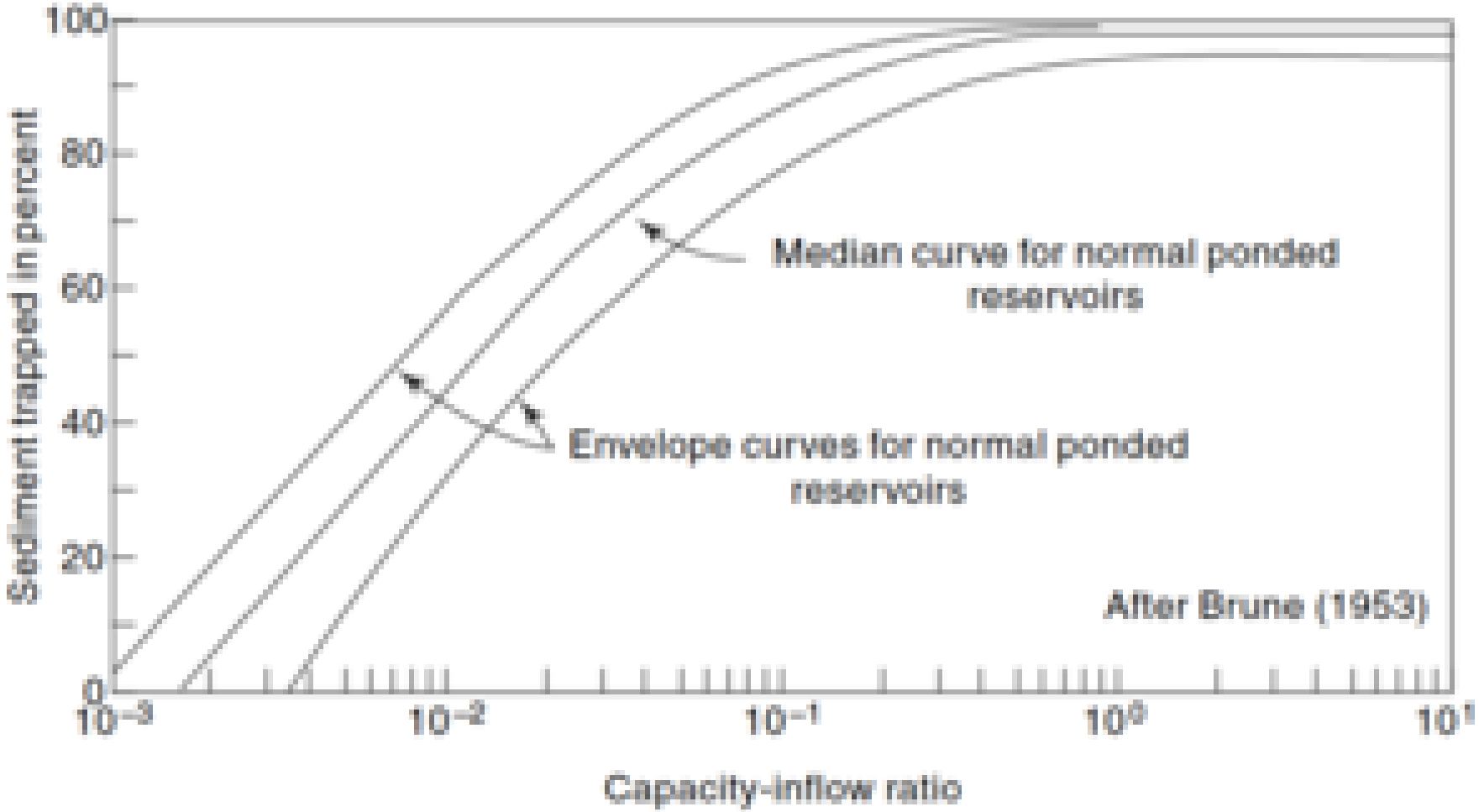

Fig. 10.4 *Brune's Curve of Trap Efficiency of a Reservoir*

