Chapter 4
Groundwater recharge, discharge, and storage

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Using ...	1 ft^3	= 7.4805 gallons
	1 acre-foot	= 43,560 $feet^3$
	1 year	= 31.536×10^6 seconds
we have ...	1 ft^3 per second	= 31.536×10^6 $feet^3$ per year
		= 235.91×10^6 gallons per year
		= 723.97 acre-feet per year

This chapter contains summary estimates of recharge and discharge for the GGRB as a whole, as well as estimates of the volume of groundwater stored and groundwater available for development, based on several approaches. Chapter 5 contains detailed discussions of individual aquifer recharge and discharge, following descriptions of the Tertiary, Mesozoic, and Paleozoic hydrogeologic units.

A previous method

Martin (1996) developed a five-layer groundwater model of the geohydrology of Tertiary rocks in the Green River Basin of Wyoming, Utah, and Colorado (**Figures 2-2** and **3-2**). Martin's model encompasses the area west from the Rock Springs Uplift to the Overthrust Belt and north from the Uinta Mountains to the Pinedale area (Green River structural basin on **Figure 2-2**; also see **Figures 5-5, 5-24,** and **5-25**). **Table 4-1** lists the five model layers. The model parameters are the lithologic and hydrologic properties of the rocks composing the layers. The following discussion of recharge and discharge in the Green River Basin Tertiary hydrogeologic units is based largely on Martin's work.

Aquifer recharge

Precipitation recharges groundwater in the GGRB as part of the hydrologic cycle. There are wet years, average years, and dry years as annual weather patterns respond to climatic cycles, but mean annual precipitation statistics are given as 30-year moving averages (**Figure 2-3**).

Recharge may also occur locally where human activities provide more water to the ground surface than occurs naturally. One example is irrigation water applied to cropland; another is infiltration from reservoirs, irrigation canals and ditches, industrial ponds, stock ponds, and wastewater ponds.

Martin (1996) and Glover et al. (1998) estimated total recharge to the Green River Basin Tertiary aquifer system as approximately 100,000 acre-feet per year (see **Figure 5-1**). Hahn and Jessen (2001) estimated the total groundwater recharge in the

Table 4-1. Tertiary hydrogeologic units in the Green River Basin (Martin, 1996)

Model layer	*South basin*	*Central basin*	*North basin*
1	Bridger aquifer	Bridger aquifer	none
2	Laney aquifer	Laney aquifer	Wasatch zone[2]
3	Wilkins Peak and Tipton confining units	New Fork aquifer[1]	Wasatch zone[2]
4	Wasatch zone[2]	Wasatch zone[2]	Wasatch zone[2]
5	Fort Union zone[3]	Fort Union zone[3]	Fort Union zone[3]

[1] Farson Sandstone-Alkali Creek aquifer of Chapter 5
[2] Wasatch zone of Wasatch-Fort Union aquifer; see Figure 5-1
[3] Fort Union zone of Wasatch-Fort Union aquifer

Wyoming GGRB as about 50,000 acre-feet per year. And, for planning purposes, Hahn and Jessen (2001) estimated the potential basin yield of groundwater to range between 50,000 and 100,000 acre-feet per year, approximately equivalent to the estimated annual aquifer recharge.

A common assumption in hydrogeology is that the annual recharge by precipitation to an aquifer in bedrock is approximately 10 percent of the amount falling on the aquifer outcrop (exposure at the ground surface). The outcrop areas of the GGRB geologic units are shown on **Plate 2**.

Precipitation in the GGRB ranges between 6 and 59 inches per year (**Figure 2-3**) – 30-year moving averages. On average, most of the GGRB area receives between 6 and 15 inches of precipitation per year (**Figure 2-3**).

Evapotranspiration (ET) rates, defined as the combined evaporation and transpiration losses of water in the vapor state to the atmosphere, are relatively high in the GGRB, due to high altitude and dry climate. In the central basin areas where the annual ET rate exceeds the annual precipitation rate, very little to no aquifer recharge occurs. Occasionally, however, heavy precipitation (0.5 inches or more from a single storm) or rapid snowmelt may recharge aquifers, as the amount of water temporarily available for recharge exceeds the local ET rate.

Martin (1996) estimates the steady-state groundwater budget for the Tertiary aquifer system in the Green River Basin of Wyoming, Colorado, and Utah (the Green River Basin lower Tertiary aquifer system of **Plate 1b**). **Table 4-2** lists the identified and estimated recharge components, in cubic feet per second (cfs).

This inflow rate converts to annual recharge as follows:

$$
\begin{aligned}
165 \text{ cfs} &= 5.21 \times 10^9 \text{ feet}^3\text{/year} \\
&= 38.9 \times 10^9 \text{ gallons/year} \\
&= 119{,}000 \text{ acre-feet/year}
\end{aligned}
$$

Thus, the total recharge to the Tertiary aquifer system in the Green River Basin (**Figure 2-2**), as estimated by Martin (1996), is approximately 119,000 acre-feet per year or 39.0 billion gallons per year.

