Limnology: Lecture 3

Physical Limnology: Hydrologic Cycle

I. Lake Inputs

A. Precipitation directly upon lake surface
    1. Normally a small proportion of total input
    2. Large lakes can receive a large proportion from direct precipitation (Lake Victoria >70%)
    3. Dead Sea has nearly zero direct precipitation upon surface

B. Surface influents of drainage basin
    1. Normally the major input
    2. Quantity, timing, and quality affected by vegetation

C. Groundwater seepage
    1. Commonly a major source in certain geological settings
        a) Rocky, mountainous, high gradient basins
        b) Glacial till
        c) Karst and doline lakes in limestone
    2. Difficult to accurately estimate

D. Groundwater as discrete springs
    1. Calcareous regions
    2. Fractured basalts

Dead Sea, Israel

II. Lake Outputs

A. Surface outlets
   1. Drainage lakes lose water mainly by flow from a surface outlet
   2. Lakes with sediments composed mainly of clays and silts usually have surface outlets

B. Seepage into groundwater
   1. Normally occurring in shallow waters
   2. Lake sediments can regulate this loss

C. Evaporation
   1. Dependent on season and latitude
   2. Wind velocity, humidity, temperature, etc. regulate the rates of evaporation
   3. Lakes in closed basins lose water primarily by evaporation

D. Evapotranspiration
   1. Hydrophytes (water loving) plants can transpire great quantities of water where present
   2. Riparian and littoral vegetation main contributors to loss
   3. Most important in shallow, small, relatively productive lakes, ponds, ditches, and streams


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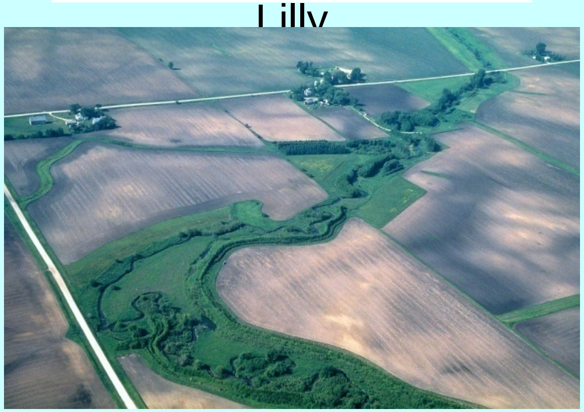
Hydrophyte, Water Lilly



Riparian Zone, Iowa

III. Global Water Balance

A. More evaporation from the oceans than returned via direct precipitation -source of most terrestrial precipitation

B. Hydrologic regions among continental land masses

   1. Exorheic - rivers originate and from which they flow to the sea
   2. Endorheic - rivers arise but never reach the sea
   3. Arheic - no rivers arise (deserts in the latitudes of the trade winds)

C. Continental average precipitation comparable except South America

   1. North America - 67 cm
   2. South America - 165 cm
   3. Africa - 69 cm
   4. Asia - 73 cm
   5. Europe - 73 cm
   6. Australia - 74 cm
   7. World Average - 83 cm