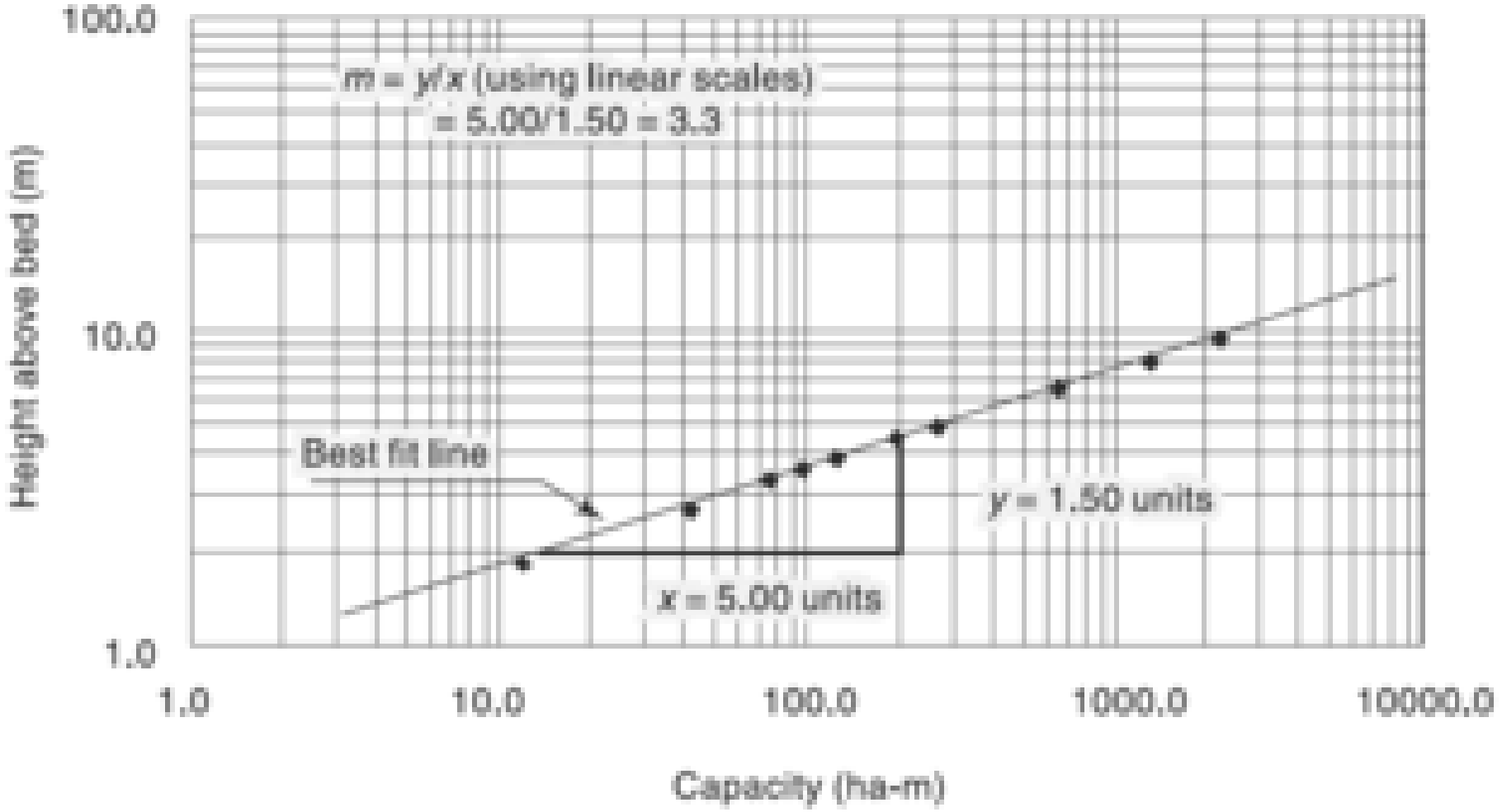

Fig. 10.5(a) ***Determination of Parameter m***