Estimated GGRB aquifer recharge

The 10,860 acre-feet per year minimum recharge for the combined Great Divide and Washakie basins estimated by Fisk (1967, p.73) plus the 119,000 acre-feet per year recharge for the Green River Basin estimated by Martin (1996, p.27) gives ***130,000 acre-feet per year*** of estimated minimum recharge to groundwater in the GGRB. We use this figure in Chapter 8 to estimate the groundwater balance in the GGRB.

The aquifer sensitivity map (**Figure 4-1**) is based on numerical data on the permeability of the surficial soils/deposits/bedrock and annual precipitation (these digital data were not available for the adjacent GGRB areas of Colorado and Utah). The distribution of estimated average aquifer recharge for the Wyoming GGRB is shown in **Figure 4-2**.

Estimated average aquifer recharge ranges from –4 inches per year to 44 inches per year in the Wyoming GGRB (**Figure 4-2**). In general, mountain and highland areas have higher rates of aquifer recharge. However, the high rate of aquifer recharge to the Precambrian outcrop areas in **Figure 4-2** does not result in storage of large quantities of groundwater in the Precambrian aquifers. The shallow groundwater (typically less than 100–150 feet

Table 4-2. Estimated inflow to the Green River Basin Tertiary aquifer system (Martin, 1996)

Recharge components	*Estimated inflow (cfs)*
Infiltration of precipitation, snowmelt runoff, and streamflow	138
Excess irrigation water in the Farson-Eden area of Wyoming	18
Streamflow leakage along the Blacks Fork, Smiths Fork, and Hams Fork	9
Total estimated recharge	**165**

deep) in the Precambrian mountain outcrop areas passes through well-drained parts of these fractured aquifers and discharges to, and sustains, surface water flow from mountain drainages. The high rate of recharge to Precambrian aquifers is thus balanced by a high rate of discharge from them.

Aquifer discharge

Martin (1996) estimated the Tertiary aquifer system discharge rate to be similar to the recharge rate, assuming dynamic equilibrium between recharge and discharge within the Green River Basin. The steady-state groundwater budget for the Tertiary aquifer system in the Green River Basin is estimated in Martin (1996): **Table 4-3** lists identified and estimated discharge components. This outflow rate converts to annual discharge as follows:

$$\begin{aligned} 163 \text{ cfs} &= 5.14 \times 10^9 \text{ feet}^3\text{/year} \\ &= 38.5 \times 10^9 \text{ gallons/year} \\ &= 118{,}000 \text{ acre-feet/year} \end{aligned}$$

Thus, the total natural discharge from the Tertiary aquifer system in the Green River Basin (**Figure 2-2**) is approximately 118,000 acre-feet per year or 38.5 billion gallons per year, as estimated by Martin (1996).

Estimated GGRB aquifer discharge

Assuming a balance of recharge with discharge, and adding Fisk's (1967) estimated recharge of 10,860 acre-feet per year as discharge in the Great Divide and Washakie basins to the 118,000 acre-feet-per-year discharge from the Green River Basin Tertiary aquifer system estimated by Martin, we have ***129,000 acre-feet per year*** of minimum discharge from groundwater in the GGRB. We use this figure in Chapter 8 to estimate the groundwater balance in the GGRB.

In addition to this natural discharge from subcrop flow and springs located along the stream and river valleys, there is also artificial discharge (pumping of wells). As discussed in Chapters 3 and 7, human activity may account for 8,000 to 16,000 acre-feet of additional estimated discharge per year – perhaps as much as 30,000 acre-feet during discharge averaged over short periods of intense industrial development.

Aquifer storage

The GGRB hydrogeologic units store groundwater in the pore spaces between clastic grains in unconsolidated rocks or crystals in solid rocks, and in fractures, voids, pipes, conduits, and caves in the rocks. Estimating this quantity of stored groundwater is difficult. The available data are not adequate for estimating the quantities of groundwater stored within the individual hydrogeologic units or the aquifer systems in the basin. In this section, we use very general parametric estimates and constraints to estimate groundwater available for production from the GGRB Tertiary hydrogeologic units.

Conceptually, a full bathtub will not hold additional water, and as more water is added to a full bathtub, the same amount of water will be discharged as overflow. The full bathtub is analogous to a saturated aquifer. Recharge water will enter permeable zones in the aquifer outcrop area, and the same amount of groundwater will eventually be discharged from the same interconnected aquifer down-gradient: the regional groundwater flow pattern in an aquifer is generally from higher-elevation

Table 4-3. Estimated outflow from the Green River Basin Tertiary aquifer system (Martin, 1996)

Discharge components	*Estimated outflow (cfs)*
Green and New Fork rivers upstream from Fontenelle Reservoir	94
Green River between Fontenelle Reservoir and the town of Green River, Wyoming	23
Green River downstream from the town of Green River, Wyoming, including Flaming Gorge Reservoir	13
Big Sandy River	17
Henrys Fork River	16
Total estimated discharge	**163**

recharge areas to lower-elevation discharge areas. Groundwater flows through porous and permeable media, much slower than surface water flows. Where surface water may take days or months to flow a given distance, groundwater may take years or millennia to flow that distance.