Endorheic Great Salt Lake

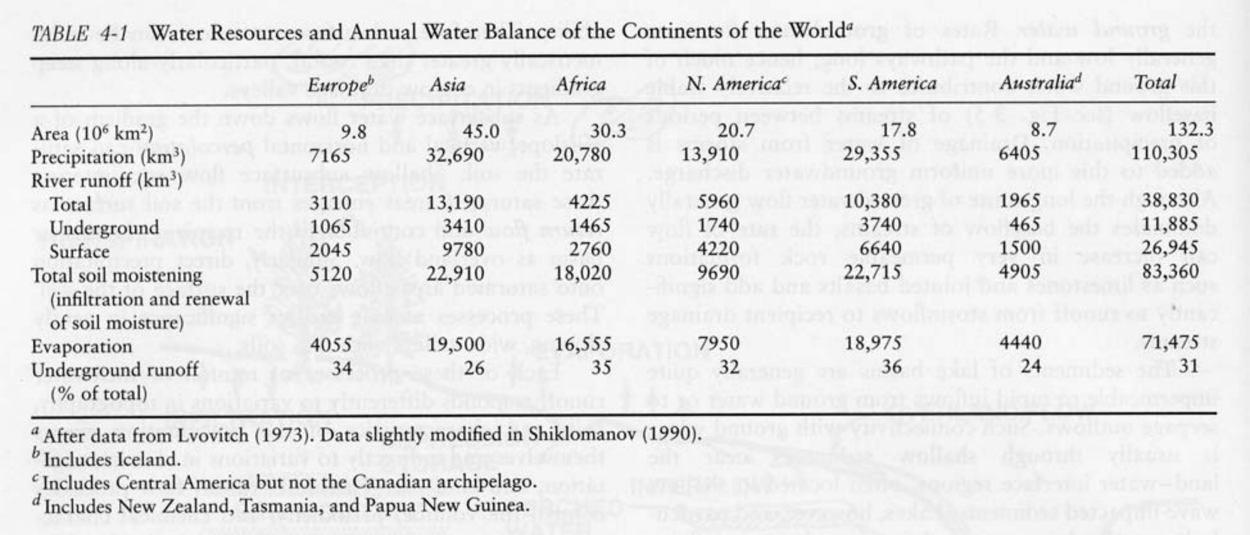


TABLE 4-1 Water Resources and Annual Water Balance of the Continents of the World[a]

	Europe[b]	*Asia*	*Africa*	*N. America*[c]	*S. America*	*Australia*[d]	*Total*
Area (10^6 km^2)	9.8	45.0	30.3	20.7	17.8	8.7	132.3
Precipitation (km^3)	7165	32,690	20,780	13,910	29,355	6405	110,305
River runoff (km^3)							
Total	3110	13,190	4225	5960	10,380	1965	38,830
Underground	1065	3410	1465	1740	3740	465	11,885
Surface	2045	9780	2760	4220	6640	1500	26,945
Total soil moistening (infiltration and renewal of soil moisture)	5120	22,910	18,020	9690	22,715	4905	83,360
Evaporation	4055	19,500	16,555	7950	18,975	4440	71,475
Underground runoff (% of total)	34	26	35	32	36	24	31

[a] After data from Lvovitch (1973). Data slightly modified in Shiklomanov (1990).
[b] Includes Iceland.
[c] Includes Central America but not the Canadian archipelago.
[d] Includes New Zealand, Tasmania, and Papua New Guinea.

III. Global Water Balance (Cont.)

D. Global fluxes, content, and retention times
    1. Retention time in atmosphere is ~9 days
    2. 57-80% of precipitation is returned to the atmosphere through evaporation (world average is 65%)

E. Can humans modify the global water balance?
    1. Dams, canals, diversions, agriculture, and basin modification
    2. Global atmospheric CO_2 increase and warming
        a. Melt 1% of global polar ice cap and sea level rises about 80 cm
        b. Melt 10% of global polar ice cap and sea level rises about 8.0 m

