Wyoming State Geological Survey

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Green River Basin Water Plan II
Groundwater Study
Level I (2007-2009)

Available Groundwater Determination

Technical Memorandum

Executive Summary

Prepared for the Wyoming Water Development Commission

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Cover: Boar's Tusk, Quaternary volcanic neck, east of Eden, Wyoming, *Photo by Meg Ewald, 2009*

EXECUTIVE SUMMARY

GREATER GREEN RIVER BASIN – GROUNDWATER STUDY, LEVEL I
Available Groundwater Determination Technical Memorandum

This memorandum represents our current assessment of available groundwater resources in the Greater Green River Basin (GGRB) of southwestern Wyoming and small adjacent areas of Colorado and Utah. The GGRB encompasses the Green River, Washakie, and Sand Wash Basins – the drainage basins of the Green River and Little Snake River – and the Great Divide Basin, an internal drainage basin, which straddles the Continental Divide (Figure 1).

This memorandum informs the 2008 Green River Basin Water Plan II – Groundwater Study (Level I), part of a larger surface water and water use plan update by a consulting team under the direction of WWC Engineering, Inc., Laramie, Wyoming (WWC Engineering Inc., forthcoming). The memorandum was prepared by personnel of the Wyoming State Geological Survey (WSGS), Laramie; the United States Geological Survey (USGS) Wyoming Water Science Center, Cheyenne; and the University of Wyoming Water Resources Data System (WRDS), Laramie.

Funding to update the 2001 Green River Basin Water Plan was provided by the Wyoming Water Development Commission (WWDC). Databases of digital data and information about groundwater, wells, springs, geology, hydrogeology, precipitation, aquifer sensitivity, aquifer recharge, and groundwater modeling for the GGRB came from the Colorado Geological Survey, U.S. Environmental Protection Agency (USEPA), U.S. Geological Survey, Utah Geological Survey, WRDS, WDEQ, Wyoming Geographical Information Science Center, Wyoming Oil and Gas Conservation Commission (WOGCC), Wyoming State Engineer's Office (WSEO), WSGS, WWDC, and The PRISM Climate Group at Oregon State University.

The 2001 Green River Basin Water Plan (States West Water Resources Corporation, 2001) is obsolescent in 2008 for some water resource issues because of energy development in the basin and the generation of additional data. The Jonah Field and Pinedale Anticline natural gas developments are ongoing in Sublette and northwestern Sweetwater counties, in an area between Farson and Pinedale. A major coalbed natural gas (CBNG) development is starting north of Baggs in western Carbon County. Other energy developments in the GGRB are continuing or are planned for the near future. Energy development, a growing population, and business development within the basin are causing increasing demand for water. Periodic economic downturns may slow the rate of increase in demand, but the trend is clearly demanding of careful stewardship of the GGRB water resource.

Groundwater is stored in most geologic units in the GGRB, but some areas of the basin have little or no useable groundwater available. The availability of groundwater in the

GGRB is determined by geologic, hydrogeologic, topographic, and climatic conditions. The quantity and quality of available groundwater are dependent on the type of unconsolidated deposit or bedrock hosting the subsurface water and its depth below the land surface. As part of the hydrologic cycle, the groundwater regime is related to the surface water regime, evapotranspiration, precipitation, and human use. The ultimate source of groundwater recharge is precipitation.

Both the surface water and groundwater resources of the GGRB carry reciprocal responsibilities across Wyoming's borders. Water planners, water regulators, and other interested parties in Wyoming need to be aware of these responsibilities. In particular, the Little Snake River flows back and forth across the Wyoming-Colorado border, and the northern flank of the Uinta Mountains in Utah provides both surface and groundwater flow northward into Wyoming, to the area west of the Green River.

