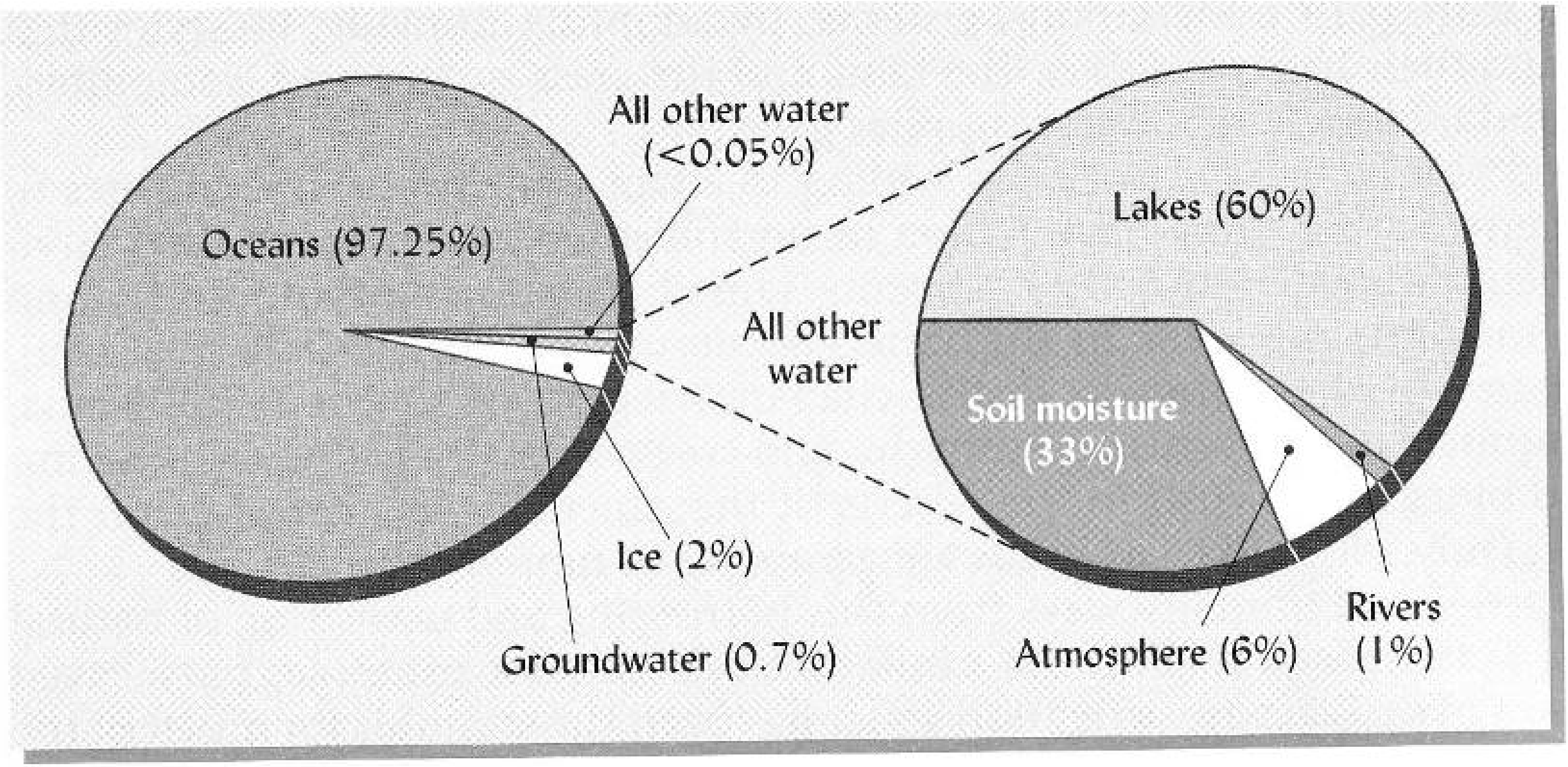
Soil Water and the Hydrological Cycle

Ecological Agriculture 1/31/2006

Steve Scheuerell

Water on Earth



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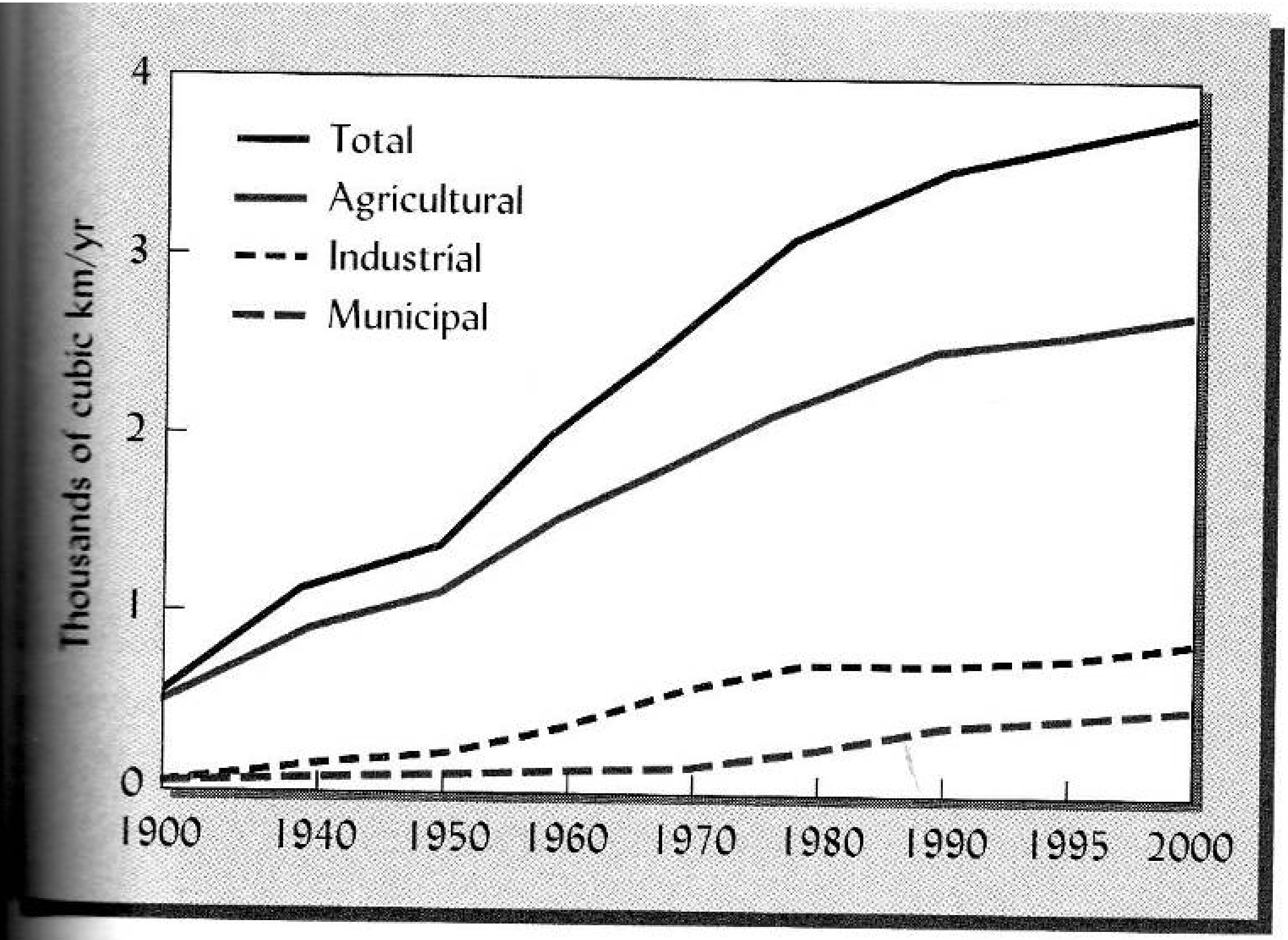
Water use by society



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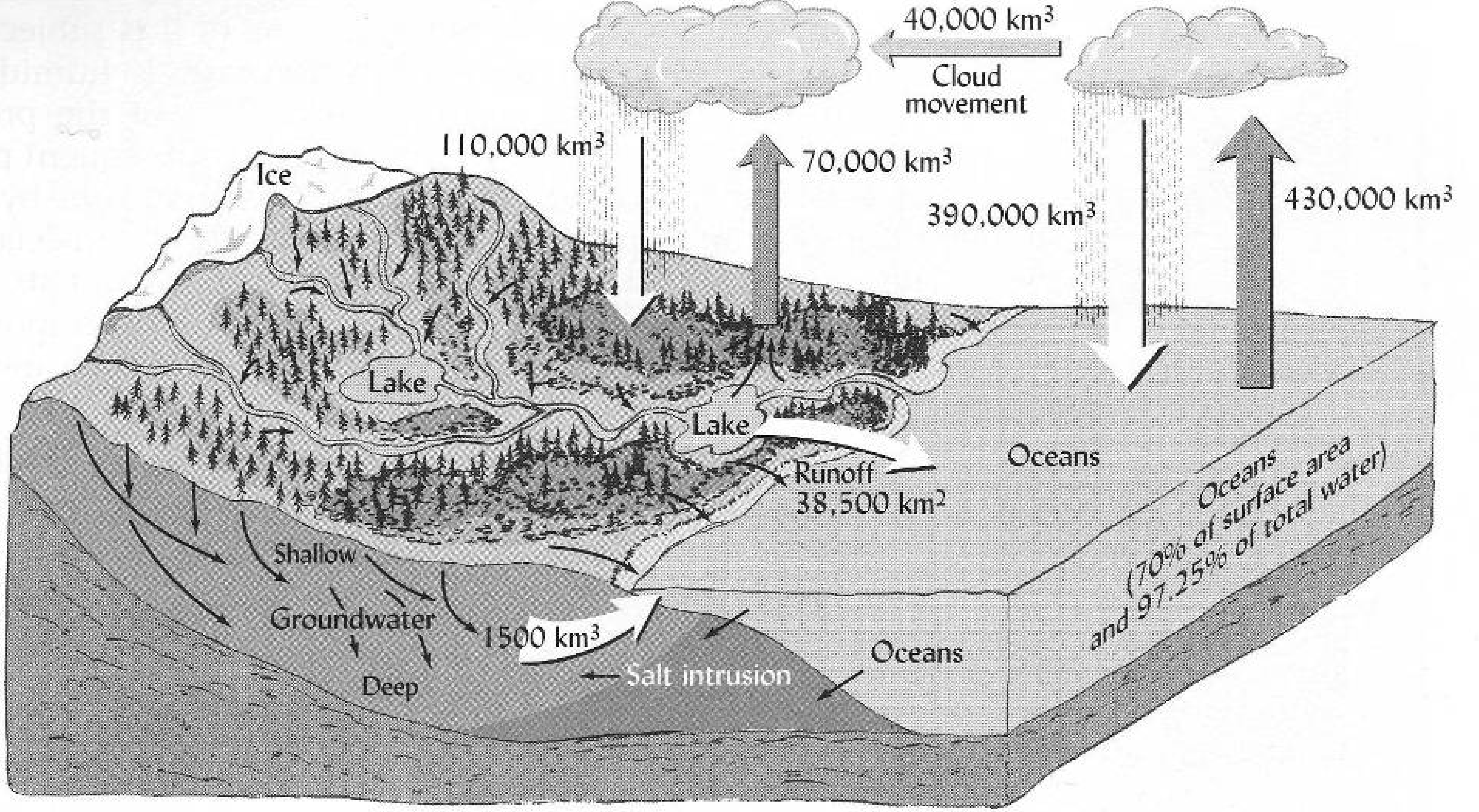
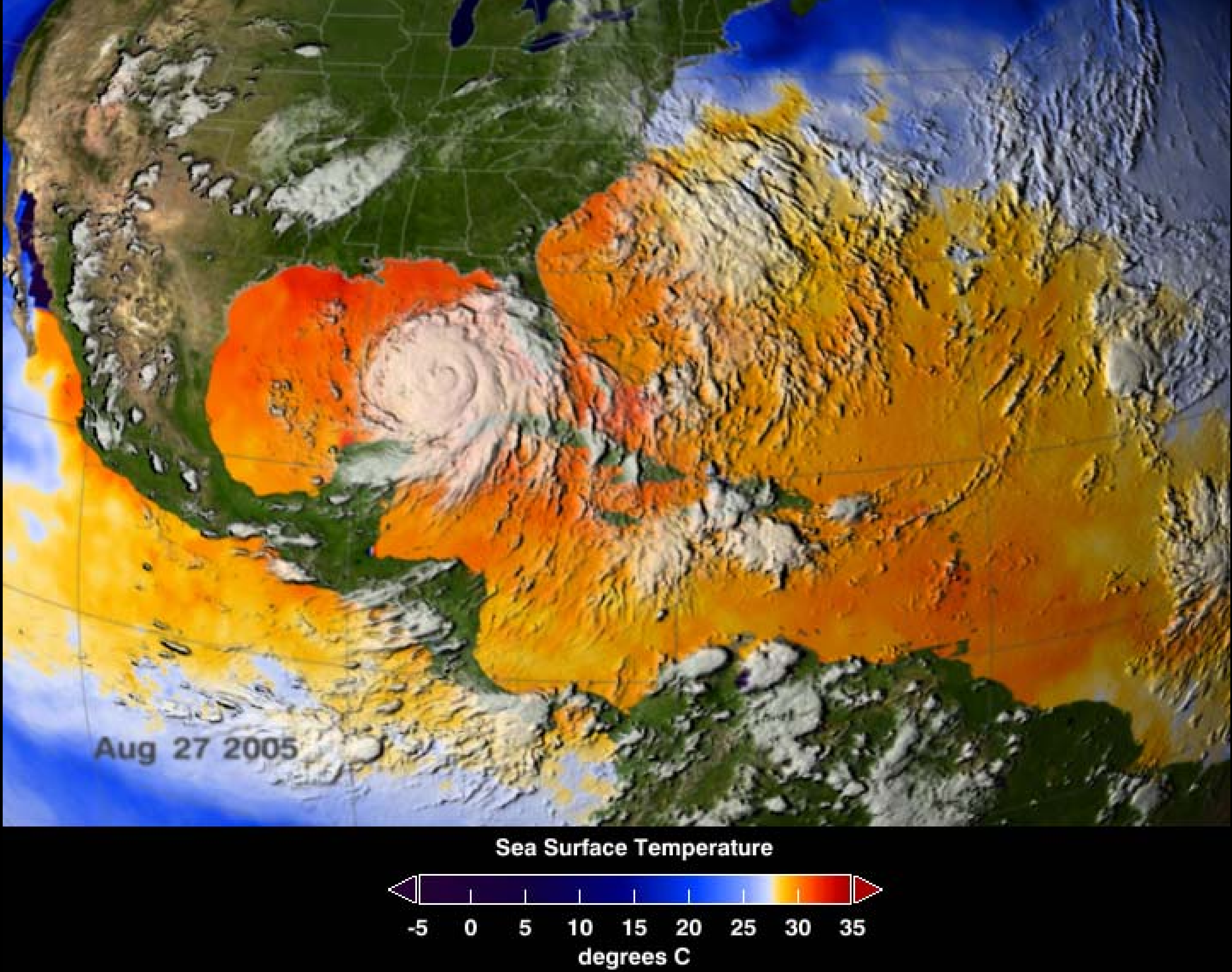


FIGURE 6.2 The hydrologic cycle upon which all life depends is very simple in principle. Water evaporates from the earth's surface, both the oceans and continents, and returns in the form of rain or snowfall. The net movement of clouds brings some 40,000 km^3 of water to the continents and an equal amount of water is returned through runoff and groundwater seepage that is channeled through rivers to the ocean. About 86% of the evaporation and 78% of the precipitation occurs in the ocean areas. However, the processes occurring on land areas where the soils are influential have impacts not only on humans but on all other forms of life, including those residing in the sea.