Drawdown

Many have expressed skepticism about the concept of *safe yield*, but the idea persists that aquifers may be artificially discharged and the groundwater used without causing long-term drawdown of the water level. Consequently, we assume that there must be a theoretical limit to how much groundwater may be extracted from an aquifer without long-term damage to the aquifer. The hydrogeologic variables for calculating a theoretical limit are numerous and complex, and most are not well understood at present. We do recognize such common-sense concepts as static yield being equivalent to recharge as modified by factors of flow. And we do know that we can identify long-term decline in groundwater levels using monitoring-well data, as evidenced in the Platte River Basin of southeastern Wyoming.

The groundwater control areas established in the Platte River Basin show that "mining" of a subsurface water supply or exceeding the "safe yield" of an aquifer does occur. These control areas were established to address the serious problem of long-term decline of groundwater levels in these heavily used aquifers. In the control areas, high well density and high overall pumping rates have allowed groundwater withdrawal to exceed safe yield, at least locally.

Again, coalbed natural gas (CBNG) development requires the mining of groundwater to deliberately lower the water level in the target coal beds, reducing groundwater pressure within a bed; the natural gases desorb from the coal and are collected in a CBNG production well.

In several areas of the GGRB, energy development is causing or is expected to cause drawdown of water levels in aquifers:

- The Pennsylvanian Tensleep Sandstone aquifer in the northeastern Great Divide Basin includes a local area of drawdown due to petroleum field development. The Tensleep groundwater in this area contains hydrocarbons and is not of drinking-water quality.

- The coal beds of the Upper Cretaceous Mesaverde Group in the eastern Washakie Basin include an area of planned drawdown as part of the Atlantic Rim CBNG development north of Baggs, Wyoming. The Mesaverde coal aquifer is not of drinking water quality, and the production water would be re-injected into other formations.

Estimation of safe or sustainable yield of aquifers

The term *sustainable groundwater development* denotes the determination of how much groundwater may be developed for future use. For this determination, pump production rates and "acceptable" drawdown must be determined or estimated.

Meinzer (1923, p. 55) defined the term *safe yield* of an aquifer as "the rate at which ground water can be withdrawn from an aquifer for human use without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible. It can be expressed in gallons or acre-feet per day or year or in second-feet (cubic feet per second)." A safe yield estimate must take into account the fourth-dimensional (time) nature and response of pumping water from an aquifer. We define the term *safe yield* as the volume of water that can be withdrawn from an aquifer without producing a significant, long-term decline in the potentiometric surface (groundwater level) of the aquifer. Safe yield is determined empirically by measuring production and drawdown over time.

A concept similar to *safe yield* is *sustainable yield*, a theoretical determination based on the recharge rate, discharge rate, and storage volume of an aquifer. The values of these parameters are mostly unknown for the GGRB, and are difficult to estimate because data is sparse and conclusive methods of data analysis are lacking.

Estimates of stored and producible available groundwater volumes in the GGRB Tertiary hydrogeologic units

Hinaman's 2005 study of groundwater in the nonmarine Upper Cretaceous and Tertiary hydrogeologic units in the Wyoming Powder River Basin used two methods to estimate the volume of groundwater available: a method based on porosity and a method based on specific yield and specific storage. It seems to us that he attempted to deal with hydrogeologic units that behave as confined aquifers at depth and as unconfined aquifers at outcrop by bridging the transition between confined behavior – as conventionally expressed by specific storage – and unconfined behavior – as conventionally expressed by porosity or specific yield.

For this report, we modified Hinaman's methods, and used them differently, to generate two sets of water volume estimates, one based on porosity, the other on specific yield and specific storage. We compared the two sets of estimates. We represent the volume of water contained in Tertiary hydrogeologic units to a depth of 1,000 feet with a model: a plate-shaped volume of rock – irregular in plan and uniformly 1,000 feet thick – with a surface area of 13,000 square miles representing the land surface of the GGRB underlain by Tertiary hydrogeologic units. Our estimates are for the stack of Tertiary hydrogeologic units taken as a whole, rather than for summed individual hydrogeologic units: Hinaman had sufficient data to treat each hydrogeologic unit separately, but we have insufficient data to do so for the GGRB. Each set of volume estimates ranges over various proportions of sand and non-sand lithologies. We take Hinaman's "sand" to include consolidated and unconsolidated sand, sandy conglomerate, and conglomerate, plus fractured carbonates and coal; and his "non-sand" to include consolidated claystone, mudstone, shale, and unfractured carbonates, as well as sand indurated with fine-grained material or cemented with precipitated material.