Project scope

This memorandum updates, revises, and expands some aspects of the groundwater memorandum that informed the 2001 Green River Basin Water Plan as the Available Groundwater Determination Technical Memorandum (Hahn and Jessen, 2001). The GGRB groundwater regime and basin subregimes are complex, and measurements are sparse and uneven in quality and distribution. This memorandum, a compilation of data available in 2008 and based on available methods of data reduction and analysis, is thus a step in the ongoing pursuit of these goals:

- Identify the aquifers in the GGRB
- Define the three-dimensional extent of these aquifers
- Compile water-well and spring locations
- Identify the hydrogeologic properties of the aquifers
- Compile and interpret water chemistry data for the aquifers
- Compare the identified aquifer water chemistries with state and federal groundwater standards
- Estimate the quantity of water available in the aquifers for various uses
- Identify aquifer recharge areas
- Estimate aquifer recharge rates
- Identify areas of groundwater and surface-water interaction
- Estimate the "safe yield" potential from the aquifers
- Identify and evaluate existing groundwater studies and models
- Identify future use opportunities to satisfy projected agricultural, municipal, and industrial demands

Mapping rock units

The computer format for organizing information with a spatial component – such as geologic information – is called a Geographic Information System, or GIS. In a geological GIS, the rock-stratigraphic units familiar to geologists are now represented as, divided into, or combined into *geologic units* for purposes of digital geologic mapping and color coding. The framework for the hydrologic information in this report is the assemblage of geologic units that forms the basins, generally as defined by the USGS Geologic Map of Wyoming (Love and Christiansen, 1985) and the Stratigraphic Nomenclature Chart of Wyoming (Love, Christiansen, and Ver Ploeg, 1993), and corresponding coverage of Colorado and Utah. Hydrogeologic units – aquifers and confining units – may contain several geologic units or parts of geologic units, and may cross geologic unit boundaries.

On the current 1:500,000-scale geologic maps of Wyoming, Colorado, and Utah, there are 170 GIS geologic units in the GGRB: 105 units in Wyoming, 40 units in Colorado, and 25 units in Utah. Each geologic unit occupies a large or small surface and subsurface area or areas in the basin and adjacent uplifts; none are present throughout the GGRB. This memorandum describes the hydrogeologic properties and water chemistry of these geologic units in the Wyoming GGRB.

Topography and structure (Figure 1)

The area – approximately 21,000 square miles in Wyoming – defined as the Greater Green River Basin was bounded and divided into subbasins during Late Cretaceous to early Tertiary structural deformation that accompanied the Laramide Orogeny. The GGRB is bounded to the north and northeast by the Wind River Range and Granite Mountains, to the east by the Rawlins Uplift, to the southeast by the Sierra Madre, to the southwest by the southern Sand Wash Basin in Colorado, to the south by the Uinta Mountains in Utah, to the west by the Overthrust Belt, and to the northwest by the Hoback Basin. Within the GGRB, the Rock Springs Uplift and Bridger Basin are located in the Green River Basin proper; the Wamsutter Arch separates the Great Divide and Washakie Basins; and Cherokee Ridge separates the Washakie and Sand Wash basins.

Figure 2 is a geologic cross section eastward from the Overthrust Belt across the Moxa Arch, Green River Basin, Rock Springs Uplift, and Washakie Basin. The cross section shows the Precambrian basement overlain by various thicknesses of Paleozoic to Cenozoic formations, some large-scale geologic structures, and major faults.

Rainfall

Average annual precipitation in the GGRB ranges from less than 7 inches in central basin areas to nearly 60 inches in the high mountain areas (Figure 3). Most of the central basin areas receive between 6 and 15 inches; the highland and mountain areas generally receive 21 to 59 inches.

Groundwater resources

The West's groundwater is considered renewable, but increasingly limited in supply. Variations in the quantity and distribution of annual precipitation may limit available water supplies and create water shortages in areas of high demand. Population growth has increased demand for Wyoming's water resources, both within the state and in downstream states.

In outcrop areas of the bedrock formations, shallow groundwater is typically unconfined. Deeper in the structural basin areas, groundwater is generally confined by low-permeability strata. Confined (artesian) groundwater in some areas of the GGRB flows at the surface from wells and springs. Within the GGRB and on the flanks of the adjacent uplifts, most aquifers yield groundwater to wells, and many confining units yield very low quantities of low-quality groundwater.

At present, data on aquifer recharge rates, groundwater flow rates, aquifer discharge rates, degree of subsurface inter-aquifer mixing, and total groundwater quantities available for development in the GGRB are sparse relative to the great area and stratigraphic complexity of the basin.