Aug 27 2005
Sea Surface Temperature
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Movement of water from soil to plants to the atmosphere

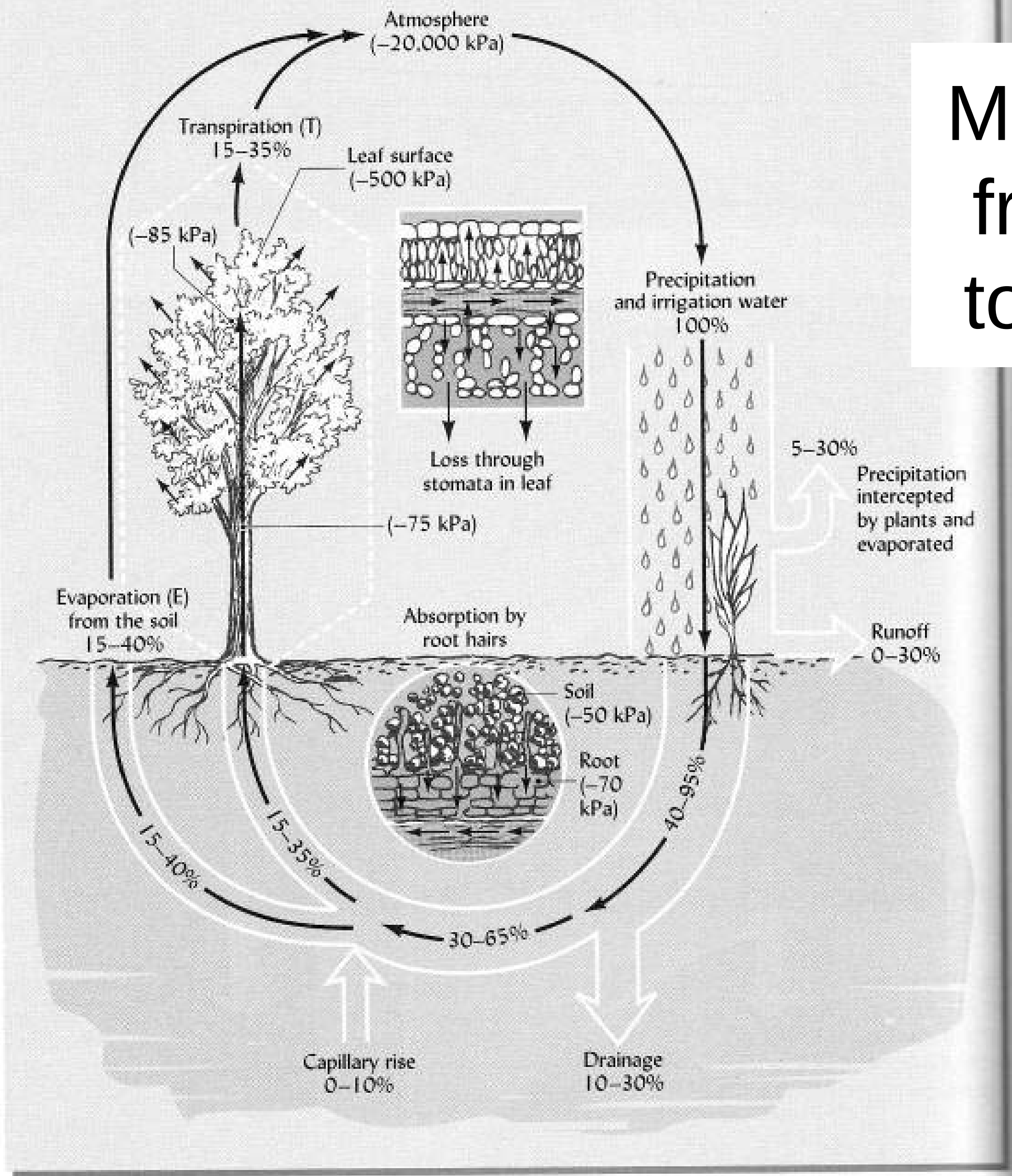


FIGURE 6.10 Soil–plant–atmosphere continuum (SPAC) showing water movement from soil to plants to the atmosphere and back to the soil in a humid to subhumid region. Water behavior through the continuum is subject to the same energy relations covering soil water that were discussed in Chapter 5. Note that the moisture potential in the soil is –50 kPa, dropping to –70 kPa

Runoff - Infiltration - Percolation

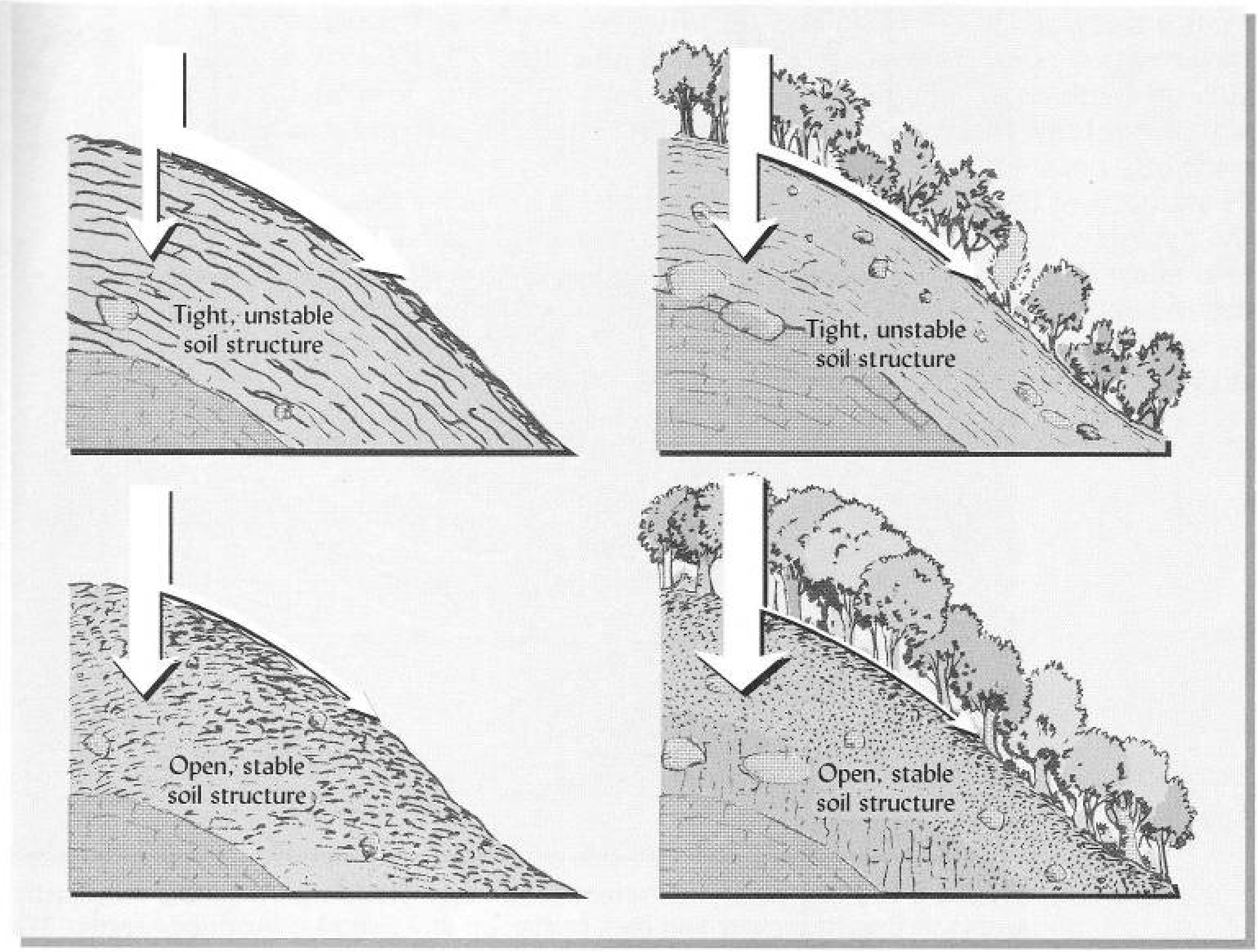


FIGURE 6.9 Influence of soil structure and vegetation on the partitioning of rainfall into infiltration and runoff. The upper two diagrams show soils with tight, unstable structure that resists infiltration and

Infiltration of water into the soil

Stem flow from plants

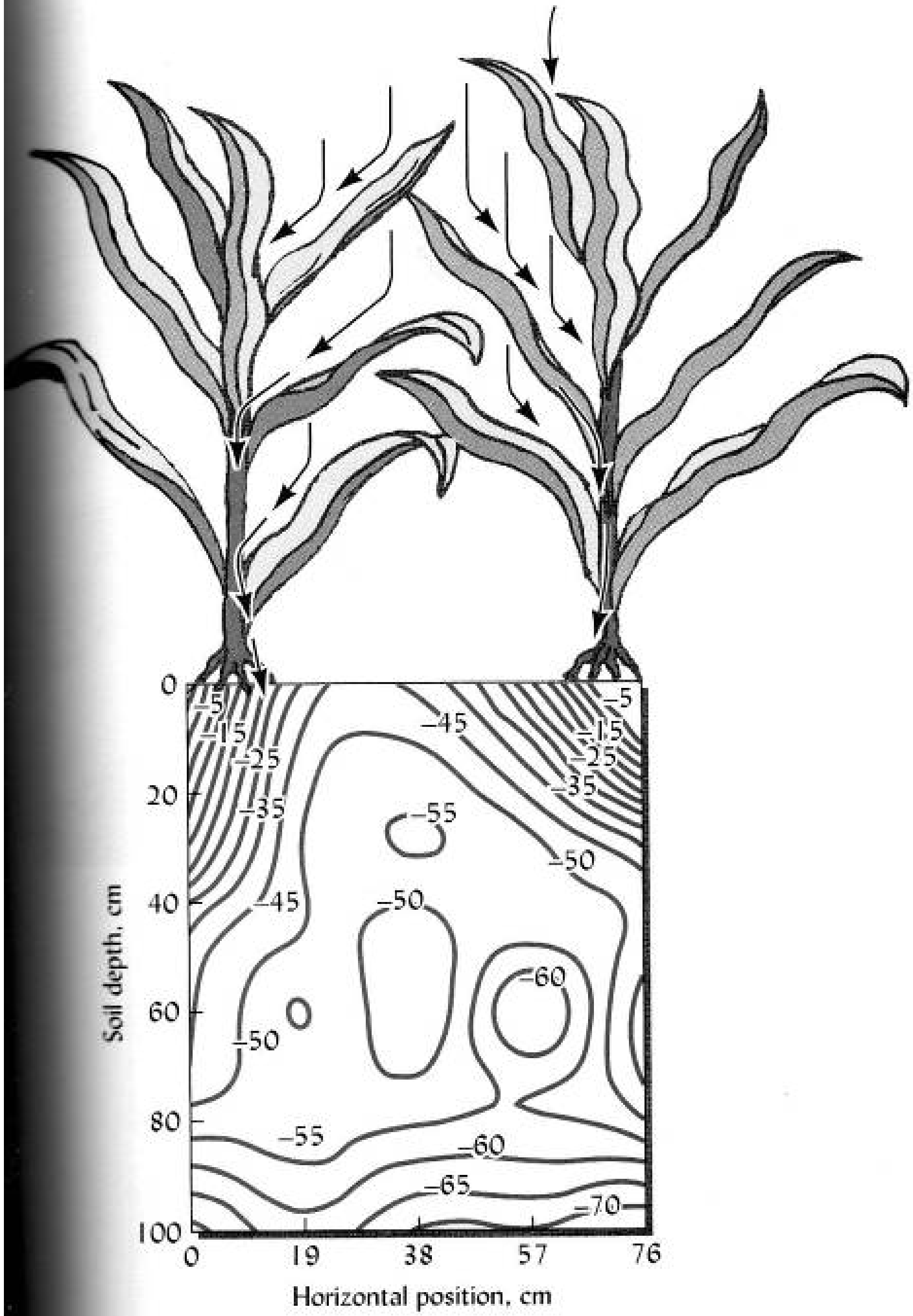


FIGURE 6.6 Vertical and horizontal distribution of soil water resulting from stem flow. The contours indicate the soil water potential in kPa between two corn rows in a sandy loam soil. During the previous two days, 26 mm of rain fell on this field. Many plant canopies, including that of the corn crop shown, direct a large proportion of rainfall toward the plant stem. Stem flow results in uneven spatial distribution of water. In cropland this may have ramifications for the leaching of chemicals such as fertilizers, depending on whether they are applied in or away from the zone of highest wetting near the plant stems. The concentration of water by stem flow may also increase the likelihood of macropore flow in soils after only moderate rainfall. [Data from Waddell and Weil (1996); used by permission of the Soil Science Society of America]

Preferential
or
Bypass flow

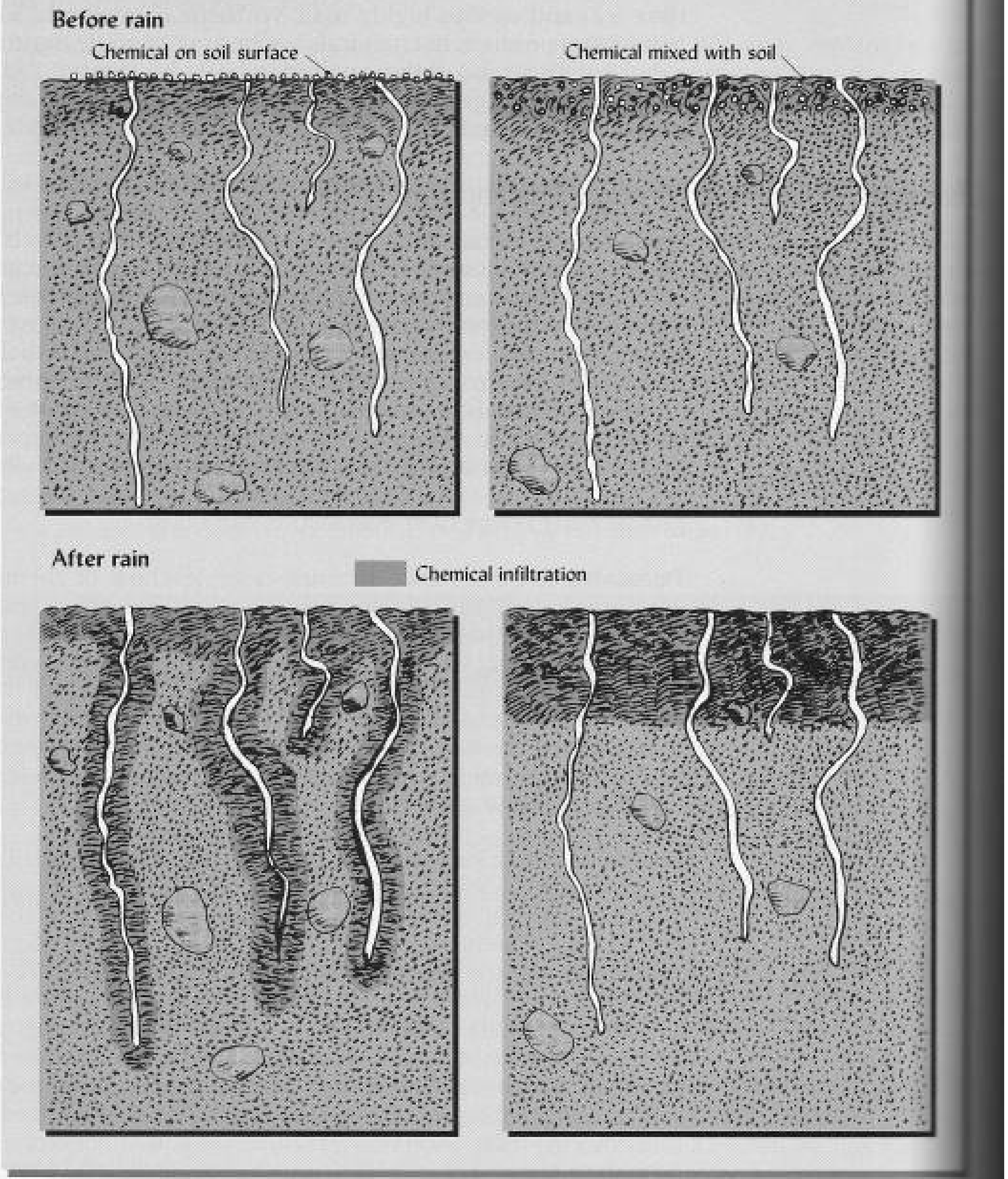


FIGURE 6.27 Preferential or bypass flow in macropores transports soluble chemicals downward thro a soil profile. Where the chemical is on the soil surface (left), and can dissolve in surface-ponded wa when it rains, it may be transported rapidly down cracks, earthworm channels, and other macrop Where the chemical is dispersed within the soil matrix in the upper horizon (right), most of the wa moving down through the macropores will bypass the chemical, and thus little of the chemical wil carried downward.

Water infiltration – water repellency after fire

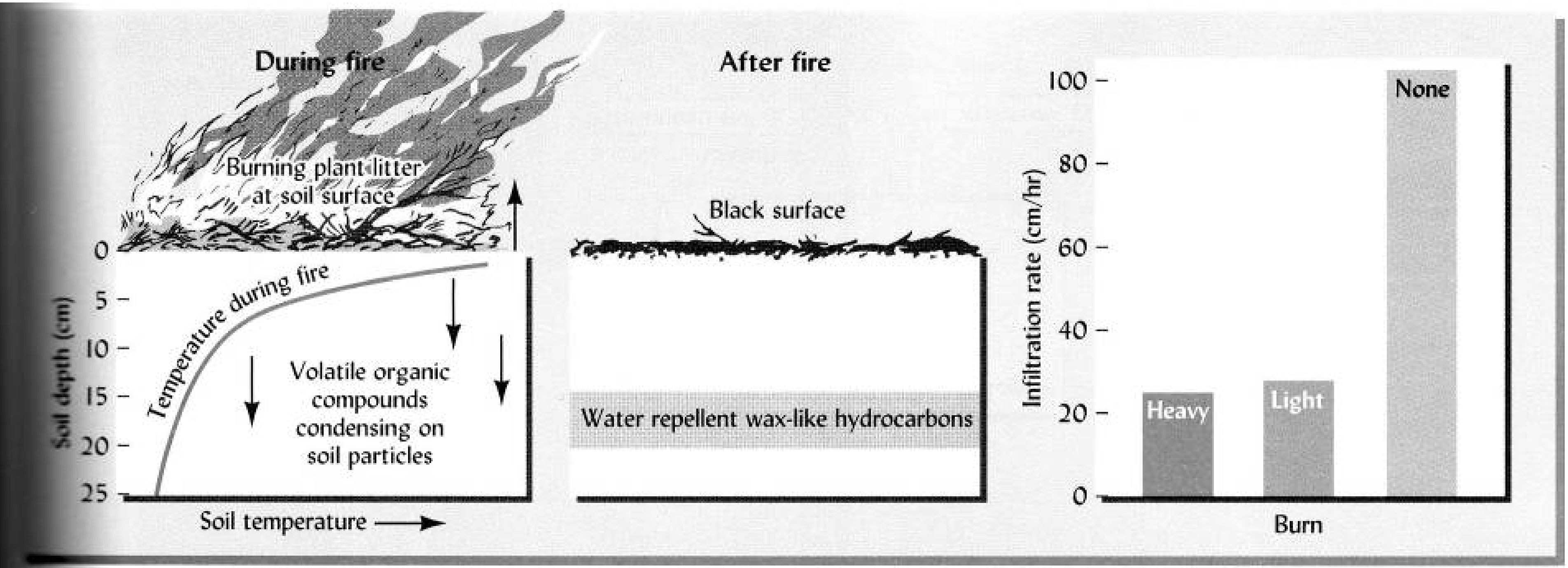


FIGURE 7.24 (Left) Wildfires of a lodgepole pine stand heat up the surface layers of this sandy soil (an Inceptisol) in Oregon. (Center) Note that the soil temperature is increased sufficiently near the surface to volatilize organic compounds, some of which then move down into the soil and condense (solidify) on the surface of cooler soil particles. These condensed compounds are waxlike hydrocarbons that are water repellent. As a consequence (right) the infiltration of water into the soil is drastically reduced and remains so for a period of at least six years. [From Dryness (1976)]

Percolation of water through the soil

- Saturated Flow
  - Gravity draining large soil pores

- Unsaturated Flow
  - Soil water potential movement of water from high potential to low potential
  - Capillary action