Because of the general low quality of groundwater in wells more than 1,000 feet deep in the GGRB, and in some areas of the basin as shallow as 300 feet deep in the Tertiary geologic units, this study assumed a maximum depth of 1,000 feet for estimating the volume of groundwater in the Tertiary geologic units (Upper and Lower Tertiary). We assume that the Quaternary units are generally thin (less than 50 feet thick) and are not significantly hydrologically different from the underlying Tertiary units. Basically, we assume that the Quaternary units are similar lithologically to the underlying Tertiary units, and we combine them.

One method Hinaman (2005) used to estimate groundwater volume is based on the estimated porosity of the nonmarine Upper Cretaceous and Tertiary hydrogeologic units in the Wyoming Powder River Basin. Hinaman assumed a sand porosity of 30 percent and a non-sand porosity of 35 percent, on the basis of literature porosity estimates for these lithologies. We followed these assumptions for the similar nonmarine Tertiary hydrogeologic units in the GGRB.

Hinaman's other method for estimating groundwater volumes is based on the estimated specific yield and specific storage of the nonmarine Upper Cretaceous and Tertiary hydrogeologic units in the Wyoming Powder River Basin. The specific yield and specific storage method that we applied to the GGRB is modified from Hinaman's. In the Powder River Basin, Hinaman assumed specific yields of 26 percent for sand and 10 percent for non-sand lithologies, and specific storages of 1×10^{-4} for sand and 1×10^{-5} for non-sand lithologies, on the basis of literature estimates. We followed these assumptions for the similar nonmarine Tertiary hydrogeologic units in the GGRB. In the Powder River Basin, the Paleocene Fort Union Formation contains 31 to 55 percent sand, and some Upper Cretaceous units contain 9 to 88 percent sand (mean 35 percent); we calculate our estimates on the basis of a 50:50 sand:non-sand ratio. To compute these estimates, we define a *unit volume of water* as either the volume of water s*tored in* a unit volume of rock, or as the volume of water *producible from* a unit volume of rock; producible groundwater is a small percentage of stored groundwater. We estimate stored water volume from porosity, and producible water volume from specific yield and specific storage, with the following calculations.

Estimate based on porosity

- Unit volume of rock (defined)
  - Unsaturated section (50 feet thick)
  - Saturated section (950 feet thick)
    - Water stored in sand component
    - Water stored in non-sand component
- **Unit volume of stored groundwater** *[Table 4-4]*

Estimate based on specific yield and specific storage

- Unit volume of rock (defined)
  - Unsaturated section (50 feet thick)
  - Saturated section (950 feet thick)
    - Unconfined part (50 feet thick)
      - Water producible from sand component
      - Water producible from non-sand component
      - Volume of producible unconfined groundwater *[Table 4-5]*
    - Confined part (900 feet thick)
      - Water producible from sand component
      - Water producible from non-sand component
      - Volume of producible confined groundwater *[Table 4-6]*
- **Unit volume of producible groundwater** *[Table 4-7]*

Estimates based on porosity

We use porosity to estimate the volume of groundwater stored in the modeled Tertiary hydrogeologic units to a depth of 1,000 feet. We set the following conditions for a unit volume in the Tertiary aquifer system of the GGRB:

- The dimensions of a unit volume are 1 square mile on the land surface by 1,000 feet deep.
- The surface area of 1 square mile is 27,878,400 square feet.
- Saturated thickness is assumed to be the lower 950 feet of the 1,000-feet-deep unit volume; the upper 50 feet is assumed to be unsaturated (above the groundwater surface or *water table*).
- The sand percentage of the aquifer is figured at 10 percent to 90 percent in 10-percent increments, and assumed sand porosity is 30 percent.
- The non-sand percentage is figured at 100 percent minus the sand percentage, and assumed non-sand porosity is 35 percent.

Sand groundwater unit volume (feet^3)

= area (feet^2) × saturated thickness (feet) × percent sand × porosity

= 27,878,400 feet^2 × 950 feet × [0.10 to 0.90] × 0.30

These values are listed in **Table 4-4**, columns 1 and 2. This 795 million to 7.15 billion cubic feet converts to 5.95 billion to 53.5 billion gallons or 18,300 to 164,000 acre-feet.