Aquifers and aquifer systems are generally anisotropic because of interbedded low-permeability confining beds or confining units (shale, claystone, mudstone, or bentonite beds). Groundwater flow rates through permeable aquifers and confining units range from very high to very low. A high flow rate through a gravel-rich, high-permeability deposit may exceed 3.3 feet per second (fps) or 2.9×10^5 feet per day (ft/day). A low flow rate within a clay-rich, low-permeability deposit may be less than 3.3×10^{-11} fps or 2.9×10^{-7} ft/day. Thus, flow rates in the GGRB vary over 11 to 12 orders of magnitude. Locally, the rate of water flow through an aquifer is generally several orders of magnitude faster than the flow rate through an adjacent confining unit.

The availability of a groundwater resource depends on the quantity, quality, and depth of the groundwater, and on its intended use. These factors also determine the cost of developing the resource. Groundwater quality reflects the natural geochemistry of the water, the result of a variety of geologic factors; and in addition, groundwater may be contaminated or flow impaired by human activity. Groundwater quality in the GGRB generally decreases with depth and with distance from outcrop. Also, permeability generally decreases with depth as compaction increases under lithostatic loading and local infilling of open pore spaces by mineral cements increases with depth.

By the end of 2007, just over 13,000 groundwater permits had been issued by the WSEO for the Wyoming GGRB. Of this total, 999 were for produced water from CBNG wells; CBNG wells were also permitted by the WOGCC for gas production. There are some springs with small yields (25 gpm or less) included within the WSEO groundwater-permit database for the GGRB. It is difficult to correctly discriminate some of the springs from wells within WSEO database.

Some wells may connect various aquifers and water-bearing zones. A well that is improperly completed or incompletely plugged and abandoned may conduct water through the well borehole from one aquifer to another.

Hydrogeologic unit classification

The hydrogeologic units in the Wyoming GGRB – aquifers and confining units comprising unconsolidated sedimentary deposits and consolidated (lithified) bedrock ranging in age from Quaternary to Precambrian – vary widely in lithology and water-bearing properties. We describe the hydrogeologic units as occurring in four major divisions that correspond to the geologic erathems – the Cenozoic, Mesozoic, Paleozoic, and Precambrian hydrogeologic units – and their subdivisions (Table 1); and we group some contiguous hydrogeologic units as "aquifer systems" (Plate 1b). Every geologic unit in the basin, and in turn every rock-stratigraphic unit, is included in these hydrogeologic divisions.

Table 1. Outcrop areas and area percentages, hydrogeologic units in the Wyoming GGRB

Hydrogeologic unit	Outcrop area (square miles)	
	Area	Percentage
Surface water and ice	***104.0***	***0.50***
Volcanic rocks (Mesozoic & Cenozoic)	***8.4***	***0.04***
Cenozoic hydrogeologic units	***17,177.1***	***82.62***
Quaternary hydrogeologic units	4,190.6	20.16
Upper Tertiary hydrogeologic units	774.0	3.72
Lower Tertiary hydrogeologic units	12,212.5	58.74
Mesozoic hydrogeologic units	***2,504.3***	***12.04***
Upper Cretaceous hydrogeologic units	1,962.3	9.44
Lower Cretaceous hydrogeologic units	179.5	0.86
Jurassic hydrogeologic units	181.8	0.87
Triassic hydrogeologic units	180.7	0.87
Paleozoic hydrogeologic units	***181.6***	***0.87***
Precambrian hydrogeologic units	***816.2***	***3.93***
Total Wyoming GGRB map area	***20,792.0***	***100.00***

Cenozoic hydrogeologic units

The Cenozoic hydrogeologic units are the most heavily used of the four major hydrogeologic divisions in the GGRB. The Cenozoic hydrogeologic units are subdivided into Quaternary hydrogeologic units, upper Tertiary hydrogeologic units, and lower Tertiary hydrogeologic units. The Tertiary sedimentary rocks are the most abundant and widely used shallow aquifers in the GGRB. The primary water-yielding beds in the lower Tertiary aquifers are sandstone, conglomeratic sandstone, conglomerate, and coal beds. The outcrop area of the lower Tertiary hydrogeologic units is the largest within the Wyoming GGRB (Table 1). Most of the existing water wells in the GGRB yield water from the various interfingered members and tongues of the Green River, Wasatch, and Bridger formations and their lateral equivalent formations. These formations compose the Green River Basin lower Tertiary aquifer system and the Great Divide/Washakie/Sand Wash basins lower Tertiary aquifer system (Plate 1b). The sandstone and conglomerate beds in the Battle Spring Formation form a shallow aquifer in the eastern Great Divide Basin. The interbedded and permeable sandstone beds in the upper Laney Member of the Green River Formation form an aquifer in the western Washakie Basin. In the Great Divide and Washakie Basins, the sandstone beds of the Wasatch Formation are aquifers in the central basin areas, and the Fort Union sandstone beds are major aquifers around the basin margins.