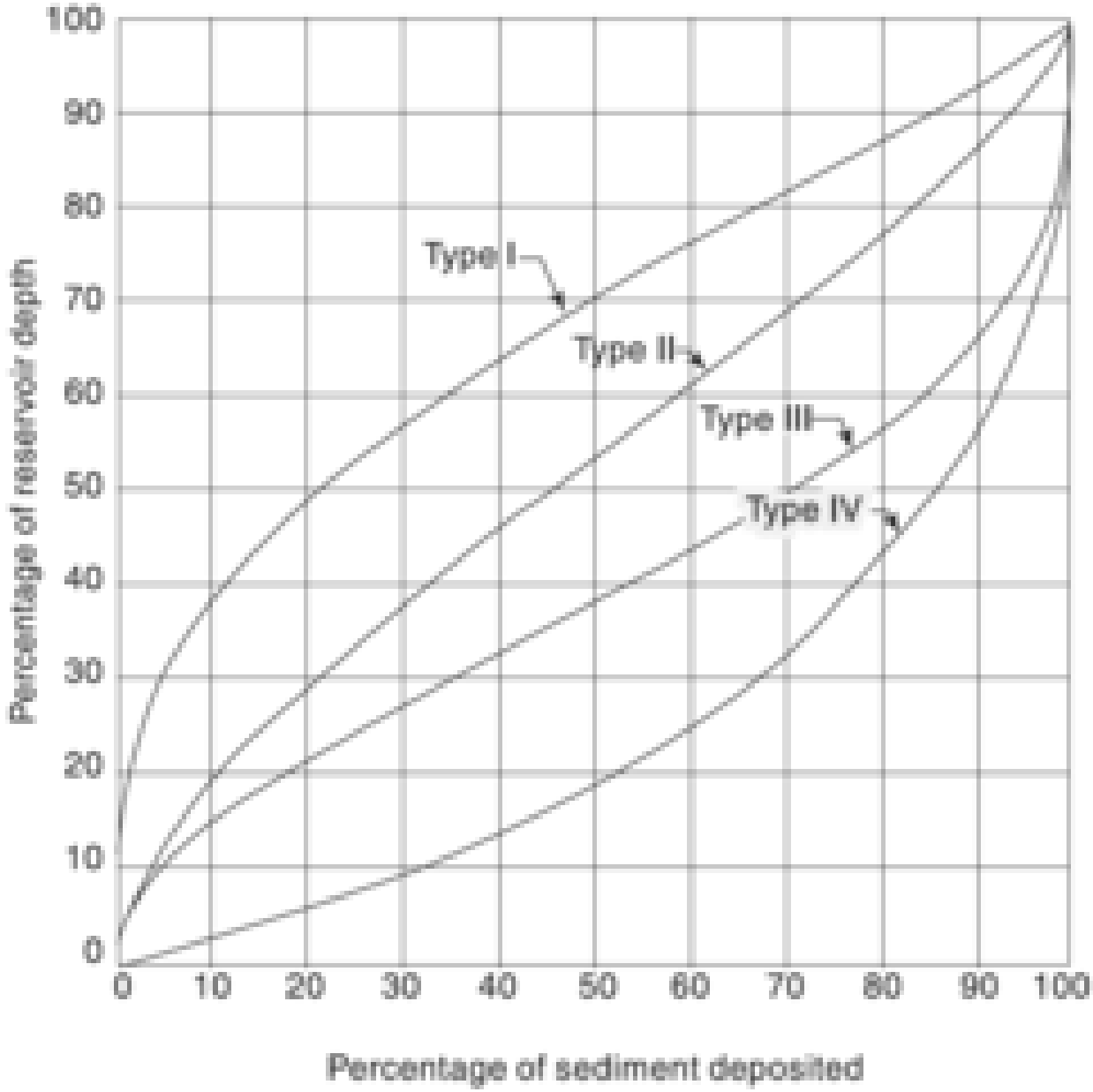

Fig. 10.5(b) *Typical Distribution of Sediment in various