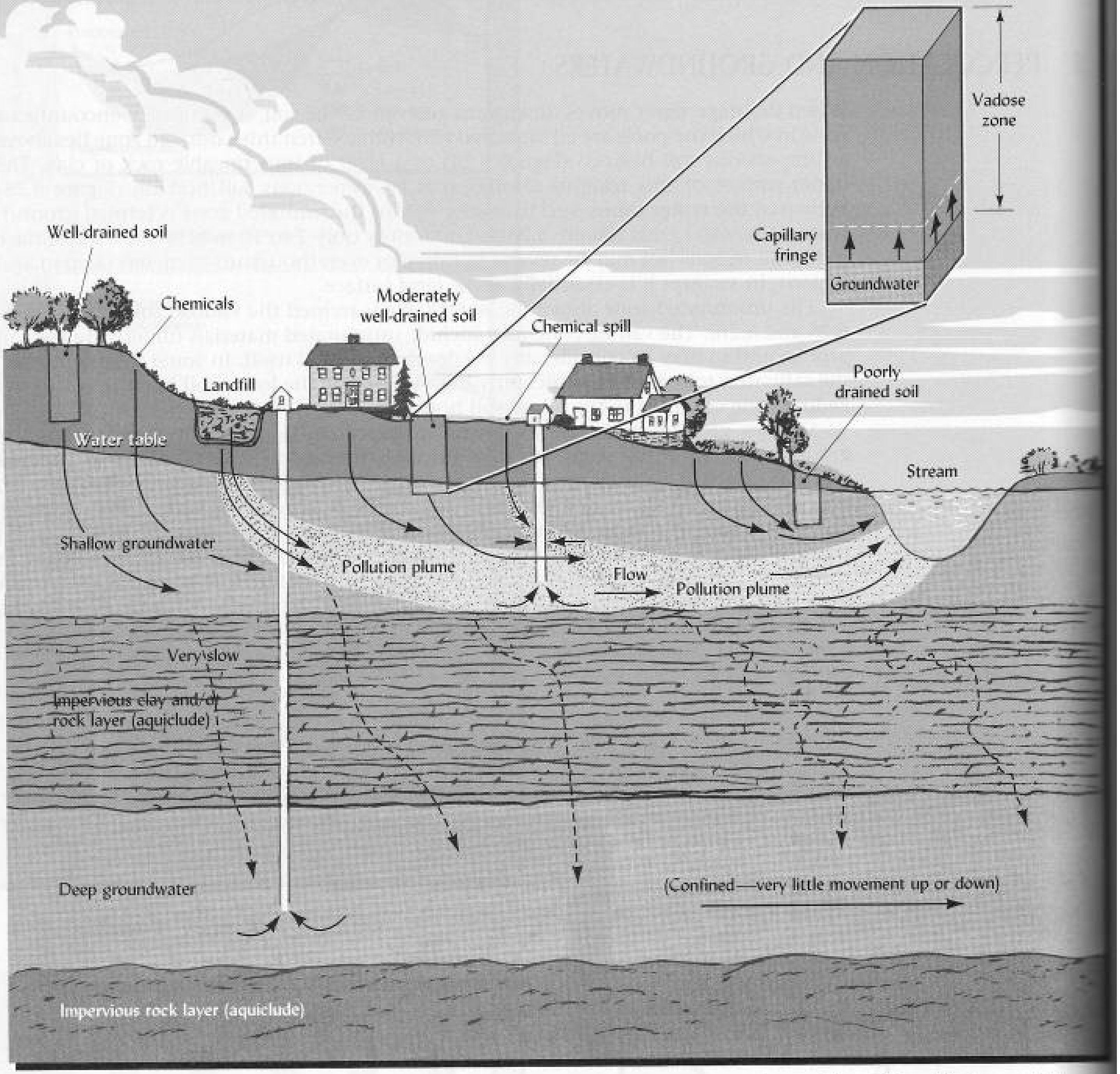


FIGURE 6.25 Relationship of the water table and groundwater to water movement into and out of the soil. Precipitation and irriga
water move down the soil profile under the influence of gravity (gravitational water), ultimately reaching the water table and und

Perched water table – look outside!

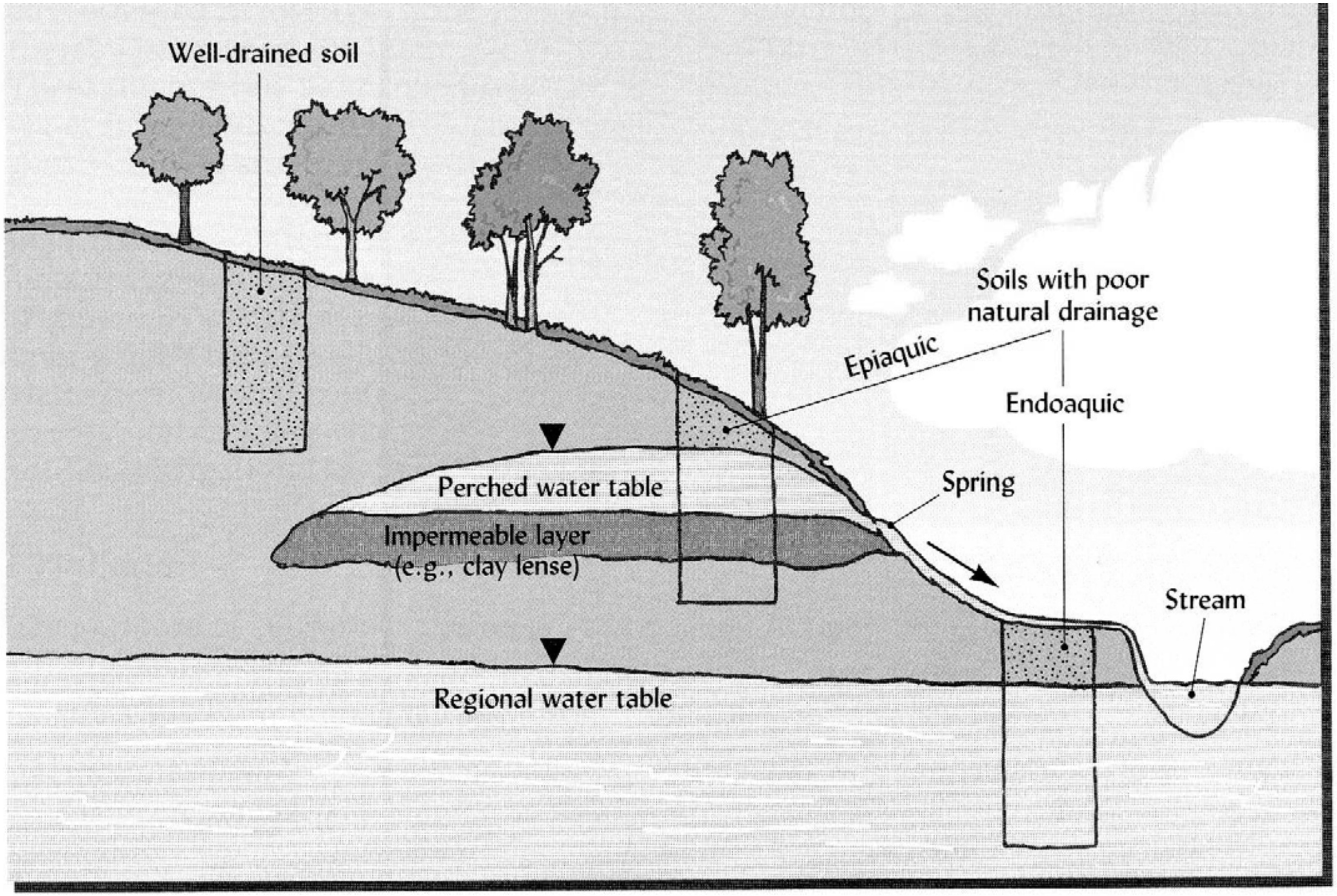


FIGURE 6.28 Cross-section of a landscape showing the regional and perched water tables in relation to three soils, one well-drained and two with poor internal drainage. By convention, a triangle (▼) is used to identify the level of the water table. The soil containing the perched water table is wet in the upper part, but unsaturated below the impermeable layer, and therefore is said to be *epiaquic* (Greek *epi*, upper), while the soil saturated by the regional water table is said to be *endoaquic* (Greek *endo*, under). Artificial drainage can help to lower both types of water tables.

Capillary rise from water table

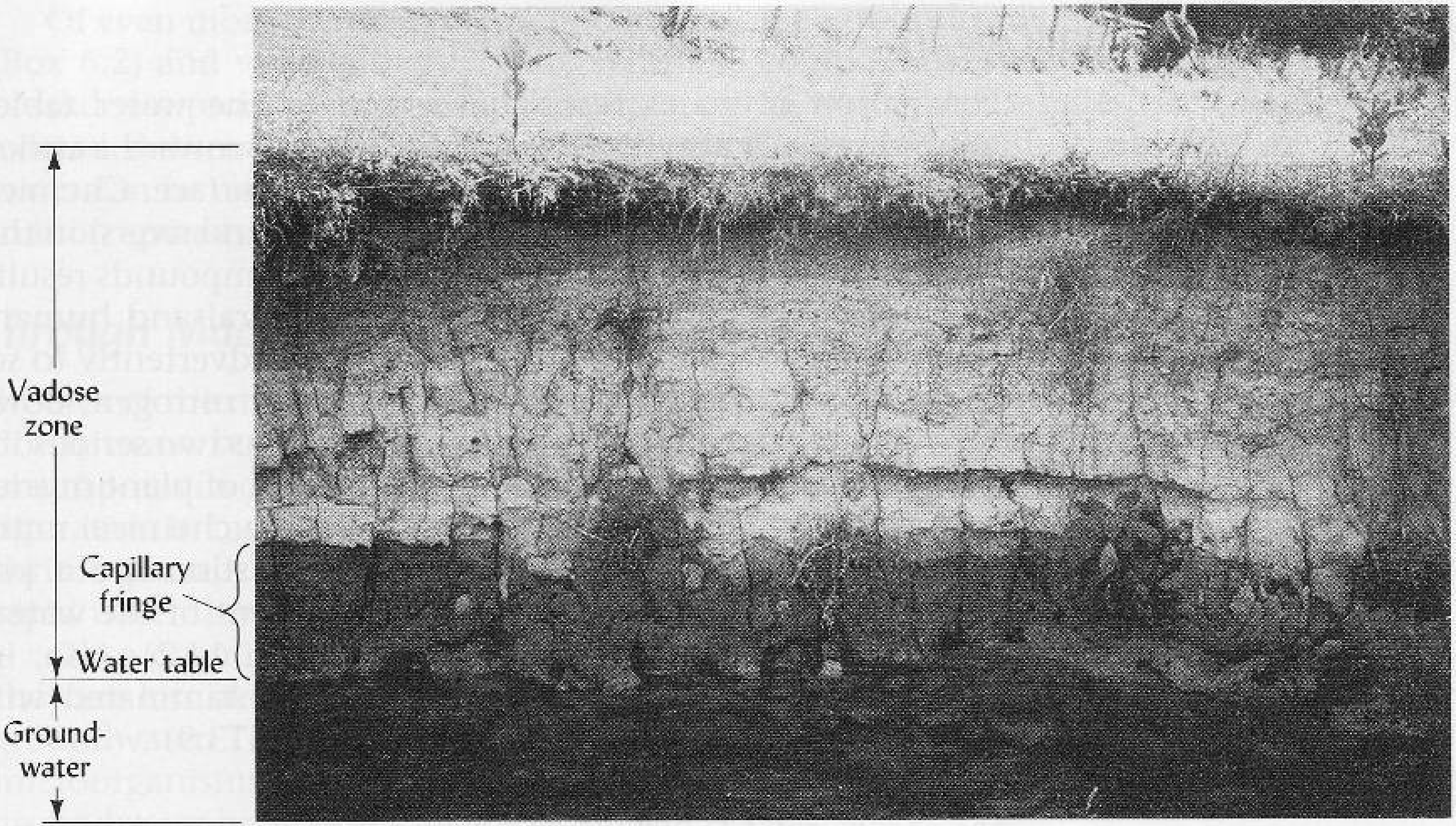
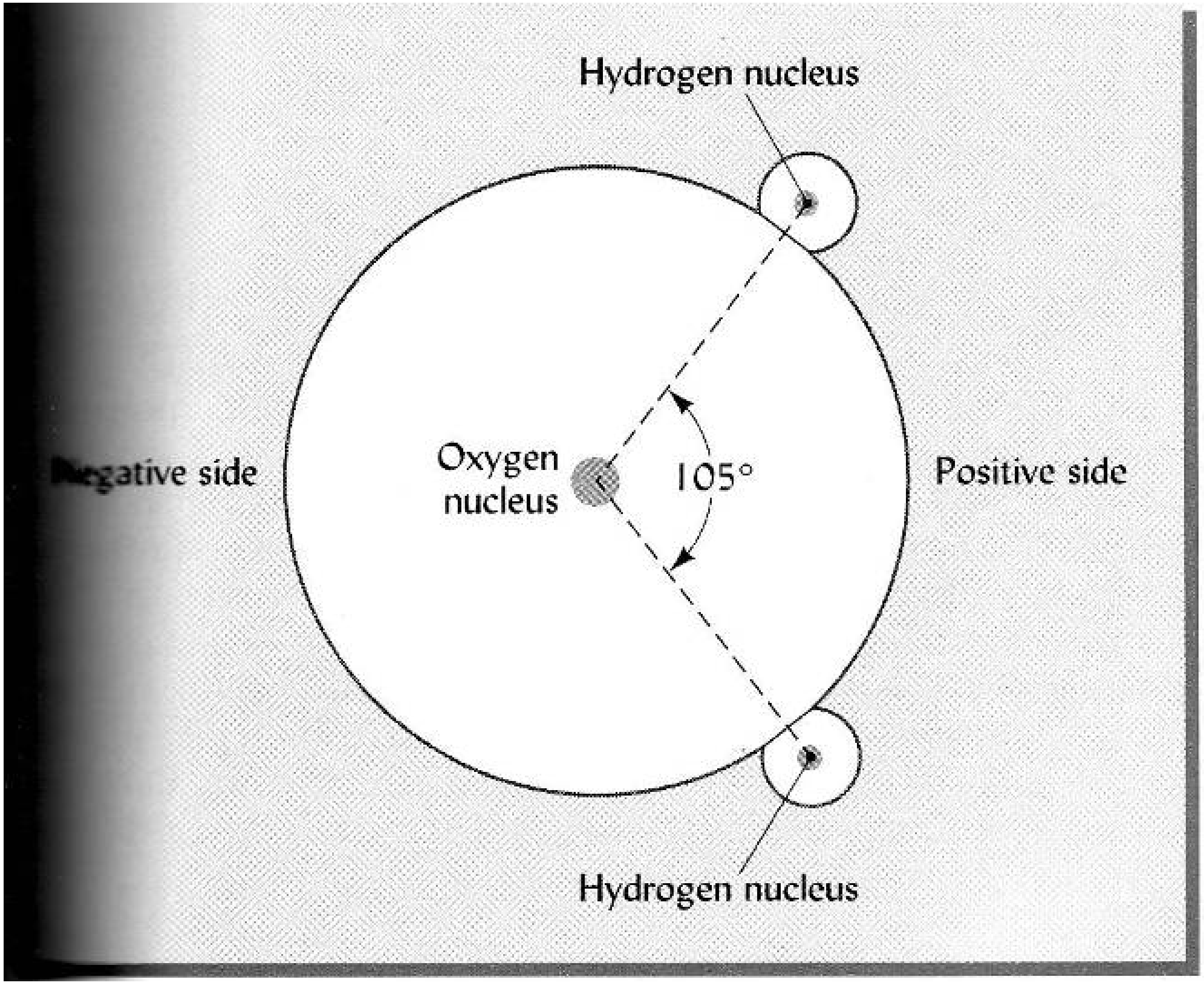


FIGURE 6.26 The water table, capillary fringe, zone of unsaturated material above the water table (vadose zone), and groundwater are illustrated in this photograph. The groundwater can provide significant quantities of water for plant uptake. (Photo courtesy of R. Weil)

Water Molecule – polarity



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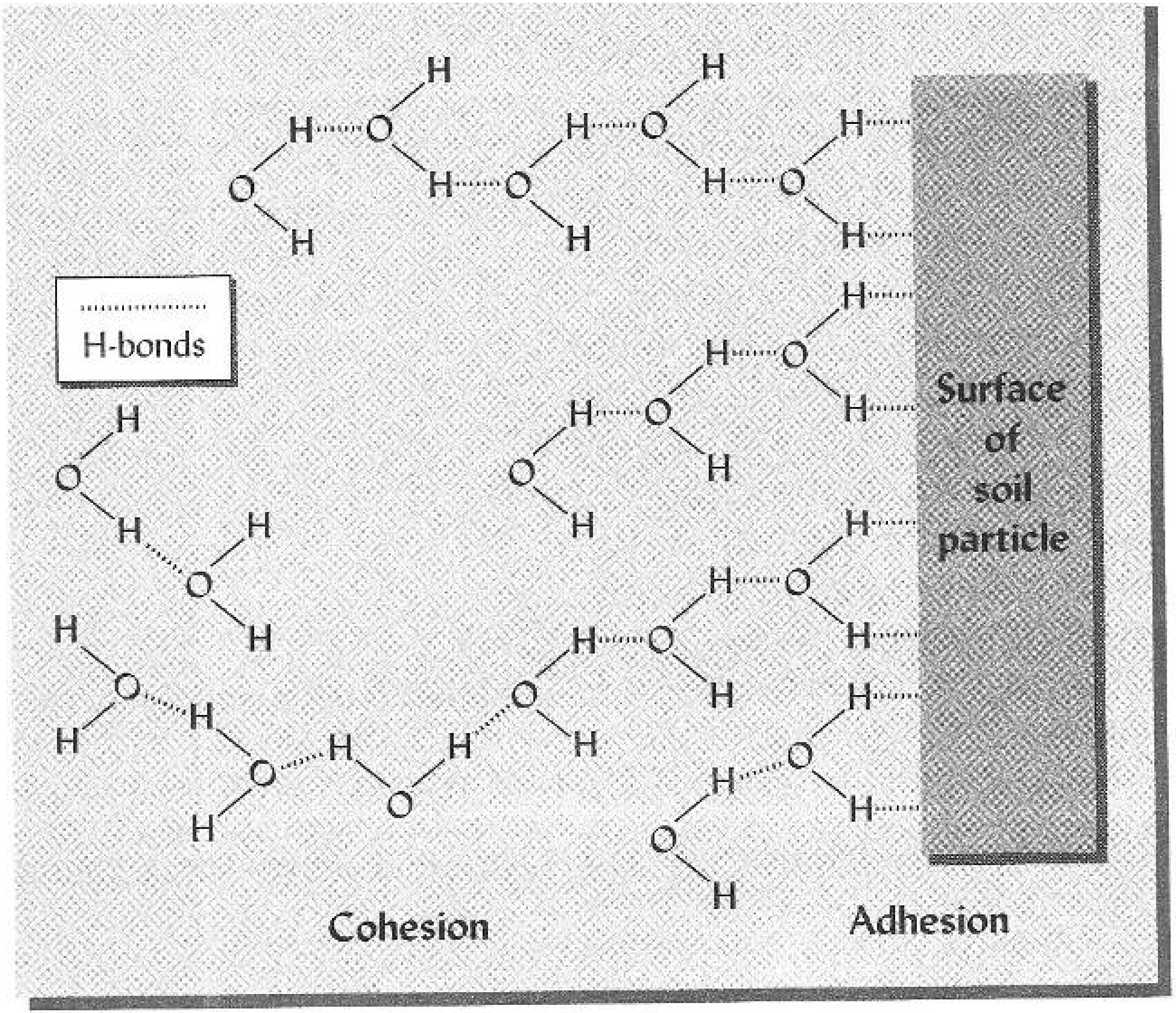
Cohesion and Adhesion of water