Mesozoic hydrogeologic units

The Mesozoic formations are distributed in Upper Cretaceous, Lower Cretaceous, Jurassic, and Triassic hydrogeologic units. The Upper Cretaceous Lance-Fox Hills aquifer, Lewis confining unit, and Mesaverde aquifer compose the Mesaverde aquifer system. The Mesozoic hydrogeologic units yield water mostly from sandstone, conglomeratic sandstone, and conglomerate beds in the:

- Upper Cretaceous Lance Formation, Fox Hills Sandstone, Adaville Formation, Blind Bull Formation, Sohare Formation, Blind Bull Formation, members of the Mesaverde Group, Bacon Ridge Sandstone, and Frontier Formation
- Lower Cretaceous Sage Junction Formation, Quealy Formation, Cokeville Formation, Thomas Fork Formation, Smiths Formation, Bear River Formation, Gannett Group, Muddy Sandstone Member, and Cloverly Formation
- Jurassic Morrison Formation, Sundance Formation, Stump Formation, Preuss Sandstone (Redbeds), and Nugget Sandstone
- Triassic Chugwater Formation, Ankareh Formation, Woodside Shale, and Dinwoody Formation

Some thin carbonate (limestone and dolomite) beds in the Morrison Formation, Twin Creek Limestone, Gypsum Spring Formation, Thaynes Limestone, and Alcova Limestone Member of the Chugwater Formation also yield water.

These Mesozoic aquifers yield water within or near formation outcrop areas – "near" defined here to be within about 1 to 5 miles of the outcrop area, depending on structural dip. The sandstone beds of the Upper Cretaceous Mesaverde Group members are notable local aquifers in their outcrop exposures on the Rock Springs Uplift and the flanks of the Sierra Madre.

The Mesozoic hydrogeologic units also include Upper and Lower Cretaceous, regionally extensive, thick marine shale confining units:

- Upper Cretaceous Lewis Shale (the youngest marine shale)
- Upper Cretaceous Hilliard Shale/Blind Bull Formation/Baxter Shale/Cody Shale/Steele Shale/Niobrara Formation, including parts of the Mancos Shale in Colorado and Utah
- Lower/Upper Cretaceous Aspen Shale/Mowry Shale, also including parts of the Lower/Upper Cretaceous Mancos Shale in Colorado and Utah; and
- Lower Cretaceous Bear River Formation/Thermopolis Shale, also including parts of the Lower-Upper Cretaceous Mancos Shale in Colorado and Utah

Paleozoic hydrogeologic units

Groundwater in Paleozoic hydrogeologic units is little used in the GGRB except near basin margins, because deep burial and high mineral content make it unsuitable for most uses. Only oil or gas wells are completed in Paleozoic hydrogeologic units where they are deeply buried. Paleozoic hydrogeologic units are subdivided into upper Paleozoic aquifers, upper Paleozoic confining units, and the lower-middle Paleozoic aquifer system.

The upper Paleozoic aquifers comprise three zones: the upper zone aquifer, composed of the Permian Phosphoria and Goose Egg (Permian section) Formations; the middle zone (or Tensleep-Weber) aquifer, composed of the Pennsylvanian Tensleep Sandstone, Weber Sandstone, and Wells Formation; and the lower zone aquifer, composed of the Ranchester Limestone Member of the Amsden Formation and the Morgan Formation.

The upper Paleozoic confining units in the GGRB are divided into an upper and a lower zone: the upper zone confining unit, composed of the Pennsylvanian Moffat Trail Limestone Member of the Amsden Formation and the Round Valley Limestone; and the lower zone confining unit, composed of the Horseshoe Shale Member of the Amsden Formation.