These calculated water volumes in the Tertiary aquifer are for the unit volume only. The total outcrop area for the Upper and Lower Tertiary aquifers in the Wyoming GGRB is approximately 13,000 square miles. Thus, the estimated volume of groundwater stored in sand in the GGRB is:

18,300 acre-feet/mi^2 × 13,000 mi^2
= 238,000,000 acre-feet (sand 10%)

164,000 acre-feet/mi^2 × 13,000 mi^2
= 2,130,000,000 acre-feet (sand 90%)

Non-sand groundwater unit volume (feet^3)

= area (feet^2) × saturated thickness (feet) × (100 – percent sand) × porosity

= 27,878,400 feet^2 × 950 feet × [0.90 to 0.10] × 0.35

These values are listed in **Table 4-4**, columns 3 and 4. This 8.34 billion to 927 million cubic feet converts to 62.4 billion to 6.93 billion gallons or 191,000 to 21,300 acre-feet. The estimated volume of groundwater stored in non-sand units in the GGRB is:

191,000 acre-feet/mi^2 × 13,000 mi^2
= 2,480,000,000 acre-feet (90% non-sand)

21,300 acre-feet/mi^2 × 13,000 mi^2
= 277,000,000 acre-feet (10% non-sand)

Unit volume of stored groundwater

We sum the sand and non-sand components to give stored groundwater unit volume estimates for the GGRB (**Table 4-4,** column 5).

We estimate the stored groundwater unit volume within the upper 1,000 feet of Tertiary hydrogeologic units to range from about 8 billion to more than 9 billion cubic feet, with a median value of about 8.60 billion cubic feet. This is not an estimate of the quantity of groundwater that can be produced, but an estimate of the total amount of groundwater contained in the water-saturated pores, conduits, openings, and fractures within the modeled Tertiary unit volume. This 8.6 billion cubic feet converts to 64.3 billion gallons or 197,000 acre-feet. The volume of stored groundwater in the modeled GGRB Tertiary hydrogeologic units to 1,000 feet, estimated on the basis of porosity, computes to:

197,000 acre-feet/mi^2 × 13,000 mi^2
= 2,560,000,000 acre-feet

Estimates based on specific yield and specific storage

We use specific yield and specific storage to estimate the volume of groundwater available for production from the saturated section to a depth of 1,000 feet. We establish the following conditions for a groundwater unit volume:

- The dimensions of a unit volume are 1 square mile on the land surface by 1,000 feet below the land surface.
- The surface area of 1 square mile is 27,878,400 square feet.
- The saturated thickness is assumed to be the lower 950 feet of the 1,000-foot-deep unit volume.
- The upper 50 feet of the saturated thickness is assumed to be unconfined; available groundwater is estimated on the basis of specific yield, assumed to be 26 percent for sand and 10 percent for non-sand.
- The lower 900 feet of the saturated thickness is assumed to be confined; available groundwater is estimated on the basis of specific storage, assumed to be 1×10^{-4} for sand and 1×10^{-5} for non-sand.
- The sand content in both the unconfined and confined volumes is figured at 10 percent to 90 percent in 10-percent increments. The non-sand content is figured at 100 percent minus the sand percentage.

Sand unconfined groundwater component unit volume (feet^3)

= area (feet^2) × thickness (feet) × percent sand × specific yield

Table 4-4. Modeled groundwater unit volumes in Tertiary hydrogeologic units, GGRB

Percent sand	*Sand volume (ft^3)*	*Percent non-sand*	*Non-sand volume (ft^3)*	*Groundwater unit volume (ft^3)*
10	795,000,000	90	8,340,000,000	9,135,000,000
20	1,590,000,000	80	7,420,000,000	9,010,000,000
30	2,390,000,000	70	6,490,000,000	8,880,000,000
40	3,180,000,000	60	5,560,000,000	8,740,000,000
50	3,970,000,000	50	4,630,000,000	**8,600,000,000**
60	4,770,000,000	40	3,710,000,000	8,480,000,000
70	5,560,000,000	30	2,780,000,000	8,340,000,000
80	6,360,000,000	20	1,850,000,000	8,210,000,000
90	7,150,000,000	10	927,000,000	8,077,000,000

$= 27{,}878{,}400 \text{ feet}^2 \times 50 \text{ feet} \times [0.1 \text{ to } 0.9] \times 0.26$

These values are listed in **Table 4-5**, columns 1 and 2. This 36.2 million to 326 million cubic feet converts to 271 million to 2.44 billion gallons or 831 to 7,480 acre-feet.

Non-sand unconfined groundwater component unit volume (feet^3)

$= \text{area (feet}^2) \times \text{thickness (feet)} \times (100 - \text{percent sand}) \times \text{specific yield}$

$= 27{,}878{,}400 \text{ feet}^2 \times 50 \text{ feet} \times [0.9 \text{ to } 0.1] \times 0.10$

These values are listed in **Table 4-5**, columns 3 and 4. This 125 million to 13.9 million cubic feet converts to 935 million to 104 million gallons or 2,870 to 319 acre-feet.

Volume of unconfined producible groundwater
We sum the sand and non-sand components to give total unconfined producible groundwater unit volume estimates (**Table 4-5,** column 5). This 161 million to 340 million cubic feet converts to 1.20 billion to 2.54 billion gallons or 3,700 to 7,810 acre-feet of unconfined producible groundwater.