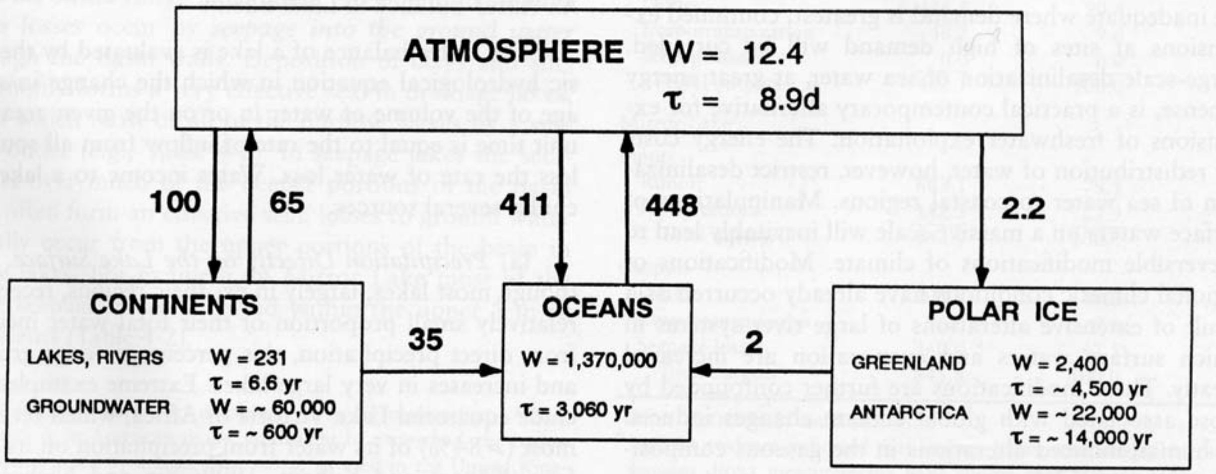


FIGURE 4-2 Global water balance. W = water content in 10^3 km^3, values on arrows = transport in 10^3 km^3 yr^{-1}, and τ = retention time. Estimate of ground water is to a depth of 5 km in the Earth's crust; much of this water is not actively exchanged. (Modified from Flohn, 1973, after L'vovich.)

IV. Runoff Flow Processes

A. Soil and geological substrate regulate the rates and pathways of hillslope runoff
    1. Landscape form, land use, and management requirements should be or are linked to these processes
    2. Overland flow occurs when absorptive capacity is exceeded by the rate of rainfall or meltwater influx

B. Subsurface flow
    1. Infiltration and percolation to the zone of saturation followed by relatively slow movement to drainage channels
    2. Subsurface stormflow is shallower and more rapid

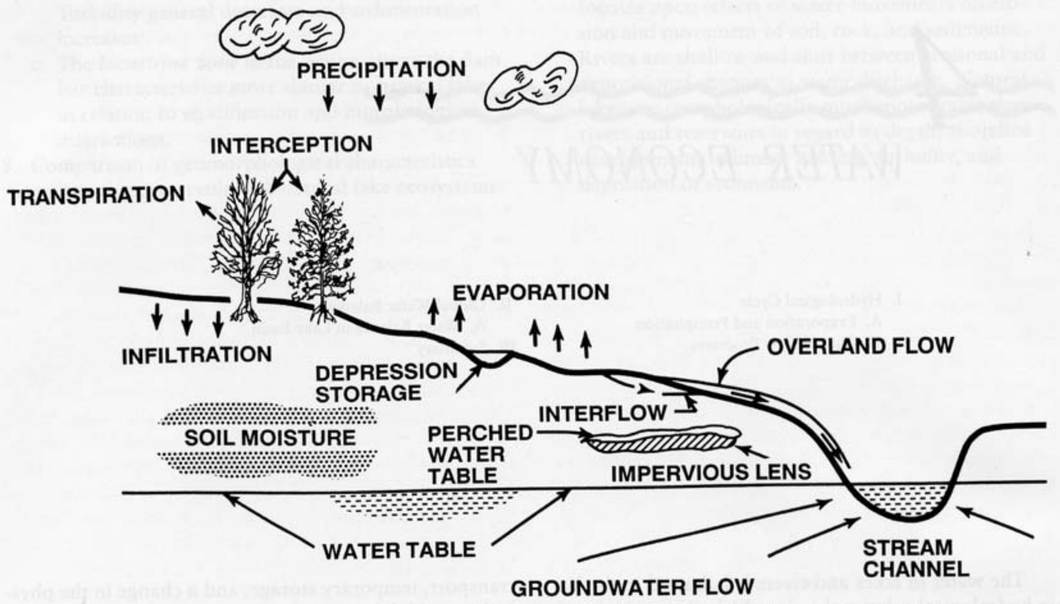


FIGURE 4-1 Major pathways of precipitation and the runoff phase of the hydrologic cycle. (From Wetzel and Likens, 1991.)