Reservoir Types*

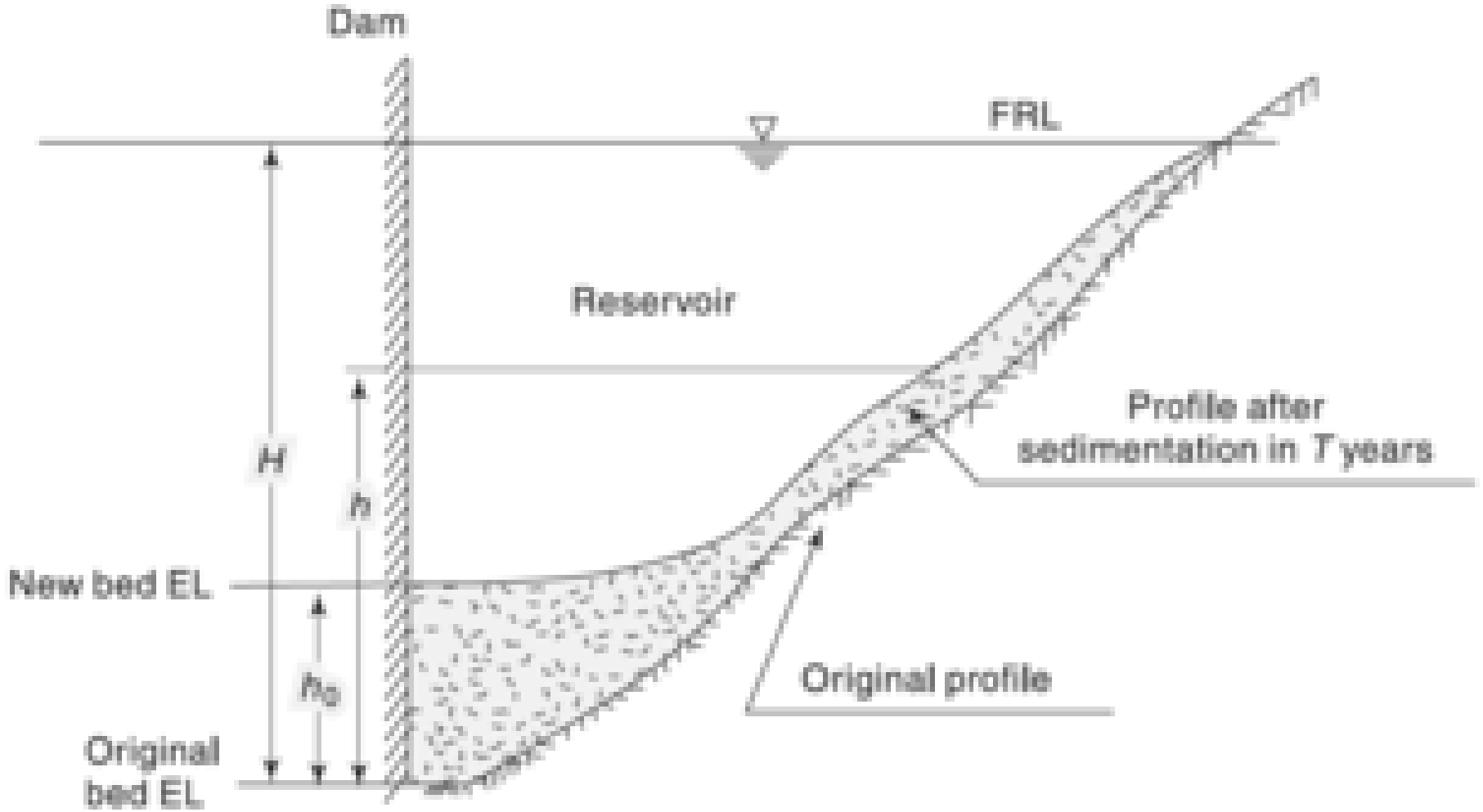

Fig. 10.6 *Definition Sketch*