Sand confined groundwater unit volume (feet^3)

$= \text{area (feet}^2) \times \text{thickness (feet)} \times \text{percent sand} \times \text{specific storage}$

$= 27{,}878{,}400 \text{ feet}^2 \times 900 \text{ feet} \times [0.1 \text{ to } 0.9] \times 0.0001$

These values are listed in **Table 4-6**, columns 1 and 2. This 251,000 to 2.26 million cubic feet converts to 1.87 million to 16.9 million gallons or 5.76 to 51.9 acre-feet.

Non-sand confined groundwater component unit volume (feet^3)

$= \text{area (feet}^2) \times \text{thickness (feet)} \times (100 - \text{percent sand}) \times \text{specific storage}$

$= 27{,}878{,}400 \text{ feet}^2 \times 900 \text{ feet} \times [0.9 \text{ to } 0.1] \times 0.00001$

These values are listed in **Table 4-6**, columns 3 and 4. This 226,000 to 25,100 cubic feet converts to 1.69 million to 188 thousand gallons or 5.19 to 0.576 acre-feet.

Volume of producible confined groundwater
We sum the sand and non-sand components to give total confined groundwater unit volume estimates (**Table 4-6,** column 5).

This 477,000 to 2.29 million cubic feet converts to 3.57 million to 17.1 million gallons or 11.0 to 52.6 acre-feet of confined groundwater.

Table 4-5. Modeled unconfined groundwater unit volumes in Tertiary hydrogeologic units, GGRB

Percent sand	*Water volume in sand (fe^3)*	*Percent non-sand*	*Water volume in non-sand (ft^3)*	*Total unconfined water volume (ft^3)*
10	36,200,000	90	125,000,000	161,000,000
20	72,500,000	80	111,500,000	184,000,000
30	108,700,000	70	97,600,000	206,000,000
40	145,000,000	60	83,600,000	229,000,000
50	181,000,000	50	69,700,000	251,000,000
60	217,000,000	40	55,800,000	273,000,000
70	252,000,000	30	41,800,000	294,000,000
80	290,000,000	20	27,900,000	318,000,000
90	326,000,000	10	13,900,000	340,000,000

Unit volume of producible groundwater

We now sum the unconfined and confined groundwater unit volumes to give total groundwater unit volumes (**Table 4-7,** column 5).

This 161 million to 342 million cubic feet converts to 1.20 billion to 2.56 billion gallons or 3,700 to 7,850 acre-feet of producible groundwater. The median estimate, the 252 million cubic feet that corresponds to a 50:50 sand:non-sand composition, converts to 1.89 billion gallons or 5,785 acre-feet. This represents the volume of groundwater that can be produced from one unit volume of rock. The volume of producible groundwater in the modeled GGRB Tertiary hydrogeologic units to 1,000 feet estimated on the basis of specific yield and specific storage computes to:

$$5{,}785 \text{ acre-feet/mi}^2 \times 13{,}000 \text{ mi}^2 = 75{,}200{,}000 \text{ acre-feet}$$

The 75.2 million acre-feet of producible groundwater estimated on the basis of specific yield and specific storage is about 3 percent of the 2.56 billion acre-feet of groundwater stored to a depth of 1,000 feet estimated on the basis of porosity. This 3-percent proportion is consistent with convention.

Table 4-6. Modeled confined groundwater unit volumes in Tertiary hydrogeologic units, GGRB

Percent sand	*Water volume in sand (ft^3)*	*Percent non-sand*	*Water volume in non-sand (ft^3)*	*Total confined water volume (ft^3)*
10	251,000	90	226,000	477,000
20	502,000	80	201,000	703,000
30	753,000	70	176,000	929,000
40	1,000,000	60	151,000	1,151,000
50	1,250,000	50	125,000	1,375,000
60	1,510,000	40	100,000	1,610,000
70	1,760,000	30	75,300	1,840,000
80	2,010,000	20	50,200	2,060,000
90	2,260,000	10	25,100	2,290,000

Table 4-7. Modeled available groundwater unit volumes in Tertiary hydrogeologic units, GGRB

Percent sand	*Percent non-sand*	*Unconfined water volume (ft^3)*	*Confined water volume (ft^3)*	*Total groundwater unit volume (ft^3)*
10	90	161,000,000	477,000	161,000,000
20	80	184,000,000	703,000	185,000,000
30	70	206,000,000	929,000	207,000,000
40	60	229,000,000	1,151,000	230,000,000
50	50	251,000,000	1,375,000	**252,000,000**
60	40	273,000,000	1,610,000	275,000,000
70	30	294,000,000	1,835,000	296,000,000
80	20	318,000,000	2,060,000	320,000,000
90	10	340,000,000	2,290,000	342,000,000

Aquifer sensitivity and groundwater contamination

A groundwater unit volume located near a basin margin at relatively high elevation has a different hydrologic character than a unit volume at a basin center, because the basin-margin unit volume is close to or includes the formation outcrop where recharge occurs. The basin margin aquifer may have a higher percentage of sand and correspondingly greater permeability. Or, the volume of water stored in the unit volume may be the same, but the recharge rate and flow rate are probably higher in a basin margin unit volume than in a unit volume located in the central basin. Additionally, surface flow toward the aquifer is probably higher, because the gradient is greater.