V. Groundwater as a Resource

Text taken from introduction of Freeze, R.A. & J.A. Cherry. 1979. Groundwater. Prentice-Hall, Englewood Cliffs, New Jersey.

The primary motivation for the study of groundwater has traditionally been its importance as a resource. For the United States, the significance of the role of groundwater as a component of national water use can be gleaned from the statistical studies of the U.S. Geological Survey as reported most recently for the year 1970 by Murray and Reeves (1972) and summarized by Murray (1973).

Table 1.2 documents the growth in water utilization in the United States during the period 1950-1970. In 1970 the nation used 1400 x 10^6 m^3/day. Of this, 57% went for industrial use and 35% for irrigation. Surface water provided 81% of the total, groundwater 19 %. Figure 1.3 graphically illustrates the role of ground-water relative to surface water in the four major areas of use for the 1950-1970 period. Groundwater is less important in industrial usage, but it provides a signifi-cant percentage of the supply for domestic use, both rural and urban, and for irrigation.

The data of Table 1.2 and Figure 1.3 obscure some striking regional variations. About 80 % of the total irrigation use occurs in the 17 western states, whereas 84 % of the industrial use is in the 31 eastern states. Groundwater is more widely used in the west, where it accounts for 46 % of the public supply and 44 % of the indus-trial use (as opposed to 29% and 16%, respectively, in the east).

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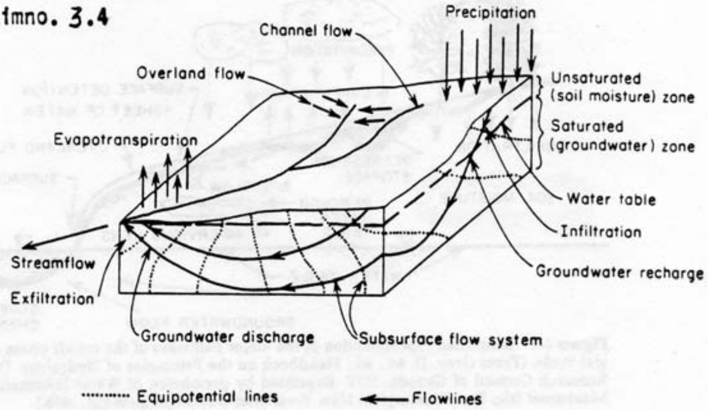

Figure 1.1 Schematic representation of the hydrologic cycle.