The lower-middle Paleozoic aquifer system comprises the Mississippian Madison aquifer, composed of the Madison Limestone and, along the basin margin, the overlying Darwin Sandstone Member of the Amsden Formation; the Darby confining unit, composed of the Devonian Darby Formation (present in the Rock Springs Uplift, Green River Basin, and Overthrust belt); the Bighorn aquifer, composed of the Ordovician Bighorn Dolomite (present in the Green River Basin and Overthrust belt), the Cambrian Gallatin Limestone, and undifferentiatied Cambrian rocks; the Gros Ventre confining unit, composed of the Cambrian

Gros Ventre Formation; and the Flathead aquifer, composed of the Cambrian Flathead Sandstone. In the Great Divide and Washakie basins, where the Darby confining unit is not present, the Madison aquifer directly overlies undifferentiated Cambrian rocks.

Precambrian hydrogeologic units

The Precambrian hydrogeologic units, the water-saturated portions of Proterozoic and Archean crystalline crustal rocks, underlie all other geologic formations at depth in the GGRB and are exposed in the cores of the Wind River Range, Uinta Mountains, and Sierra Madre. The Precambrian hydrogeologic units act as the basal confining unit for the Cambrian Flathead aquifer. Local shallow wells and springs are related to weathered, fractured, or faulted rocks underlying outcrop areas. Where the Precambrian formations are buried, they are unlikely to yield useable quantities of water to wells.

Permitted wells (Figure 4)

Most of the 13,002 WSEO groundwater permits issued through 2007 for wells in the Wyoming GGRB are for depths of less than 300 feet and yields of 25 gpm or less. The permitted wells are classified by well type (permitted use), depth range, and yield range in Tables 2, 3, and 4.

Table 2. WSEO permitted wells in the Wyoming GGRB by well type
[2007 WSEO data]

Well type (permitted use)	Number
Domestic	5,288
Monitoring	3,290
Stock	2,757
Miscellaneous	1,902
Coalbed natural gas (CBNG)	999
Industrial	225
Irrigation	115
Dewatering	83
Reservoir supply	74
Municipal	55
Railroad	27
Test well	25
Oil refining/production	16
Drilling	11
Temporary use	8
Commercial	3
Public utility	2
Culinary	1
TOTAL	**[1]14,881**

[1]Some of the 13,002 wells are permitted for more than one use

The *miscellaneous use* category in Table 2 comprises about two dozen categories of use not (or equivocally) included in the other listed categories – e.g., aquaculture, bathing, environmental, fire protection, flood control, groundwater recharge, ice cutting, mining, recreation, refining, steam engine, wetlands, wildlife – and, sometimes in the past, multiple-use wells.

Table 3. 13,002 WSEO permitted wells in the Wyoming GGRB by depth range
[2007 WSEO data]

Depth range (ft)	Number of permits	Percentage of permits	Cumulative percentage
0 – 50	6,623	50.9	50.9
50 – 100	2,147	16.5	76.4
100 – 200	1,983	15.3	82.7
200 – 300	773	5.9	88.6
300 – 500	608	4.7	93.3
500 – 5,000	847	6.5	99.8
5,000 – 12,660	21	0.2	100.0

Well yield

Actual well yield (as against permitted yield) is a function of actual groundwater use. Because we have only very general estimates of groundwater use, we use other data to estimate yield.

Of the 13,002 WSEO groundwater permits issued through 2007 for the Wyoming GGRB, 6,455 permits listed yield, between 1 and 3,600 gallons per minute (gpm) (Table 4). The sum of the listed permitted yields is 171,891 gpm, giving an average yield of 26.6 gpm per well. This 172,000 gpm equals 248×10^6 gallons per day, 90.3×10^9 gallons per year, or 227,000 acre-feet per year from the 6,455 wells with listed yield.

Table 4. WSEO permitted wells in the Wyoming GGRB by yield range
[2007 WSEO data for the 6,455 permits listing yield]

Yield range (gpm)	Number of permits	Percentage of permits	Cumulative percentage
0–25	5,841	90.5	90.5
25–100	401	6.2	96.7
100–300	149	2.3	99.0
300–375	12	0.2	
400–500	33	0.5	100.0
500–3,600	19	0.3	
TOTAL	6,455	100.0	

We cannot reasonably extrapolate these statistics to include all 13,002 permitted wells. We have no data on how many of the other 6,547 permitted wells have been completed, how many are monitoring wells with zero yield, or how many are inactive. We think it improbable that any of these wells are high-yield wells, so we can't mimic the yield distribution of the listed wells. Therefore, we arbitrarily increase our 277,000 acre-feet-per-year estimated permitted yield by 15 percent to a 319,000 acre-feet-per-year estimate for all 13,002 permitted wells in the Wyoming GGRB.