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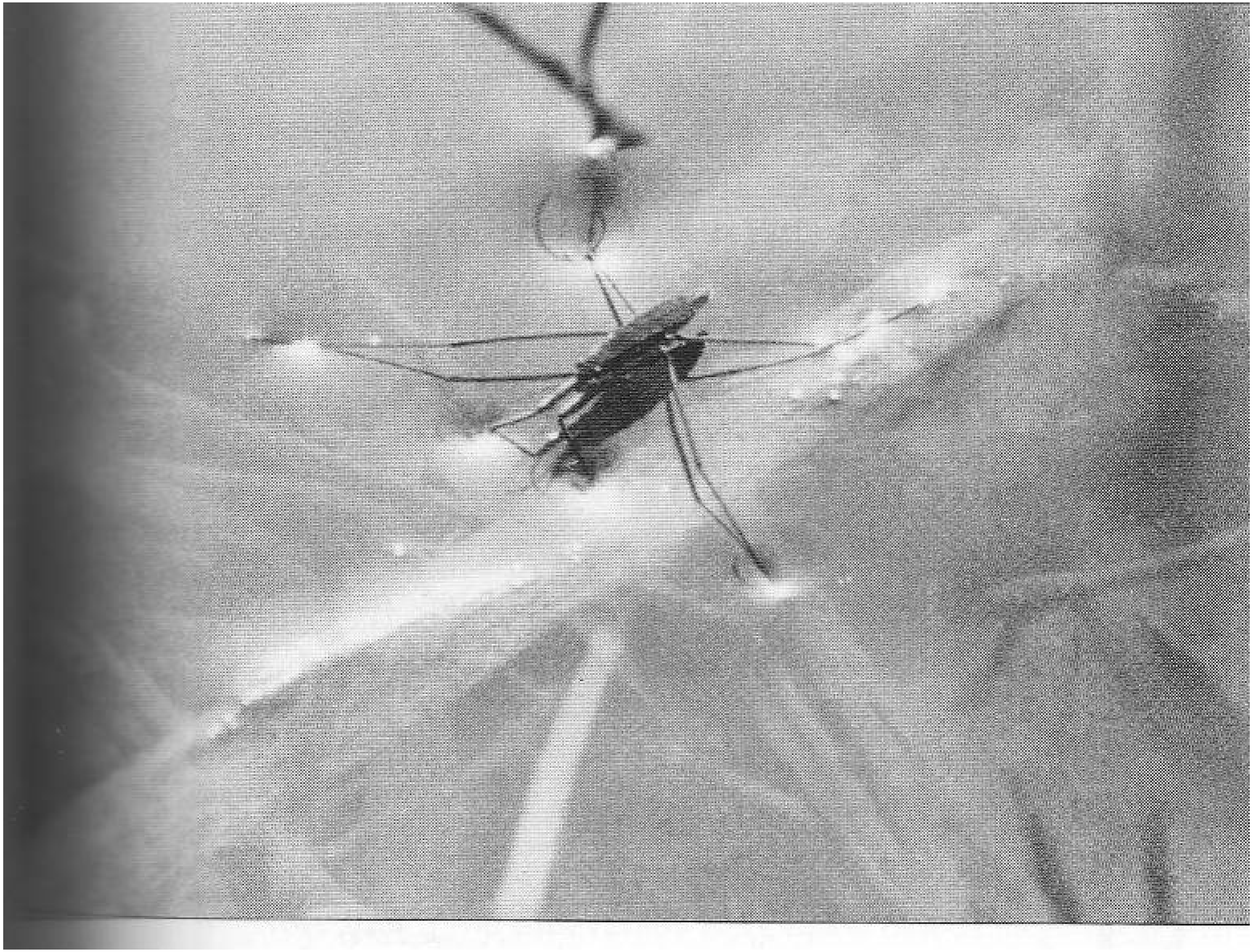
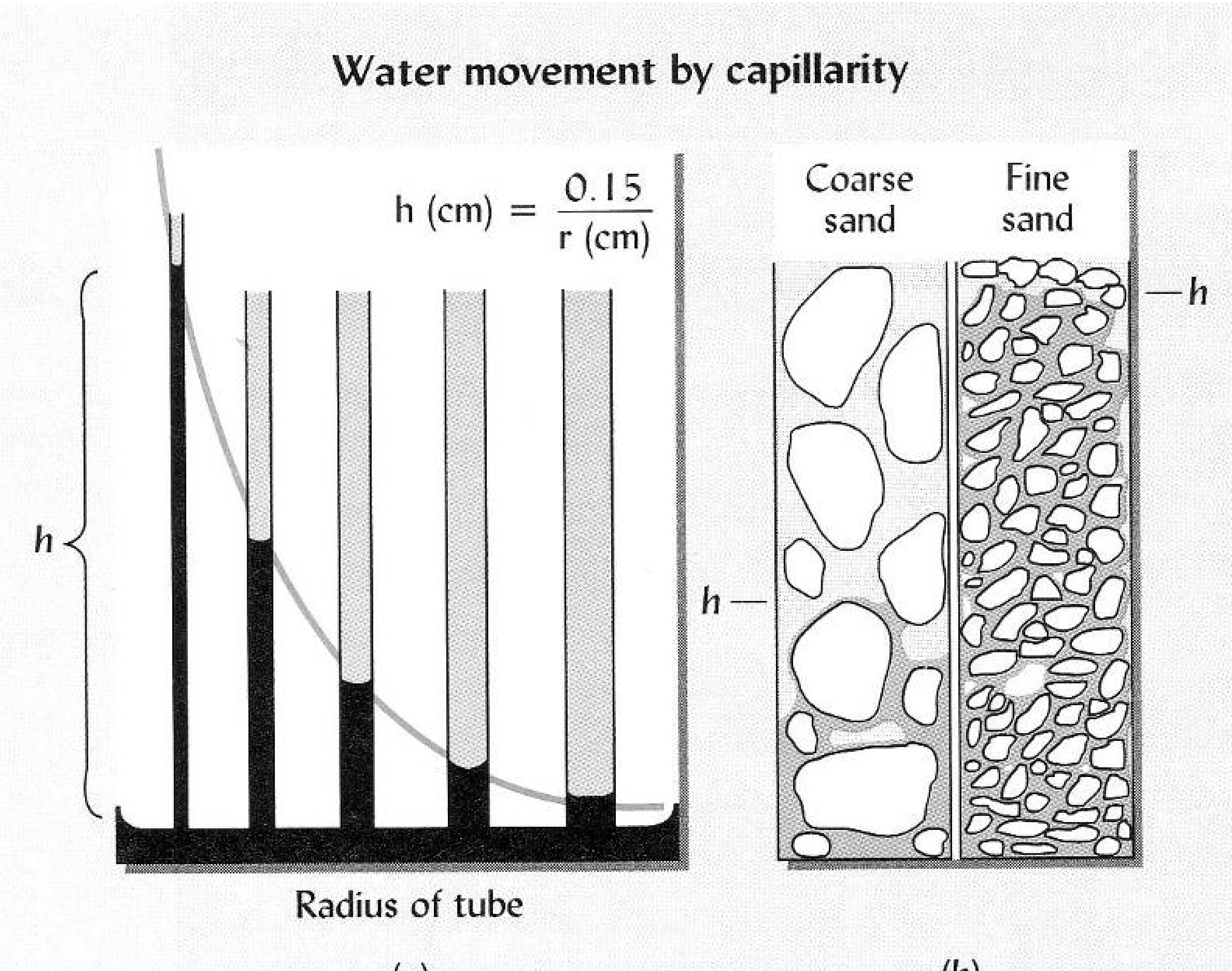
Water surface tension - cohesion of water molecules

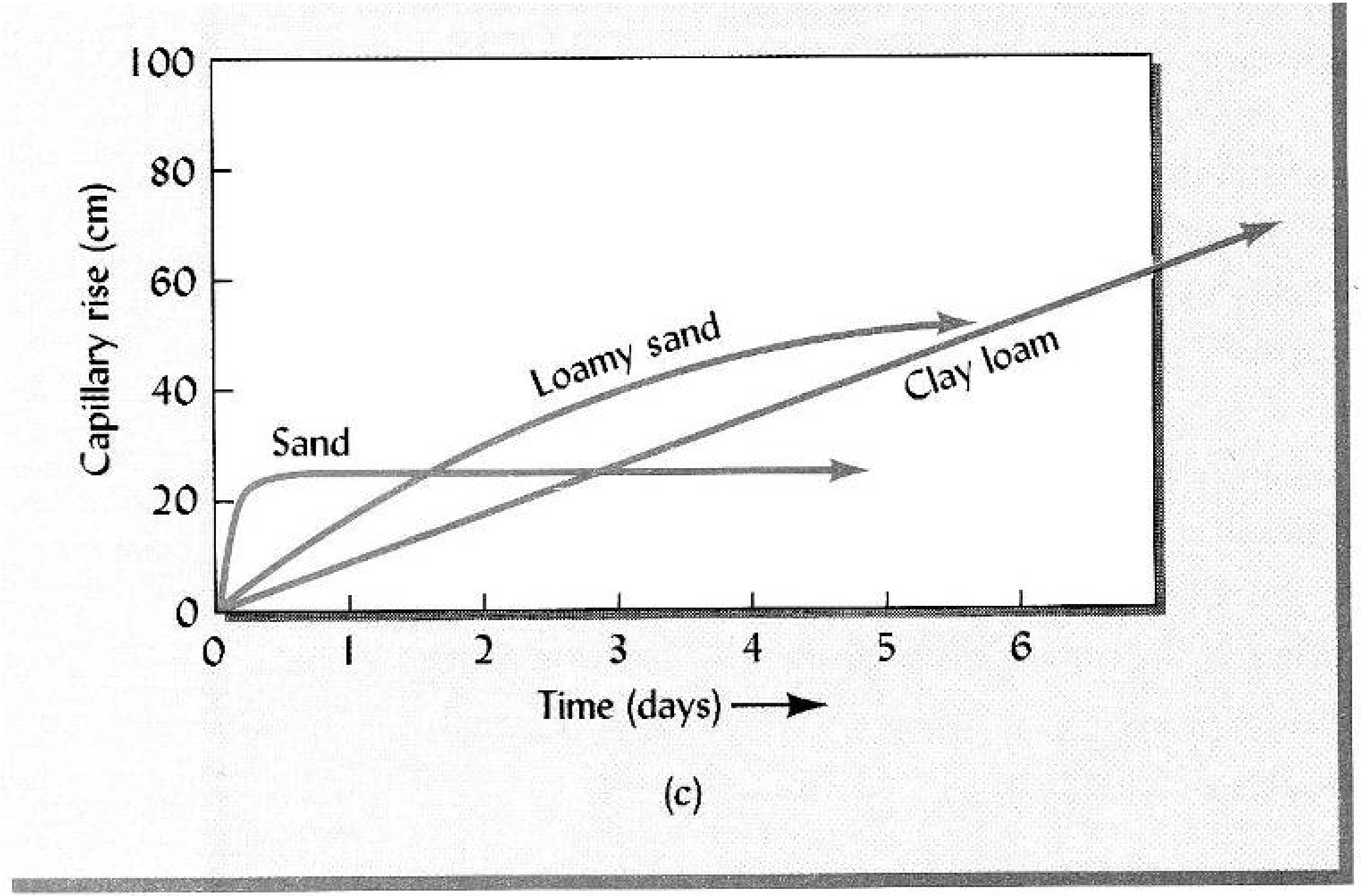


Capillary water movement – soil pore diameter



Water movement by capillarity

Capillary rise (cm) over days



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Percolation rate influenced by soil texture
Sandy loam verses Clay loam

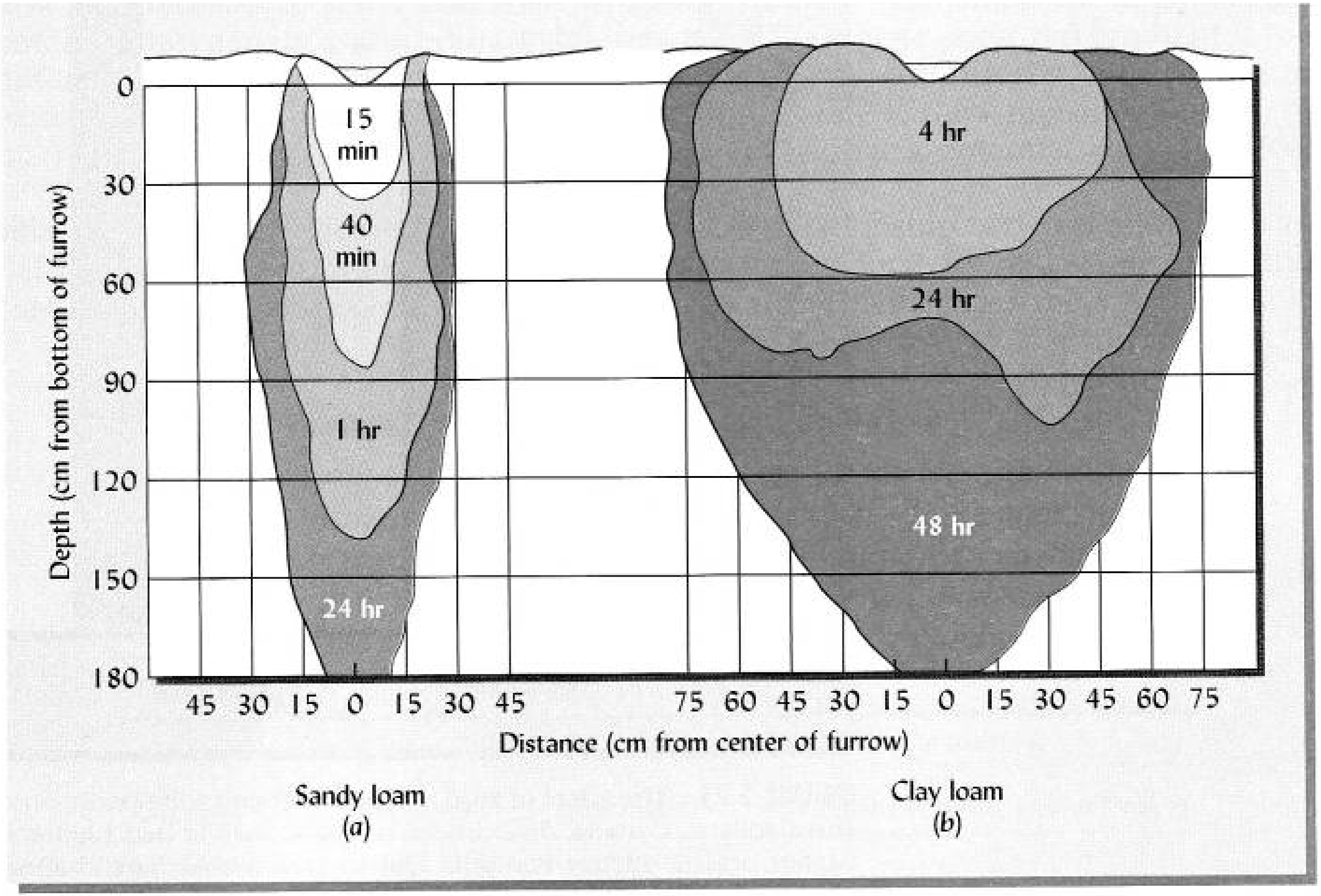


FIGURE 5.20 Comparative rates of irrigation water movement into a sandy loam and a clay loam. Note the much more rapid rate of movement in the sandy loam, especially in a downward direction. [Redrawn from Cooney and Peterson (1955)]