From : Freeze and Cherry 1979

V. Groundwater as a Resource (Cont.)

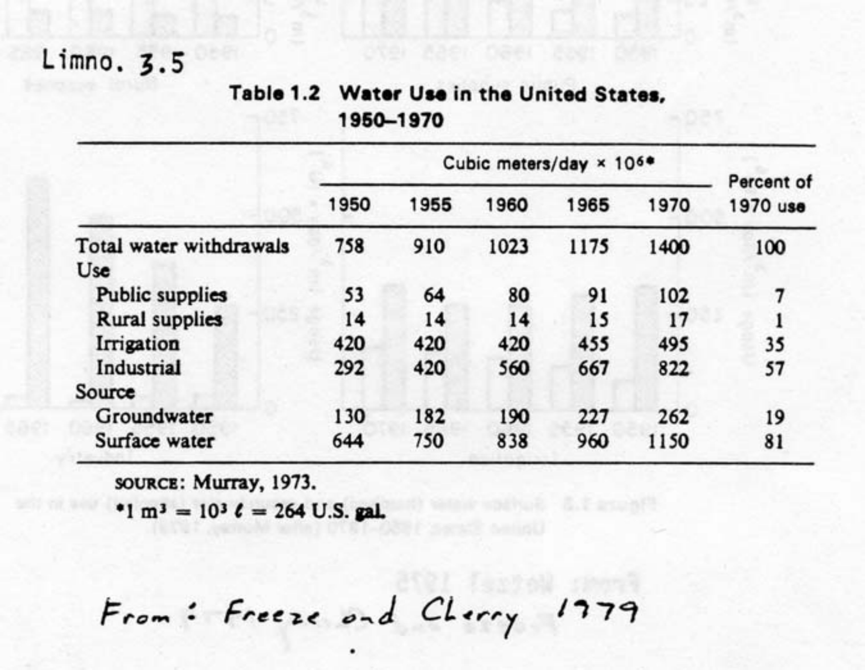

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Table 1.2 Water Use in the United States, 1950–1970

	Cubic meters/day × 10⁶*					Percent of
	1950	1955	1960	1965	1970	1970 use
Total water withdrawals	758	910	1023	1175	1400	100
Use						
Public supplies	53	64	80	91	102	7
Rural supplies	14	14	14	15	17	1
Irrigation	420	420	420	455	495	35
Industrial	292	420	560	667	822	57
Source						
Groundwater	130	182	190	227	262	19
Surface water	644	750	838	960	1150	81

SOURCE: Murray, 1973.

*1 $m^3 = 10^3 \ell$ = 264 U.S. gal.

From: Freeze and Cherry 1979

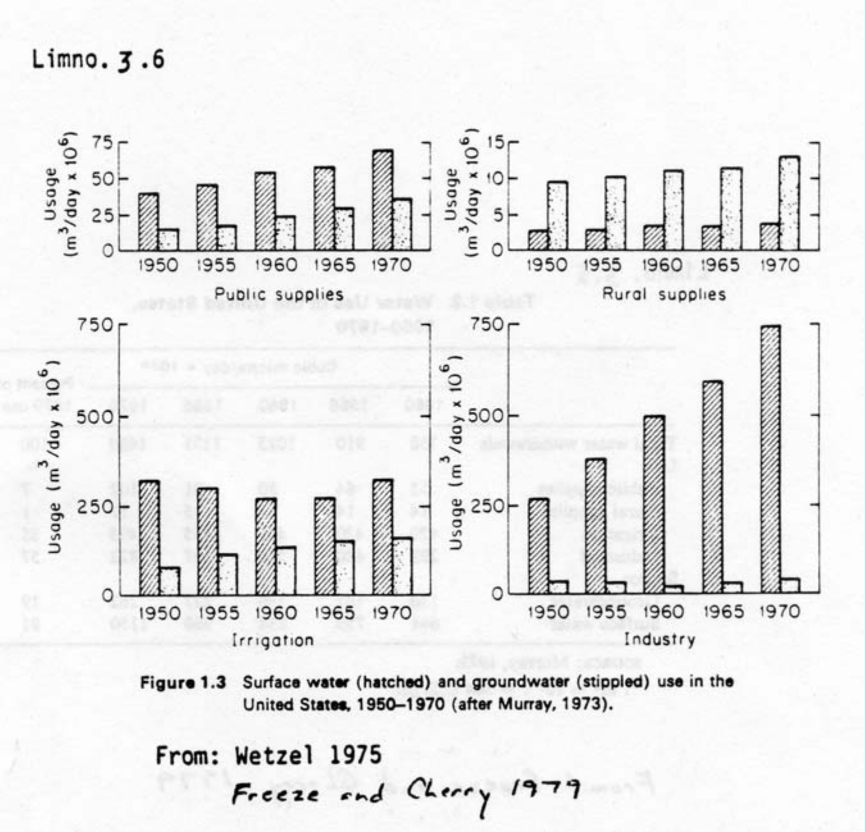

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Figure 1.3 Surface water (hatched) and groundwater (stippled) use in the United States, 1950–1970 (after Murray, 1973).