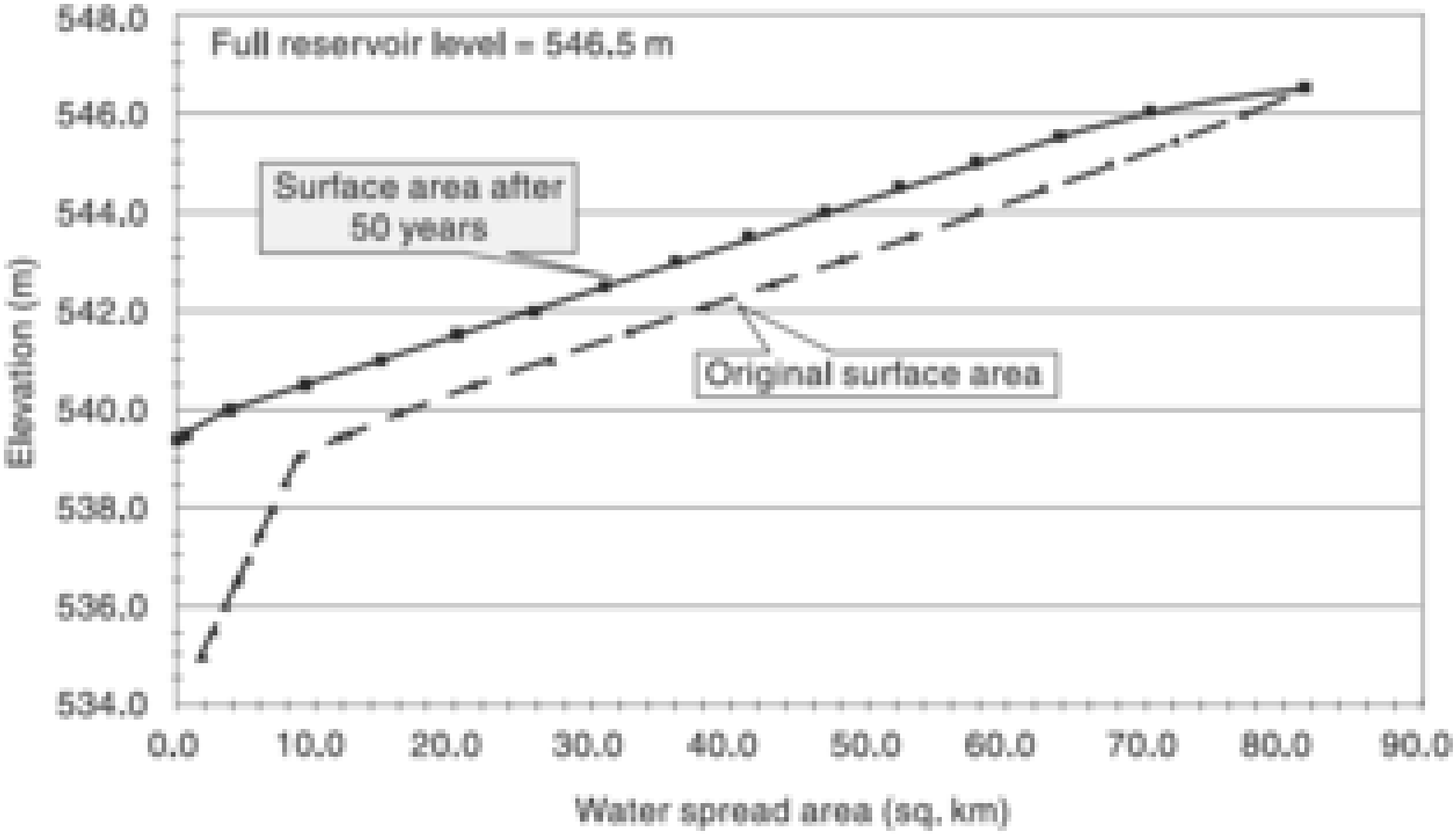

Fig. 10.7(a) *Reservoir Elevation–Area Curves—Example 10.6*