Soil Texture and Structure – Saturated Conductivity

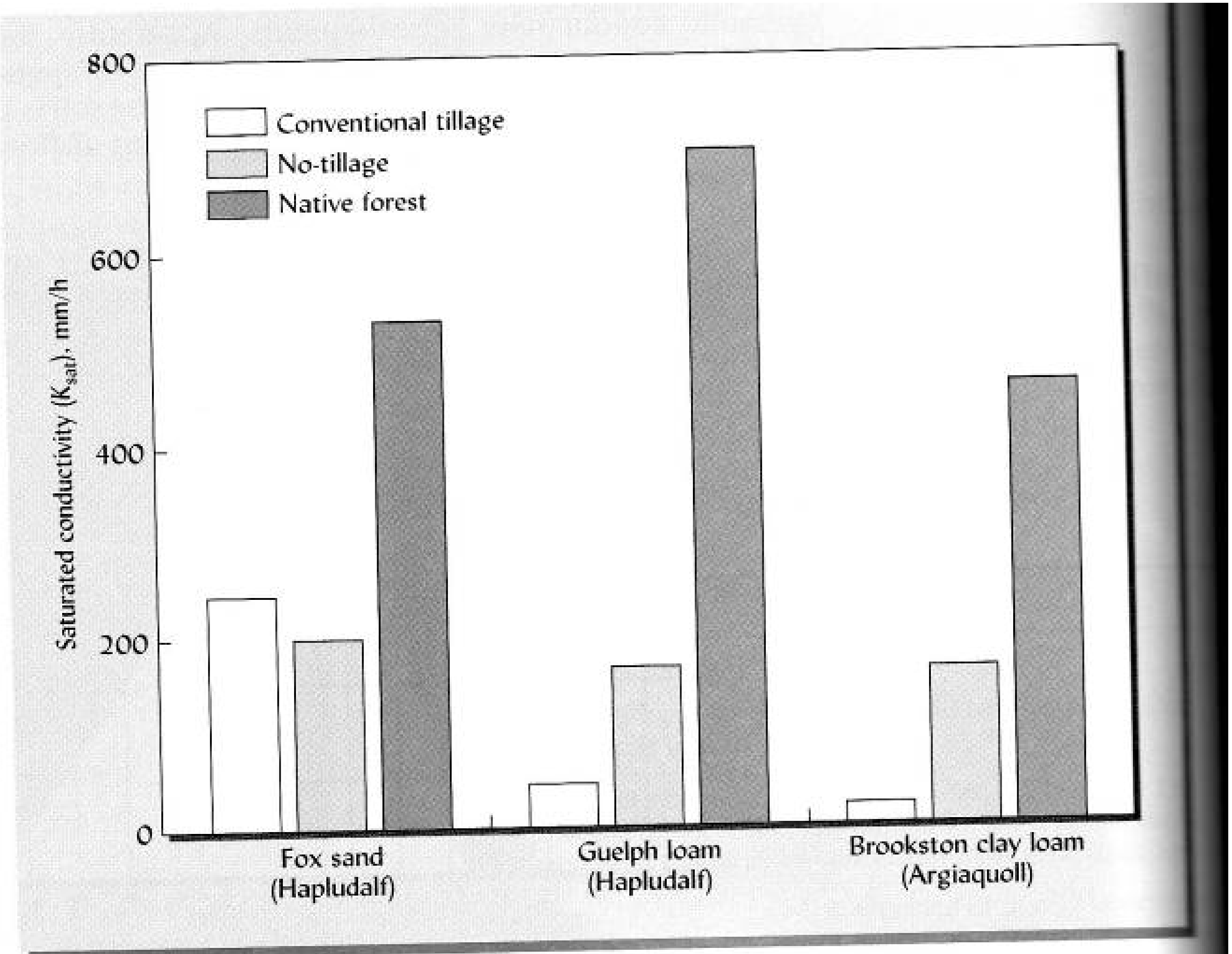


FIGURE 5.21 The effect of land management and soil texture on saturated conductivity (K_{sat}) of three soils in Canada. Soils under native woodlots had higher K_{sat} values, apparently due to higher organic matter contents and to preferential flow channels provided by decayed root channels and burrowing animals. Tillage practices had little effect on conductivity in sand, but in loam and clay loam soils conductivity was higher where no-tillage systems had been used, suggesting that no-till had increased the proportion of larger, water-conducting pores. [Drawn from averages of three methods of measuring K_{sat} in Reynolds et al. (2000)].

Water availability to plants

- Root – soil interface

- Soil Texture and structure

Root – Soil interface

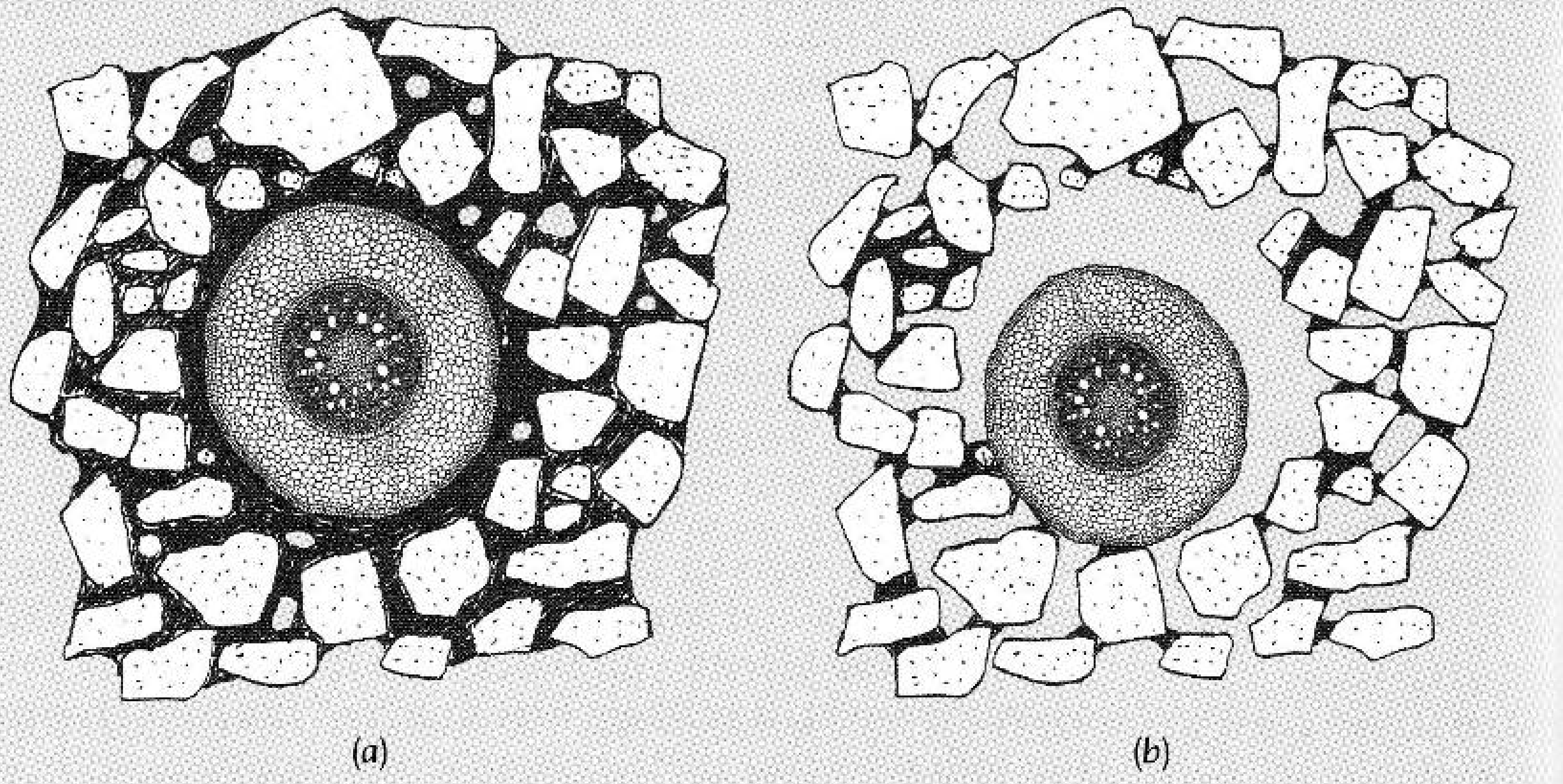
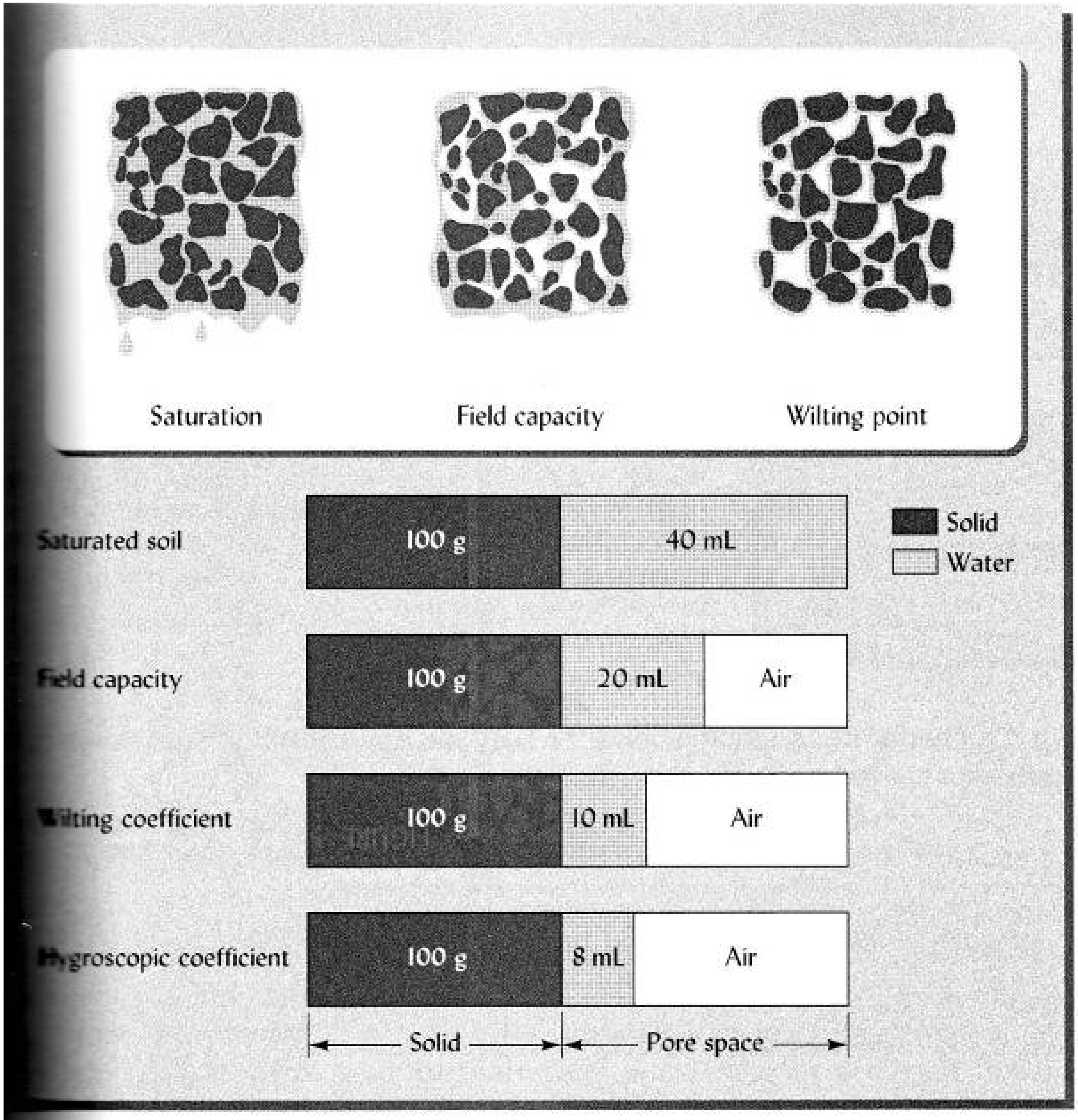


FIGURE 5.40 Cross-section of a root surrounded by soil. (*a*) During periods of adequate moisture an low plant moisture stress the root completely fills the soil pores and is in close contact with the so water films. (*b*) When the plant is under severe moisture stress, such as during hot, dry weather, the roo shrinks (mainly in the cortical cells), significantly reducing root–soil contact. Such root shrinkage ca occur on a hot day even if soil water content is high. Based on concepts in [Huck, et al. (1970)].

Water in soil pores –Saturation, Field capacity, and Wilting point



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Tensiometer in soil to measure water potential

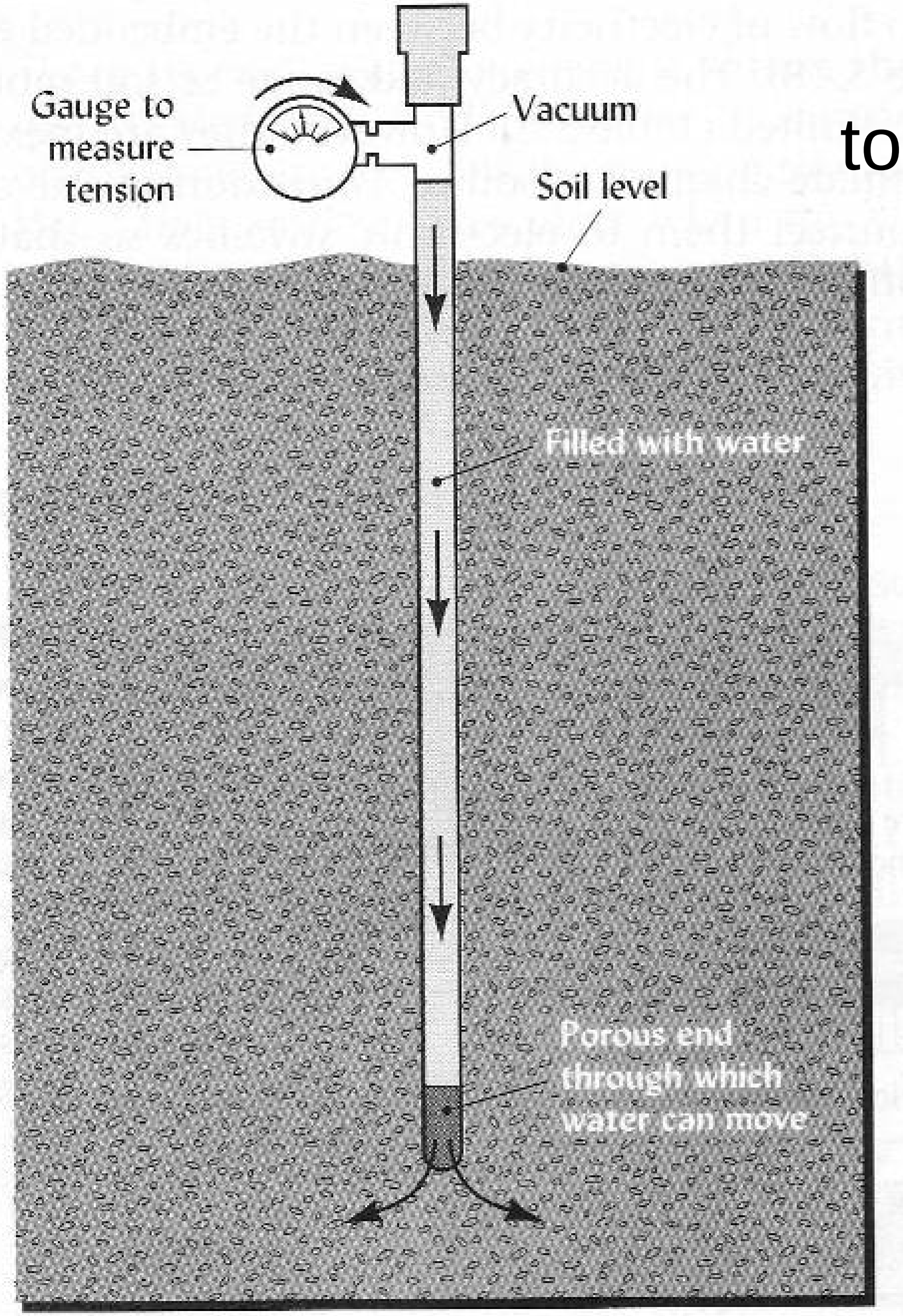


FIGURE 5.16 Tensiometer method of determining water potential in the field. Cross section showing the essential components of a tensiometer. Water moves through the porous end of the instrument in response to the pull (matric potential) of the soil. The vacuum so created is measured by a gauge that reads in kPa of tension (–kPa water potential).