From: Wetzel 1975

Freeze and Cherry 1979

V. Groundwater as a Resource (Cont.)

In Canada, rural and municipal groundwater use was estimated by Meyboom (1968) at 1.71 x 10^6 m^3/day, or 20% of the total rural and municipal water con-sumption. This level of groundwater use is considerably lower than that of the United States, even when one considers the population ratio between the two countries. A more detailed look at the figures shows that rural groundwater devel-opment in Canada is relatively on a par with rural development in the United States, but municipal groundwater use is significantly smaller. The most striking differences lie in irrigation and industrial use, where the relative total water con-sumption in Canada is much less than in the United States and the groundwater component of this use is extremely small.

McGuinness (1963), quoting a U.S. Senate committee study, has provided predictions of future U.S. national water requirements. It is suggested that water needs will reach 1700 x 10^6 m^3/day by 1980 and 3360 x 10^6 m^3/day by the year 2000. The attainment of these levels of production would represent a significant acceleration in the rate of increase in water use outlined in Table 1.2. The figure for the year 2000 begins to approach the total water resource potential of the nation, which is estimated to be about 4550 x 10^6 m^3/day. If the requirements are to be met, it is widely accepted that groundwater resources will have to provide a greater proportion of the total supply. McGuinness notes that for the predictions above, if the percent groundwater contribution is to increase from 19% to 33%, ground-water usage would have to increase from its current 262 x 10^6 m^3/day to 705 x 10^6 m^3/day in 1980 and 1120 x 10^6 m^3/day in the year 2000. He notes that the desirable properties of groundwater, such as its clarity, bacterial purity, consistent, temperature, and chemical quality, may encourage the needed large-scale development, but he warns that groundwater, especially when large quantities are sought, is inherently more difficult and expensive to locate, to evaluate, to develop, and to manage than surface water. He notes, as we have, that groundwater is an integral phase of the hydrologic cycle. **The days when groundwater and surface water could be regarded as two separate resources are past.** Resource planning must be carried out with the realization that groundwater and surface water have the same origin.

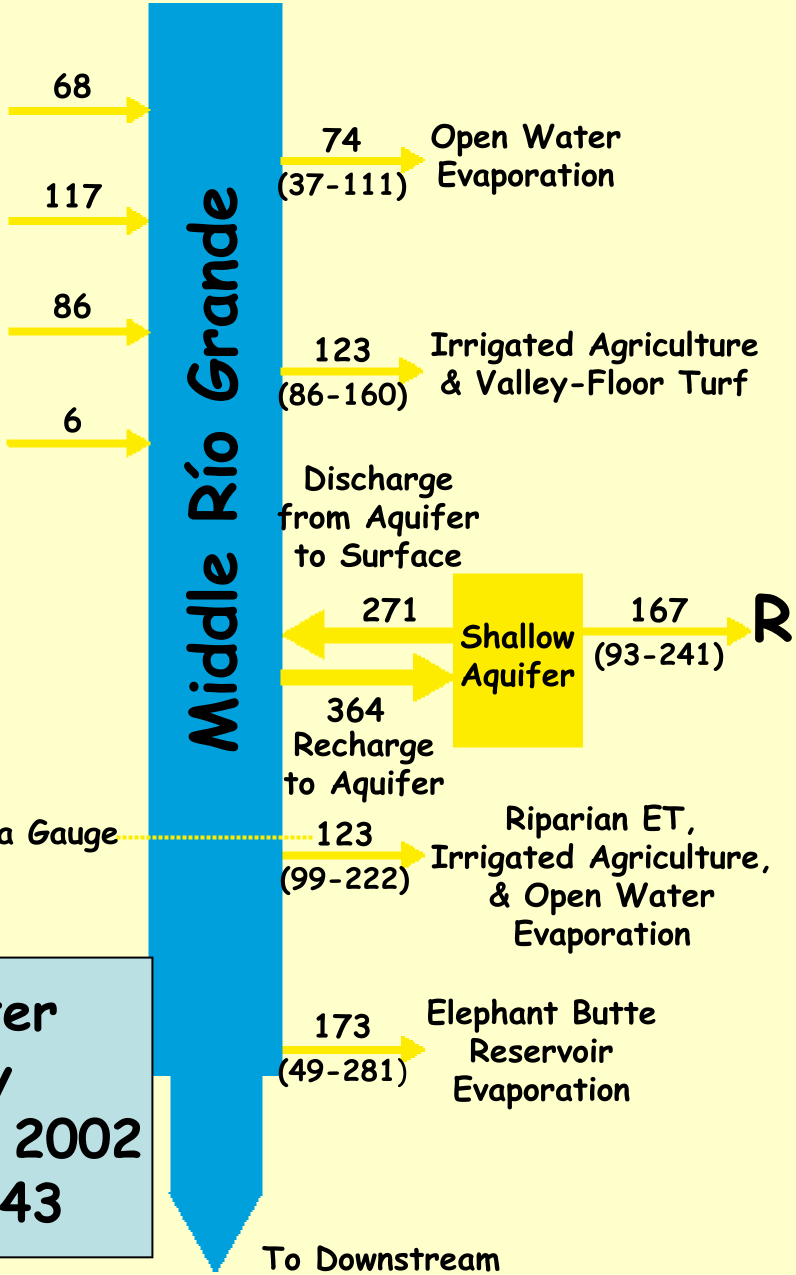
In Chapter 8, we will discuss the techniques of groundwater resource evaluation: from the geologic problems of aquifer exploration, through the field and laboratory methods of parameter measurement and estimation, to the simulation of well performance, aquifer yield, and basin-wide groundwater exploitation.