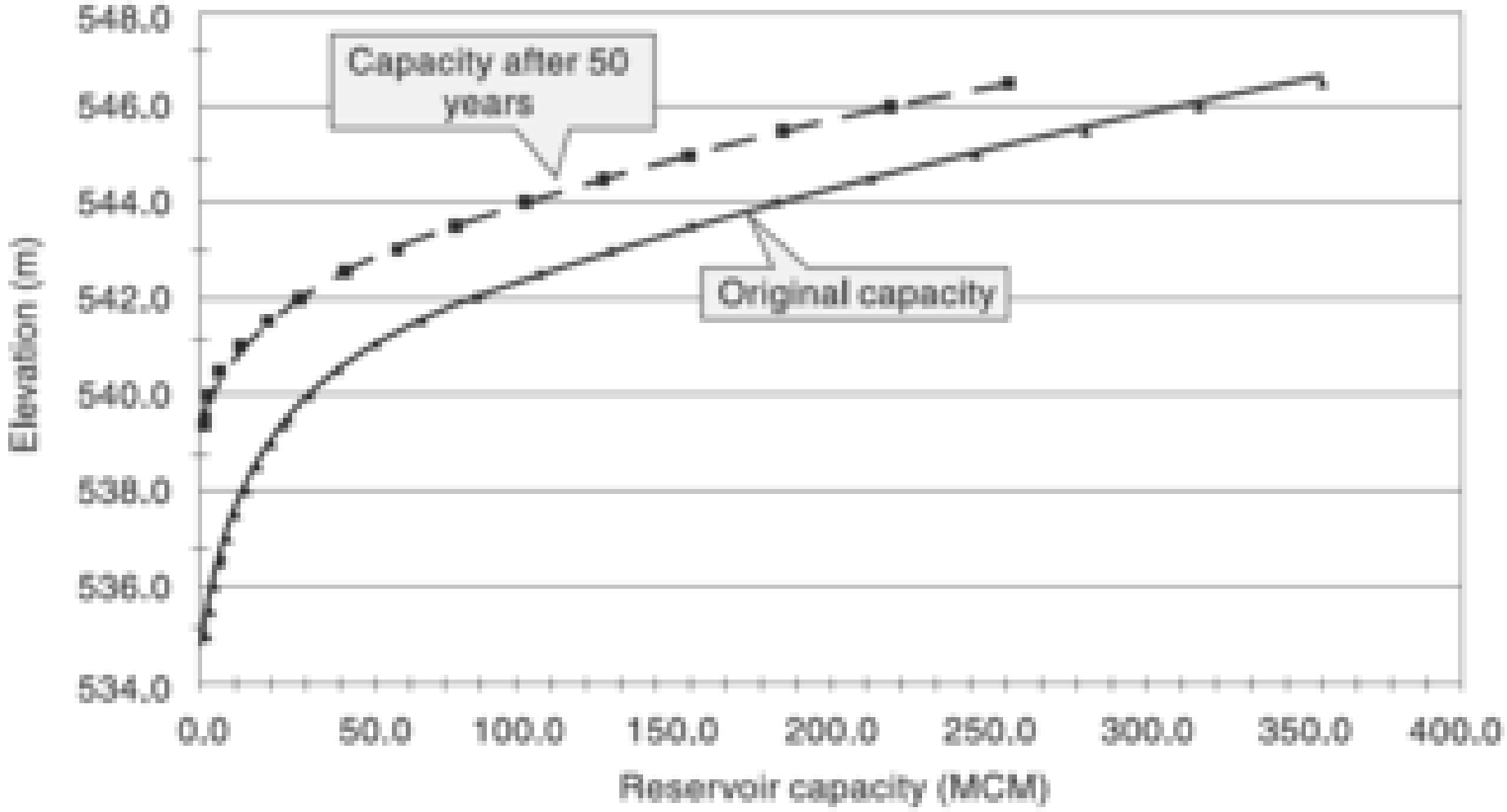

Fig. 10.7(b) *Reservoir Elevation–Capacity Curves—Example 10.6*