Soil Water Content – Matric Potential

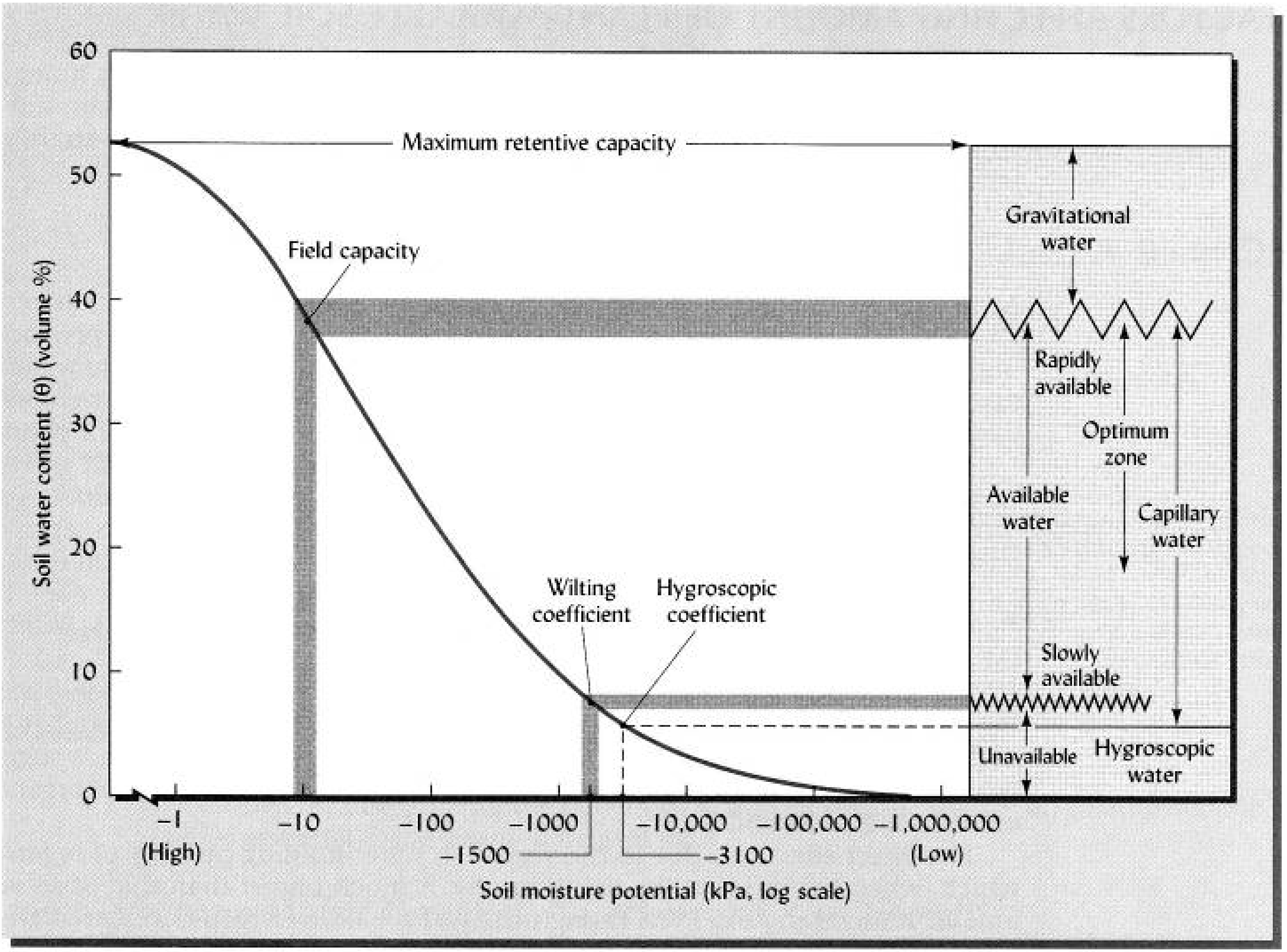
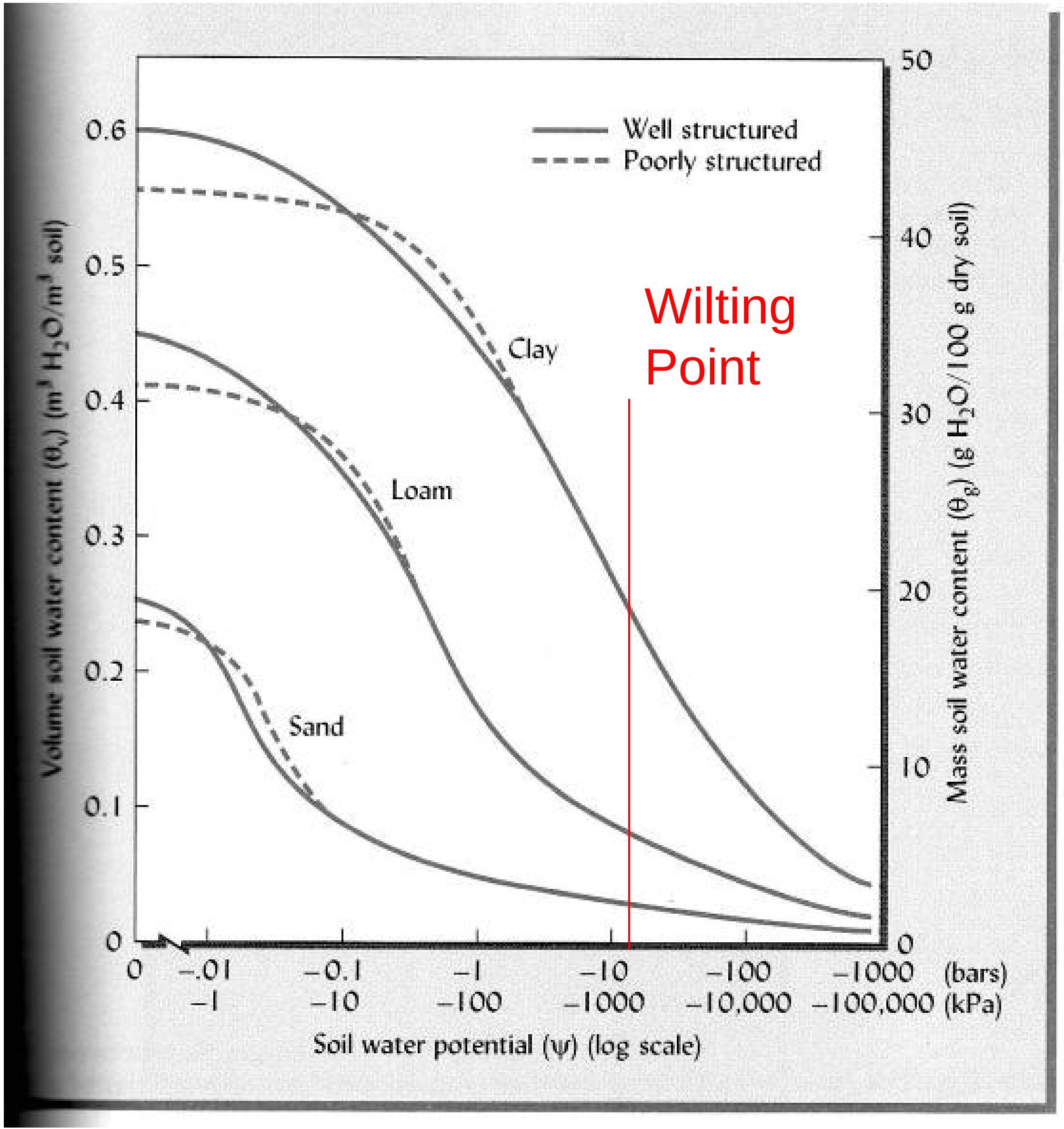


FIGURE 5.34 Water content–matric potential curve of a loam soil as related to different terms used to describe water in soils. The wavy lines in the diagram to the right suggest that measurements such as field capacity are only approximations. The gradual change in potential with soil moisture change discourages the concept of different "forms" of water in soils. At the same time, such terms as *gravitational* and *available* assist in the qualitative description of moisture utilization in soils.

Soil Texture and Structure affect water availability



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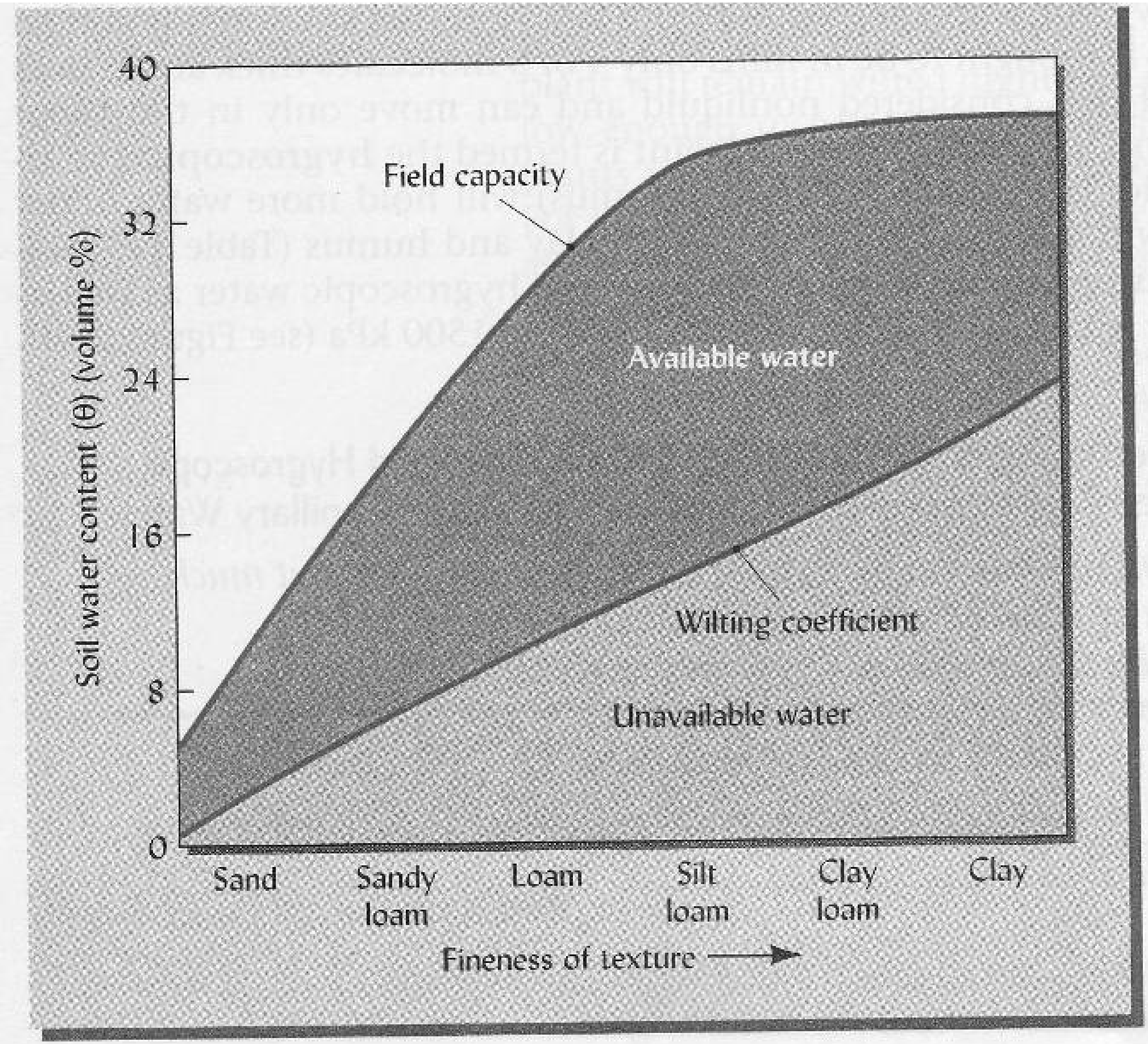
Soil Texture and Available Water



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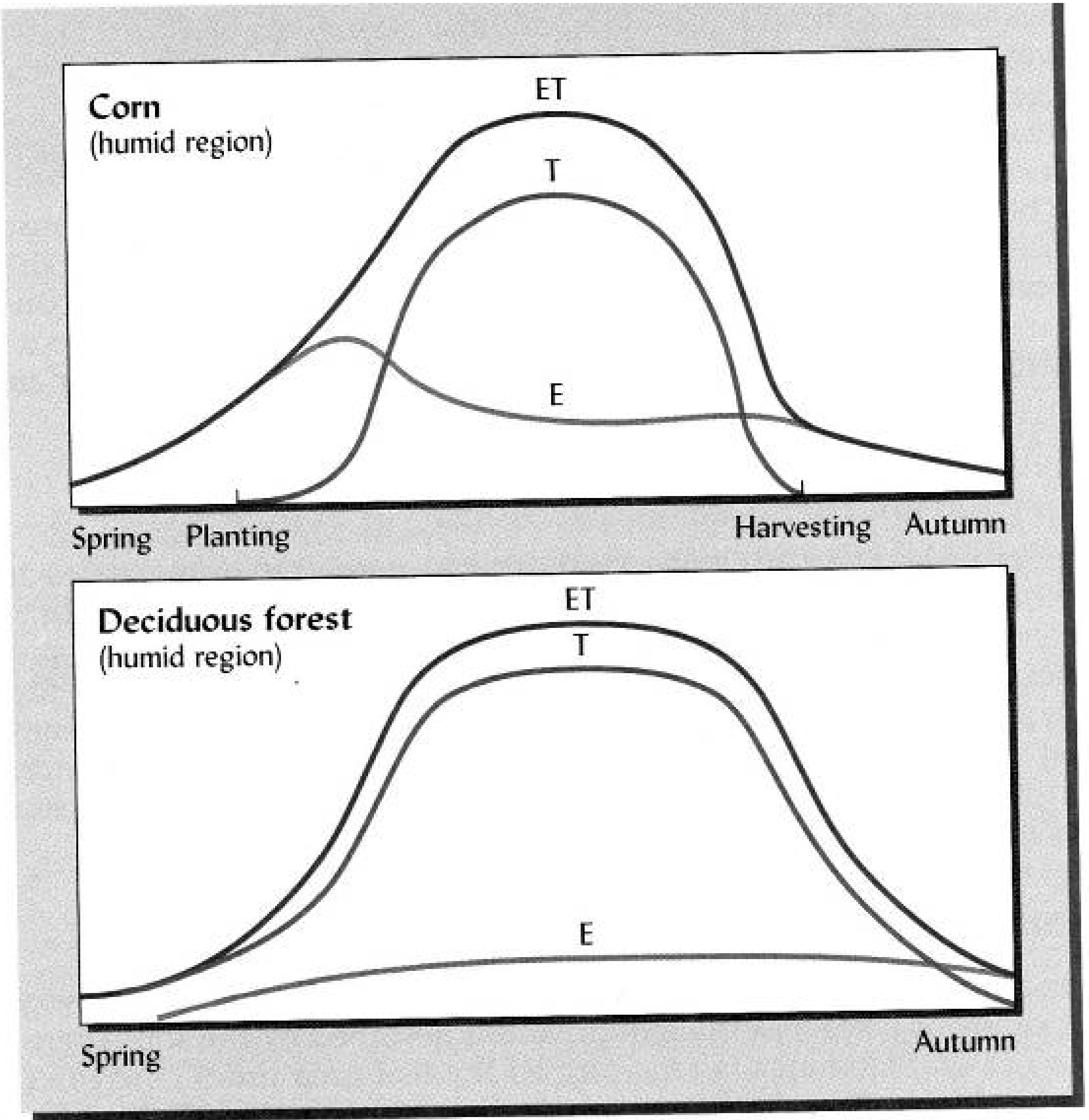
Water leaving the soil

- Evapotranspiration
  - Evaporation
  - Transpiration
- Discharge to groundwater or surface water

Evapotranspiration over a season in annual crops and forest



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Potential Evapotranspiration Rate

- Used to model moisture loss under ideal soil moisture conditions
- Determined by climatic variables – temperature, humidity, wind speed, etc that influence the *Vapor Pressure Gradient*
- Estimated from evaporating pan of water, correction factor applied
  - 0.65 evaporation for dense, well-watered vegetation

Surface mulch to reduce evaporation

Discharge to surface water

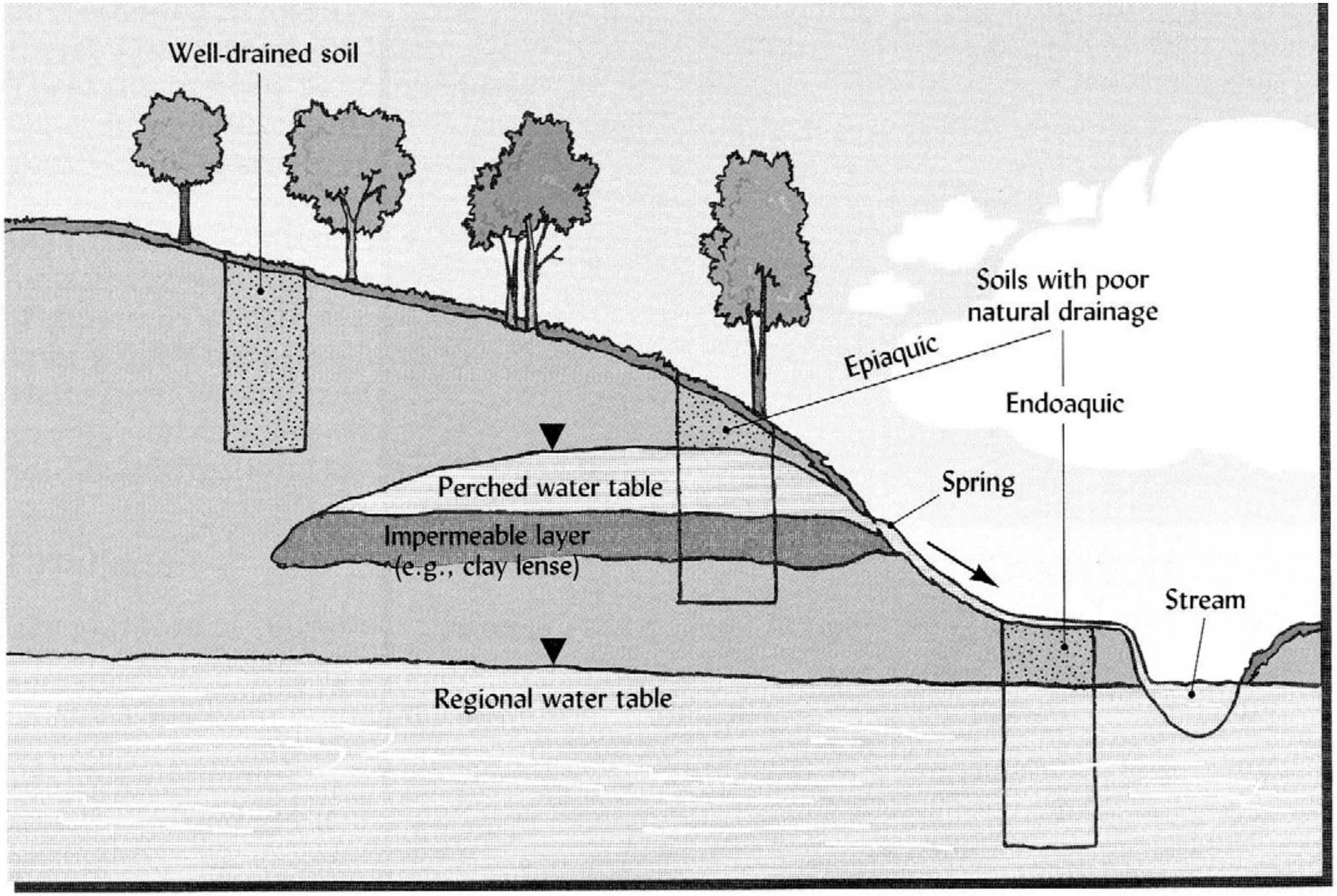


FIGURE 6.28 Cross-section of a landscape showing the regional and perched water tables in relation to three soils, one well-drained and two with poor internal drainage. By convention, a triangle (▼) is used to identify the level of the water table. The soil containing the perched water table is wet in the upper part, but unsaturated below the impermeable layer, and therefore is said to be *epiaquic* (Greek *epi,* upper), while the soil saturated by the regional water table is said to be *endoaquic* (Greek *endo,* under). Artificial drainage can help to lower both types of water tables.