Figure 4-1 shows an aquifer sensitivity map of the Wyoming GGRB; these data were not available for the adjacent GGRB areas of Colorado and Utah. The dark blue areas on the figure denote areas with the highest probability of interaction between surface water and groundwater. In these higher-sensitivity areas, surface water and groundwater are likely to exchange in complex gains and losses as water moves between the ground surface and the subsurface.

These identified higher sensitivity areas (**Figure 4-1**) are also considered more susceptible to shallow groundwater contamination due to high permeability and relatively shallow depth to groundwater. Contamination released at the ground surface or in the shallow subsurface (such as leakage from underground storage tanks) will likely migrate downward from the shallow soils or sediments to contaminate the shallowest groundwater underlying a site. Groundwater contamination tends to follow the direction of local groundwater flow from a contamination point source. Non-point-source groundwater contamination may arise in an area of multiple sources.

In some areas of the GGRB, groundwater contamination is natural, resulting from high concentrations of chemical constituents dissolved from natural sources. Examples of naturally occurring contamination include uranium and other radioactive element contamination in Tertiary formations in the Great Divide Basin, and high levels of inorganic constituents such as selenium or fluorine throughout the GGRB. Chapter 6 identifies constituents that exceed water quality standards (for various uses) in GGRB geologic units and rock-stratigraphic units.