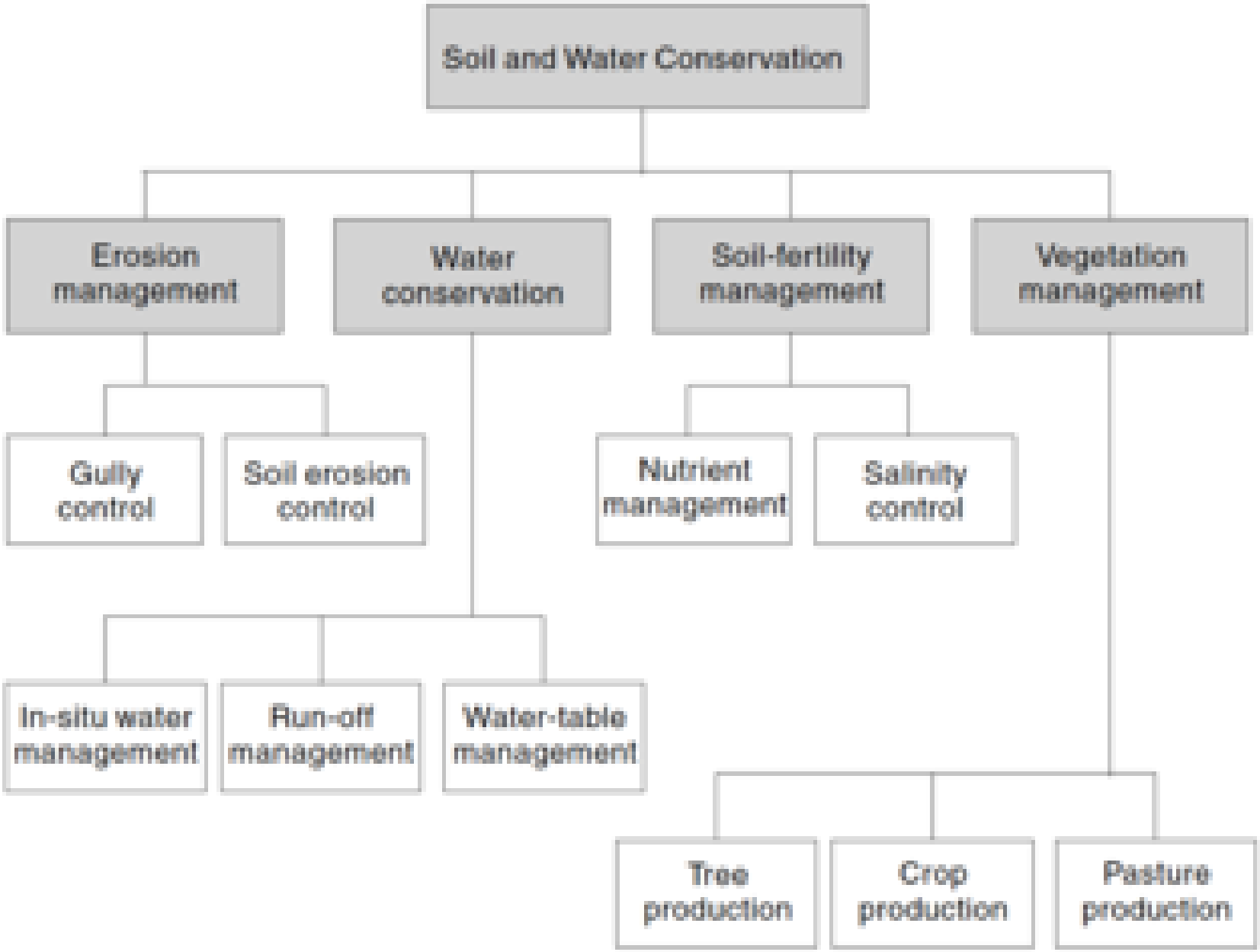

Fig. 10.8 *Integrated Soil and Water Conservation*