Manipulating soil water for plant production

- Irrigation
  - Flood, furrow, sprinkler, drip

- Drainage
  - Ditch, sub-surface tile (perforated pipes)

Furrow Irrigation

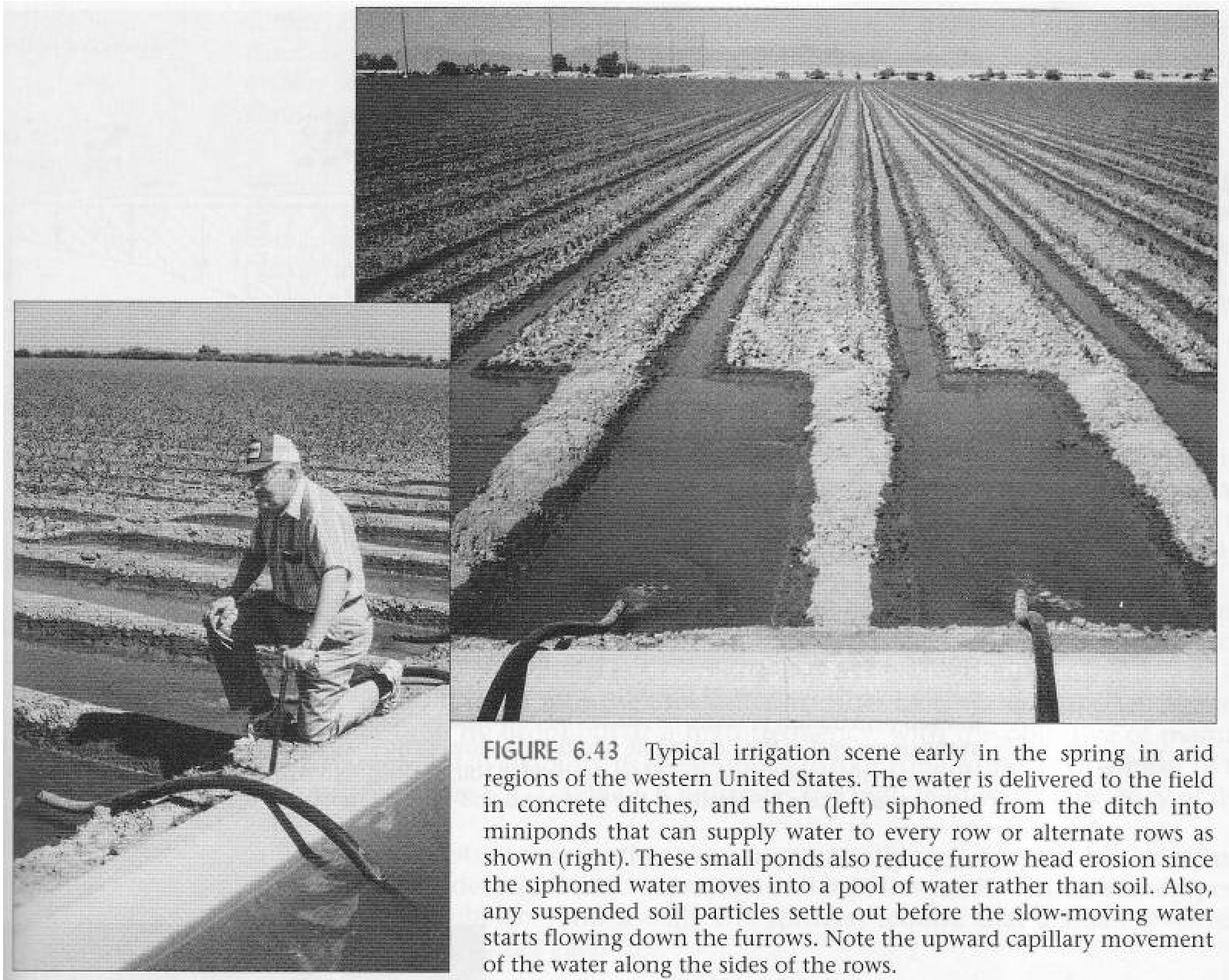


FIGURE 6.43 Typical irrigation scene early in the spring in arid regions of the western United States. The water is delivered to the field in concrete ditches, and then (left) siphoned from the ditch into miniponds that can supply water to every row or alternate rows as shown (right). These small ponds also reduce furrow head erosion since the siphoned water moves into a pool of water rather than soil. Also, any suspended soil particles settle out before the slow-moving water starts flowing down the furrows. Note the upward capillary movement of the water along the sides of the rows.

Furrow irrigation problems

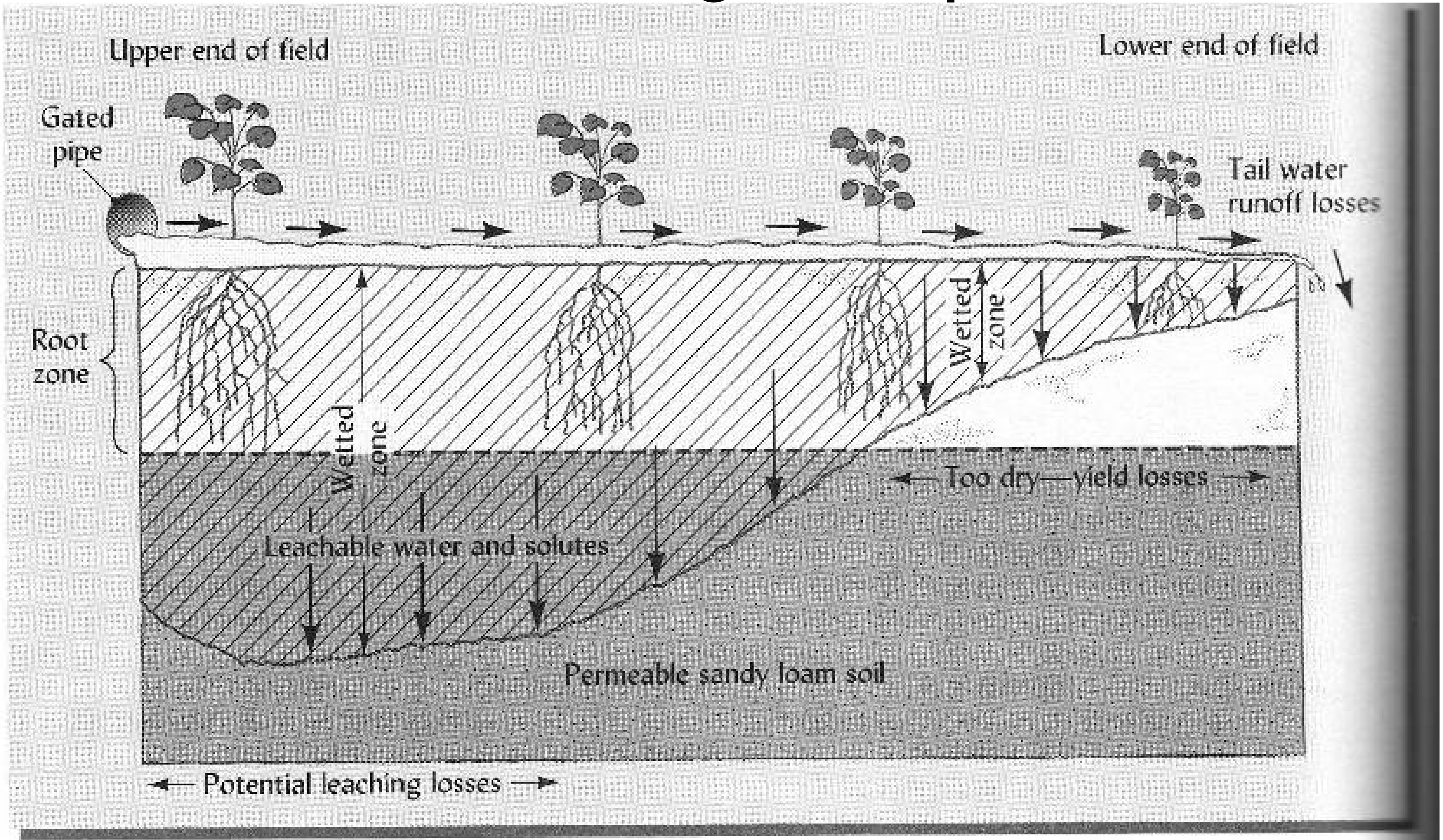


FIGURE 6.44 Penetration of water into a coarse-textured soil under surface irrigation. The high in tration rate causes most of the water to soak in near the gated pipe at the upper end of the field. Th uneven penetration of water results in the potential for leaching losses of water and dissolved chemic at the upper end of the field, while plants at the lower end may receive insufficient water to moisten th entire potential root zone. On a less-permeable soil, or on a field with a steep slope, the tail water run losses would likely be greater at the lower end and leaching potential less at the upper end.

Microirrigation – drip and microsprayer

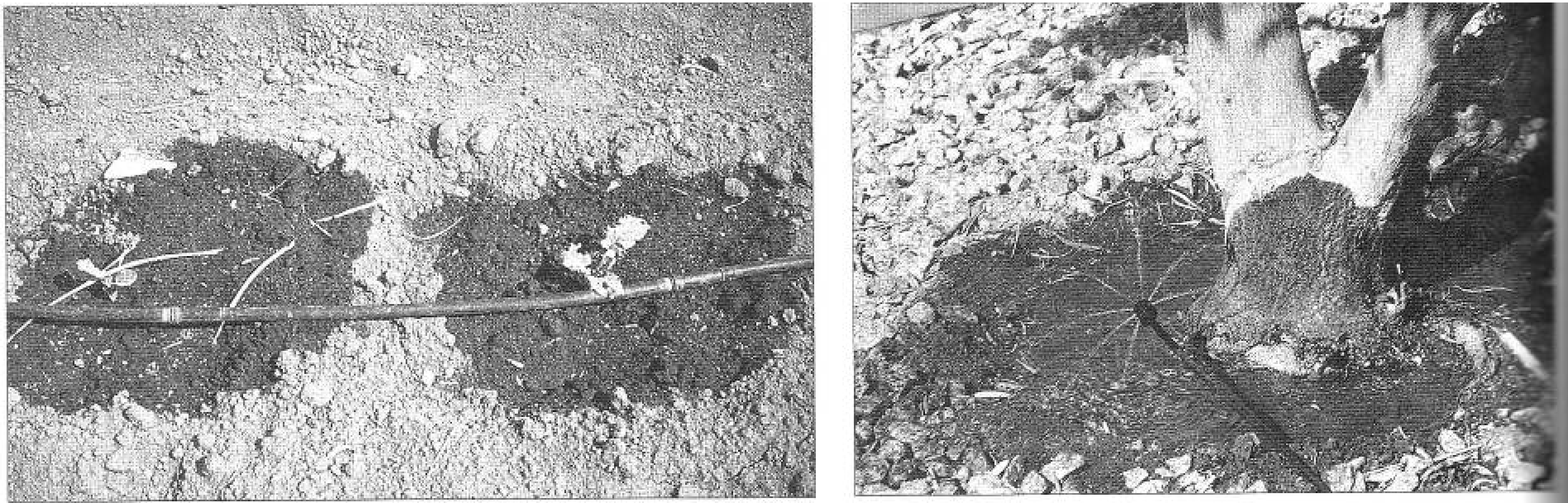


FIGURE 6.47 Two examples of microirrigation. (Left) *Drip* or *trickle* irrigation with a single emitter for each seedling in a cabbage fie
in Africa. (Right) A *microsprayer* or *spitter* irrigating an individual tree in a home garden in Arizona. In both cases, irrigation wets only th
small portion of the soil in the immediate root zone. Small quantities of water applied at high frequency (such as once or twice a da
ensures that the root zone is kept almost continuously at an optimal moisture content. (Left photo courtesy of R. Weil)

Water efficiency of irrigation methods

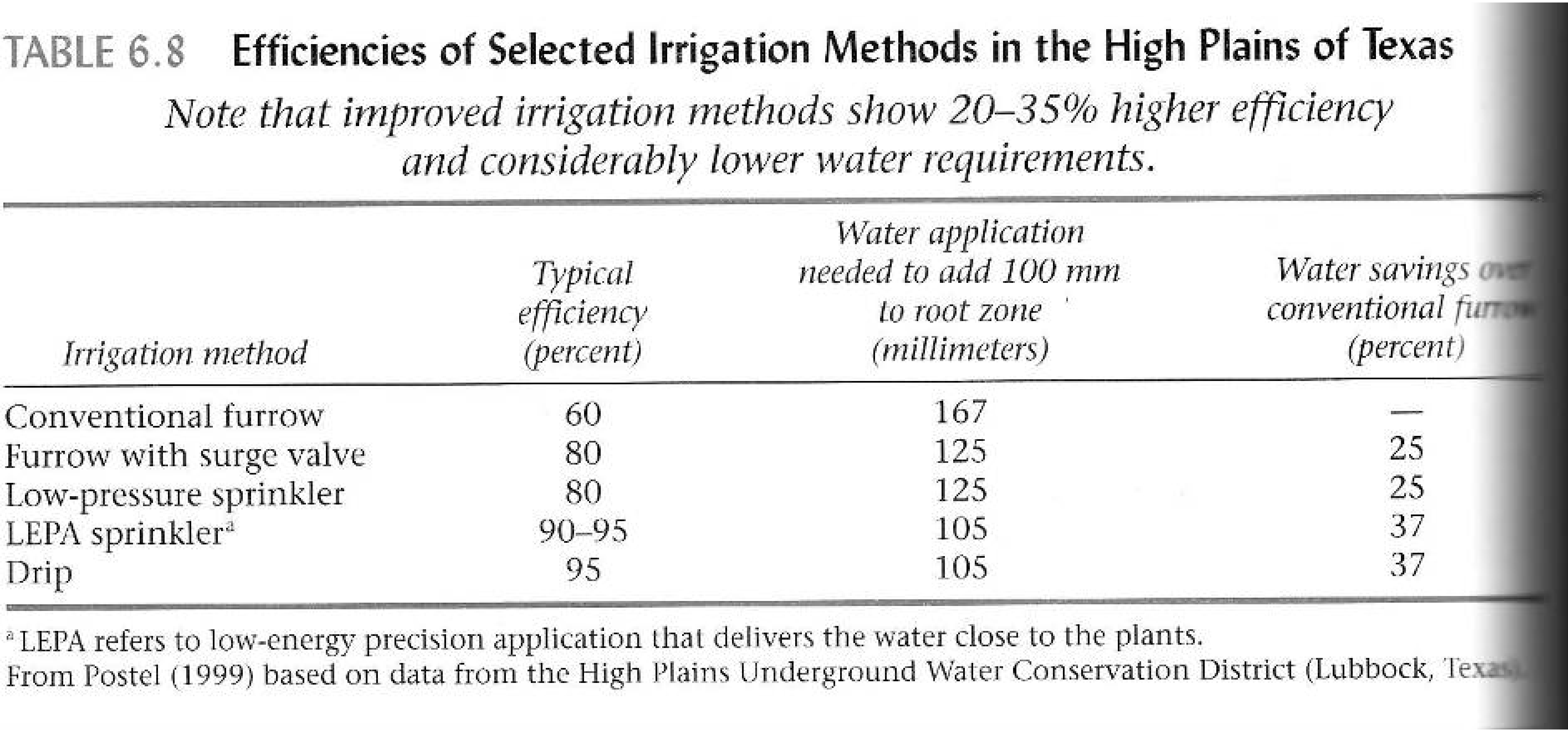


TABLE 6.8 Efficiencies of Selected Irrigation Methods in the High Plains of Texas

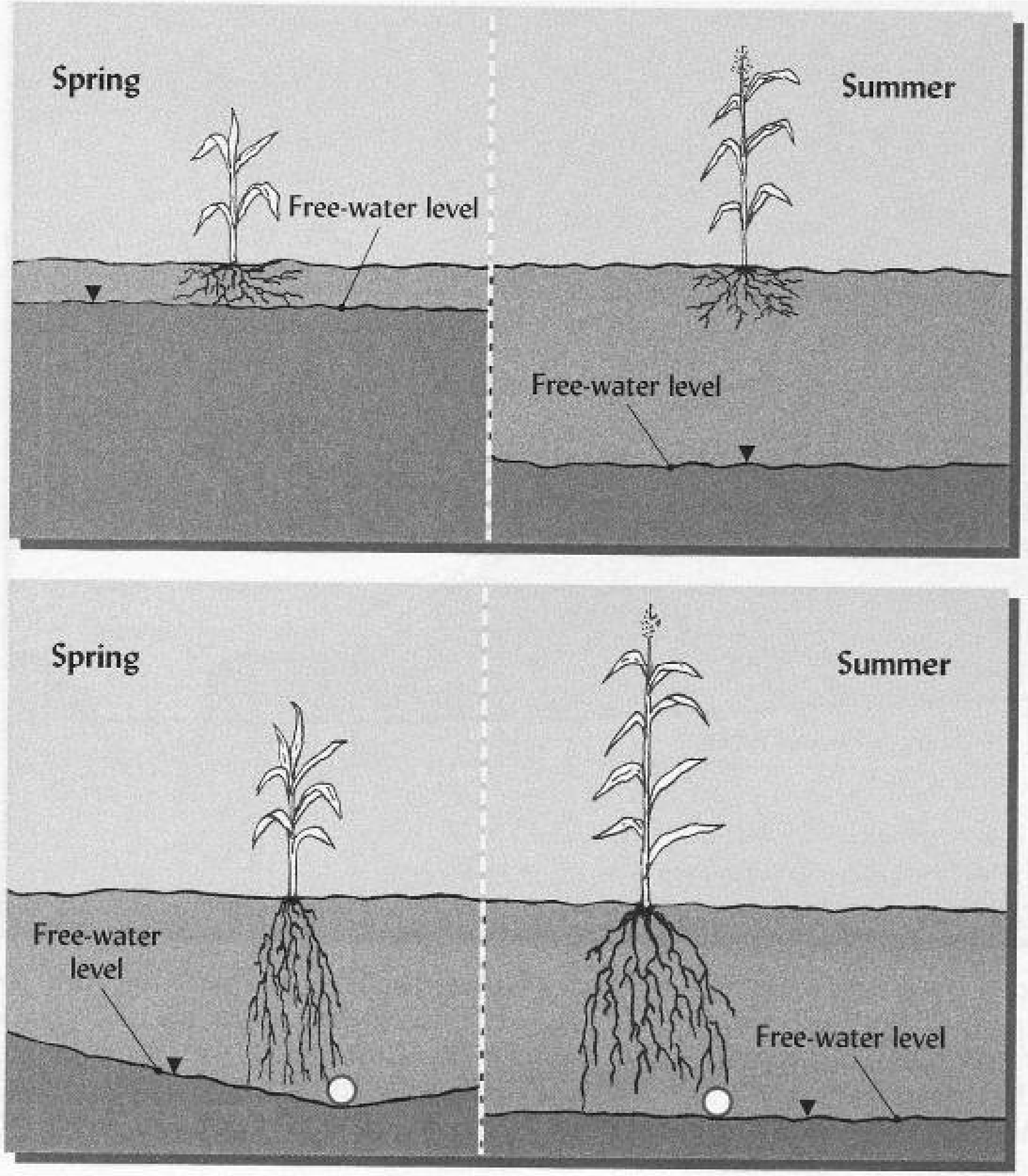
Note that improved irrigation methods show 20–35% higher efficiency and considerably lower water requirements.