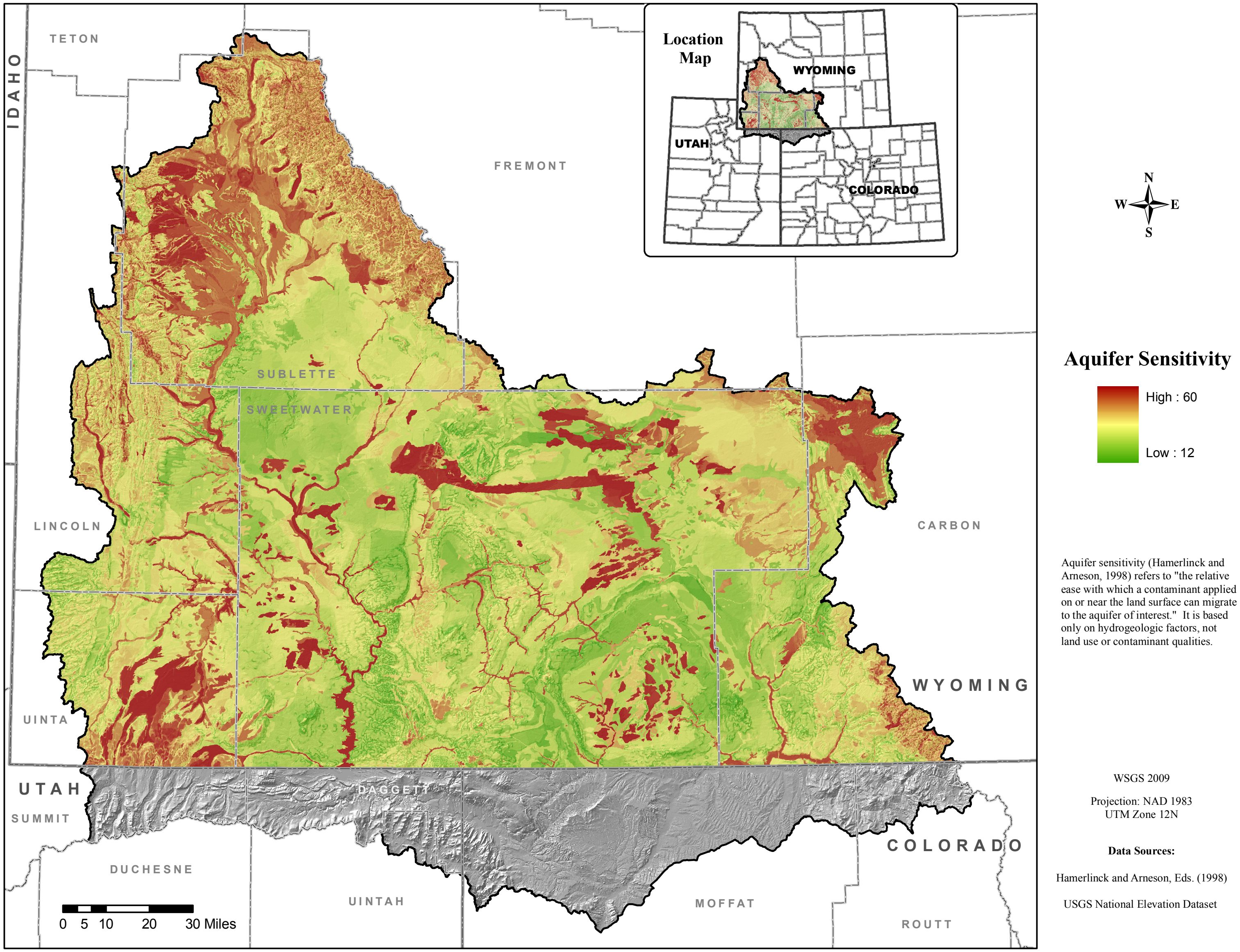

Figure 4-1. Aquifer sensitivity, Wyoming Greater Green River Basin.

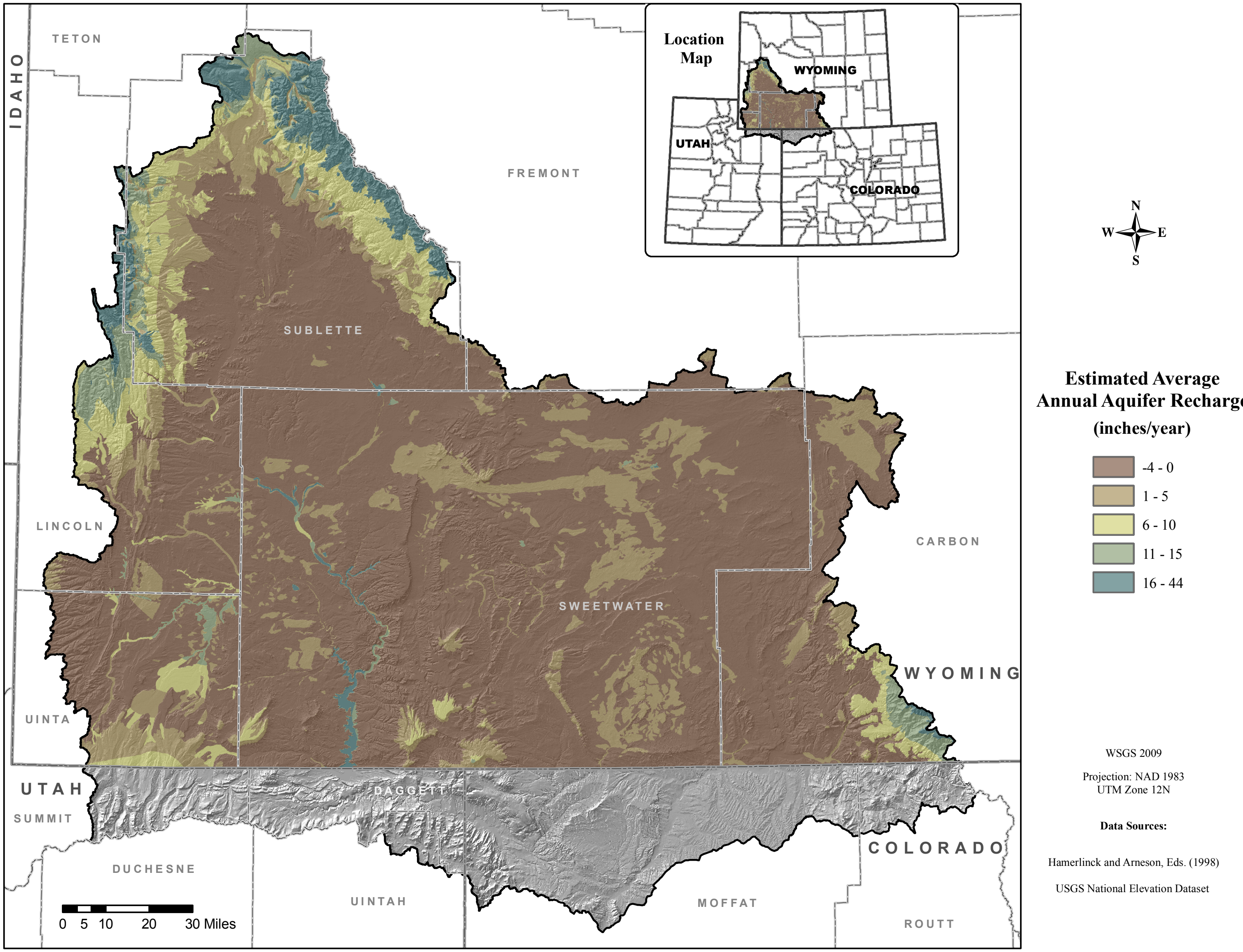

Figure 4-2. Estimated aquifer recharge, Wyoming Greater Green River Basin.