V. Groundwater as a Resource (Cont.)

Groundwater Contamination

If groundwater is to continue to play an important role in the development of the world's water-resource potential, then it will have to be protected from the increasing threat of subsurface contamination. The growth of population and of industrial and agricultural production since the second world war, coupled with the resulting increased requirements for energy development, has for the first time in man's history begun to produce quantities of waste that are greater than that which the environment can easily absorb. The choice of a waste-disposal method has become a case of choosing the least objectionable course from a set of objectionable alternatives. As shown schematically on Figure 1.4, there are no currently-feasible, large-scale waste disposal methods that do not have the potential for serious pollution of some part of our natural environment. While there has been a growing concern over air- and surface-water pollution, this activism has not yet encompassed the subsurface environment. In fact, the pressures to reduce surface pollution are in part responsible for the fact that those in the waste management field are beginning to covet the subsurface environment for waste disposal. Two of the disposal techniques that are now being used and that are viewed most optimistically for the future are deep-well injection of liquid wastes and sanitary landfill for solid wastes. Both these techniques can lead to subsurface pollution. In addition, subsurface pollution can be caused by leakage from ponds and lagoons which are widely used as components of larger waste-disposal systems, and by leaching of animal wastes, fertilizers, and pesticides from agricultural soils.

Río Grande Water Budget (1972-1997) (10^6 m^3 yr^{-1})



Otowi Gauge
1419
(370-2714)

Middle Río Grande

San Juan-Chama Inflow 68

Tributary Inflow (gauged) 117

Municipal Waste Water 86

Albuquerque Storm Drain Inflow 6

74 (37-111) Open Water Evaporation

123 (86-160) Irrigated Agriculture & Valley-Floor Turf

Discharge from Aquifer to Surface 271

364 Recharge to Aquifer

Shallow Aquifer

167 (93-241)

San Acacia Gauge

123 (99-222) Riparian ET, Irrigated Agriculture, & Open Water Evaporation

173 (49-281) Elephant Butte Reservoir Evaporation

(370-1770) To Downstream Users

Riparian Evapotranspiration (ET) ~ 150-250

Major Depletions

1. Evaporation
2. Riparian ET
3. GW Recharge
4. Agriculture

Freshwater Biology
Dahm et al. 2002
47:831-843