Irrigation method	*Typical efficiency (percent)*	*Water application needed to add 100 mm to root zone (millimeters)*	*Water savings over conventional furrow (percent)*
Conventional furrow	60	167	—
Furrow with surge valve	80	125	25
Low-pressure sprinkler	80	125	25
LEPA sprinkler[a]	90–95	105	37
Drip	95	105	37

[a] LEPA refers to low-energy precision application that delivers the water close to the plants.

From Postel (1999) based on data from the High Plains Underground Water Conservation District (Lubbock, Texas).

Lowering the water table to enhance plant growth



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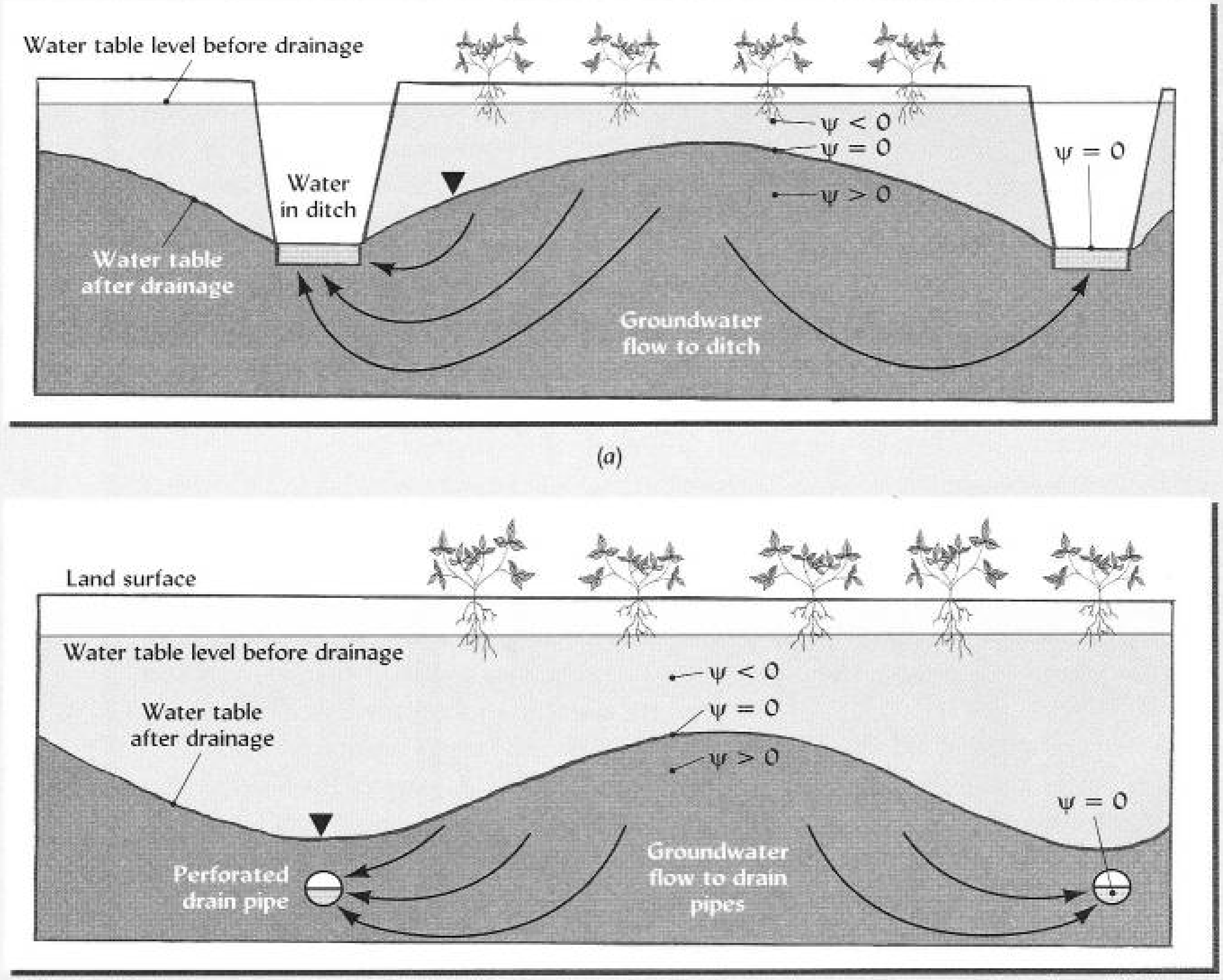
Open-ditch and tile drainage



(a)

(b)

Open-ditch drainage system

FIGURE 6.35 An open-ditch drainage system designed to lower the water table during the wet se
son. The water flowing in the ditch has seeped in from the saturated soil. Such ditches also speed th

Tile drainage system

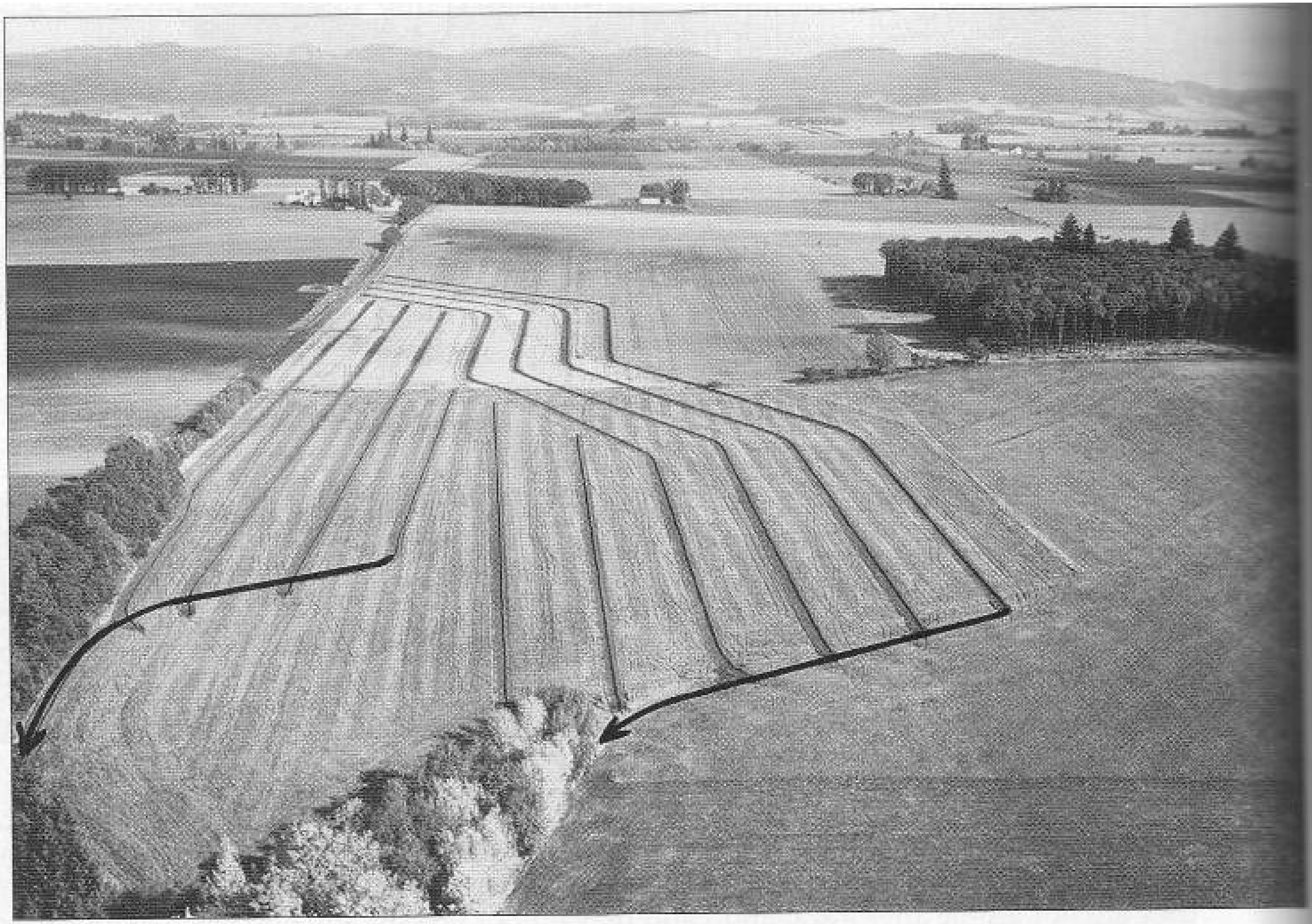
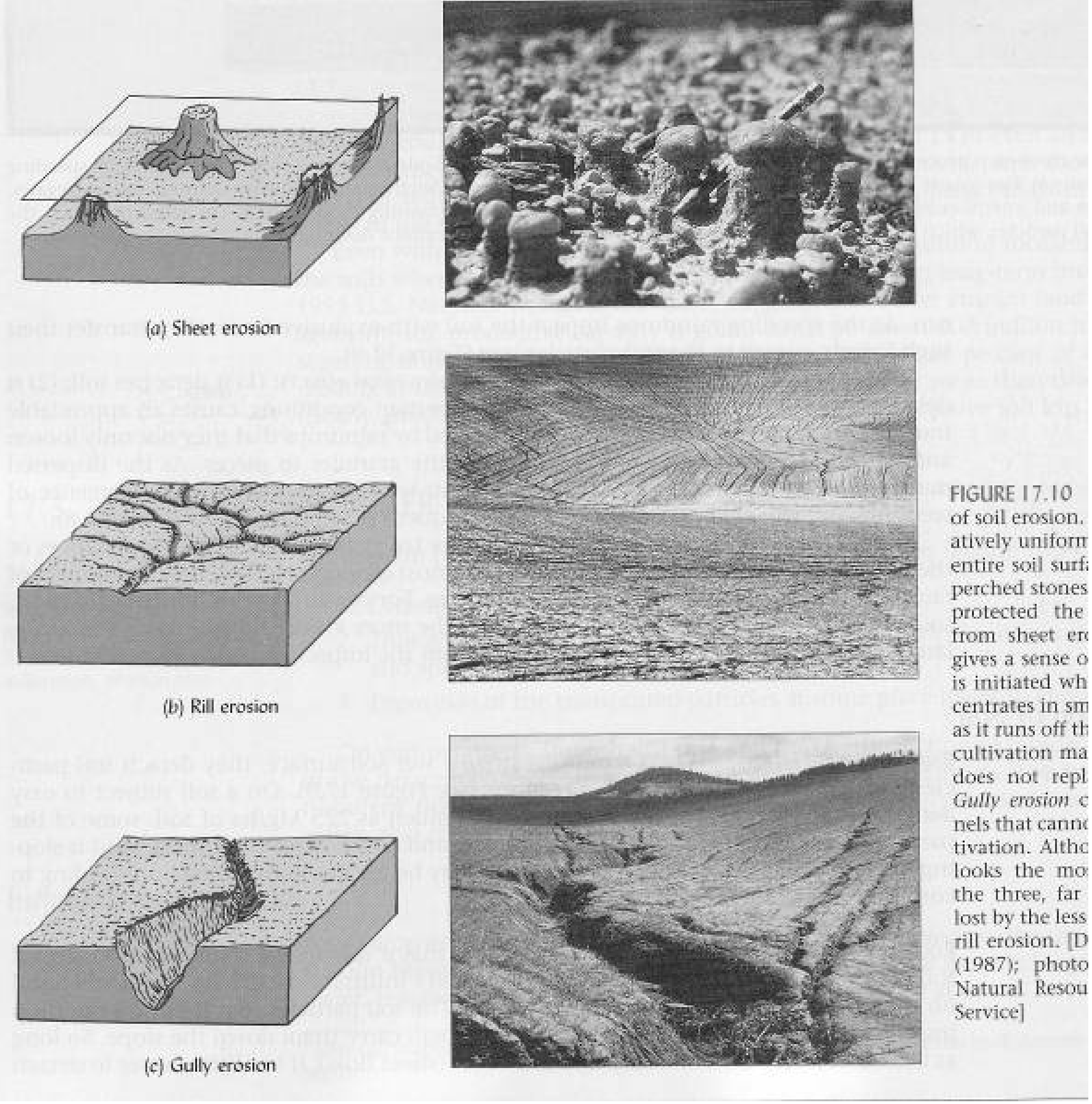


FIGURE 6.34 Tile drainage systems. (Top) Four typical systems for laying tile drain: (1) *natural,* wh
merely follows the natural drainage pattern; (2) *interception,* which cuts off water seeping into lower gro

Water discharge

- Percolate to groundwater
  - Effect on plant nutrients?
  - What retains plant nutrients?

- Discharge to surface water
  - What land “improvement” increases discharge rates?



(a) Sheet erosion

(b) Rill erosion

(c) Gully erosion

FIGURE 17.10
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Sheet Erosion

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Gully Erosion

Grassed waterway to manage surface runoff

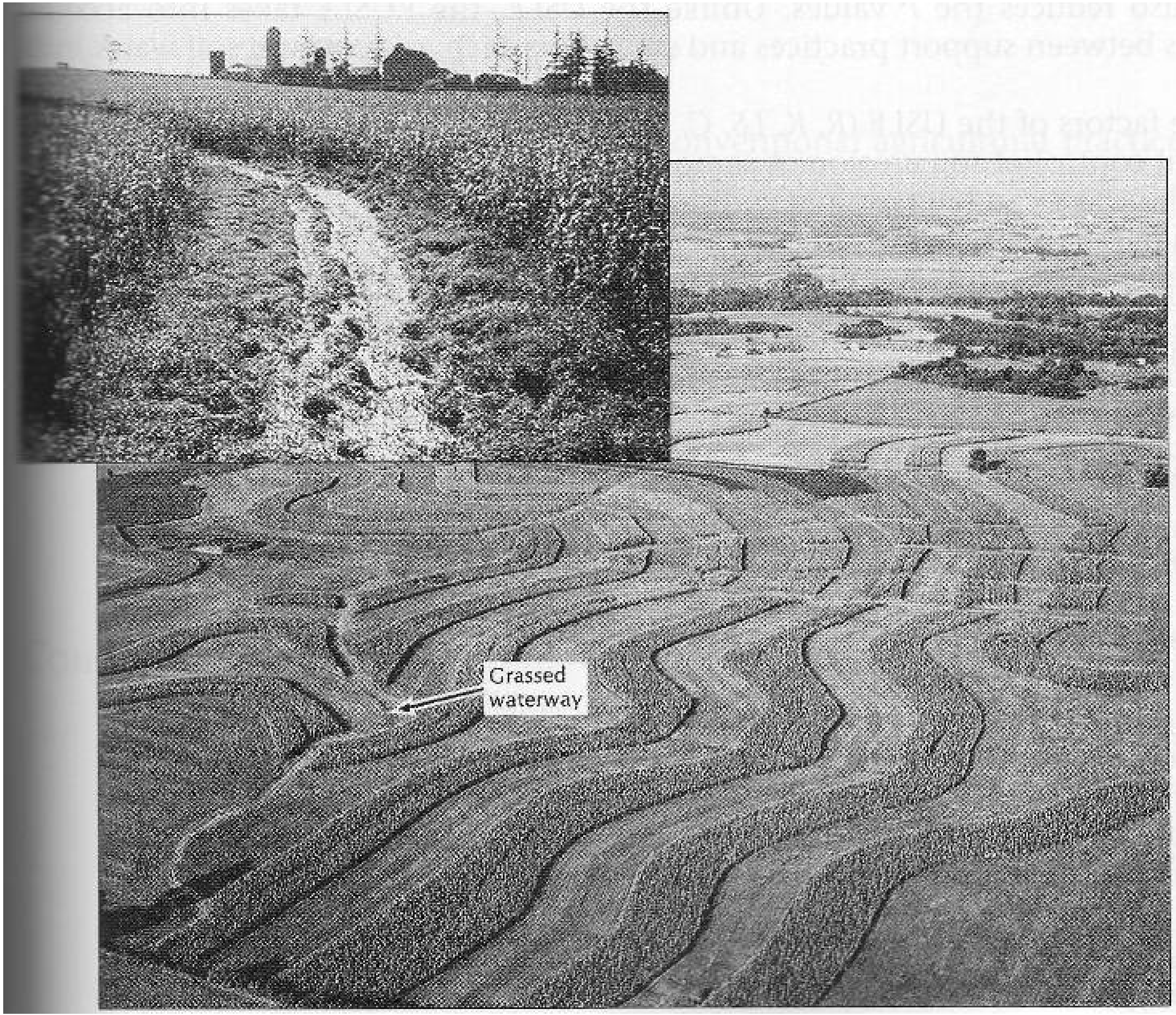

FIGURE 17.15
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Study Questions

- Brady and Weil Chapter 5
  - Questions 9 & 10
- Brady and Weil Chapter 6
  - Questions 2, 4, 6, 7, 8, 14