This 319,000 acre-feet per year of groundwater pumping represents a maximum estimate for 2007, attainable only if all permitted wells had been pumped continuously at their permitted yield rate 24 hours a day, 365 days a year. But, water wells are not pumped continuously; typically, they are pumped in brief, cyclical intervals. Some wells are never pumped during a year. Some wells may remain idle for years, and some wells may have been destroyed, lost, or plugged and abandoned. However, if we assume that all 2007-permitted wells were pumped an average of 10 percent of the time, an estimated maximum volume would be 31,900 acre-feet per year of groundwater produced from the Wyoming GGRB. This estimate appears too high, on the basis of a previous estimate.

Purcell (2000) estimated total groundwater use in the Wyoming GGRB in 2000 to be between 5,300 and 7,200 acre-feet per year, depending on the proportion of sprinkler irrigation in total irrigation. To yield 7,200 acre-feet in 2007, considering the 2007 maximum permitted yield of 319,000 acre-feet per year, the 13,002 permitted wells would have been pumped 2.26 percent of the time.

Our approach is to assume that wells are pumped 2.5 percent to 5 percent of the time. Using this assumption, and our 319,000 acre-feet per year estimate of maximum permitted yield, our 2007 estimate for total artificial groundwater withdrawal from the Wyoming GGRB would range between about **8,000 and 16,000 acre-feet per year**. We use this range as an estimate of current use.

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

For this report, we generate two sets of water volume estimates, one based on porosity, the other on specific yield and specific storage. 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 approximate 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 (for which we have insufficient data).

For a one-square-mile unit area, we assumed a 50:50 ratio of sand and non-sand lithologies, taking "sand" to include consolidated and unconsolidated sand, sandy conglomerate, and conglomerate, plus fractured carbonates and coal; and “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.

For our estimate based on porosity we assumed a sand porosity of 30 percent and a non-sand porosity of 35 percent. For our estimate based on specific yield (for unconfined hydrogeologic units) and specific storage (for confined units), we 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 these assumptions, we calculated estimates of the volume of water stored in the Tertiary hydrogeologic units and the volume of water producible from the Tertiary hydrogeologic units; producible groundwater is a small percentage of stored groundwater: the volume of *stored* groundwater in the modeled GGRB Tertiary hydrogeologic units to 1,000 feet, estimated on the basis of porosity, computes to:

$$197{,}000 \text{ acre-feet/mi}^2 \times 13{,}000 \text{ mi}^2 = 2{,}560{,}000{,}000 \text{ acre-feet}$$

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 ground-water 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.

Recharge

Recharge of 10,860 acre-feet per year to the combined Great Divide and Washakie basins (Fisk, 1967) plus recharge of 119,000 acre-feet per year to the Green River Basin (Martin, 1996) gives 130,000 acre-feet per year of estimated recharge to the GGRB. The distribution of estimated annual aquifer recharge to the Wyoming GGRB is shown in Figure 5. Martin’s estimate includes excess irrigation water in the Farson-Eden area, in addition to natural infiltration.

Discharge

Assuming a balance of discharge and recharge and so taking Fisk’s (1967) estimate of recharge as combined discharge from the Great Divide and Washakie basins of 10,860 acre-feet per year, and adding Martin’s (1996) estimate (unrelated to recharge) of 118,000 acre-feet per year of discharge from the Green River Basin, gives 129,000 acre-feet per year of estimated discharge from the GGRB.

In addition to this natural discharge, there is also artificial discharge (pumping of wells). As discussed above under *well yield*, human activities may account for 8,000 to 16,000 acre-feet of additional estimated discharge per year.

The groundwater balance

On the basis of many assumptive numbers from disparate sources and sundry times, we have borrowed or generated tentative estimates – many of them average values representing wide ranges – of groundwater recharge, discharge, available storage, and current use in the Wyoming GGRB. Flow regime, a basic parameter for accurate water balance assessment, has not been addressed because we have no data (although adequate flow is implicit in the identity of a "major aquifer"). Applying these estimates to the entire GGRB, we have:

Available stored groundwater	75,200,000 acre-feet
Annual recharge	130,000 acre-feet/yr
Annual discharge	129,000 acre-feet/yr
Annual use	8,000–16,000 acre-feet/yr

and we can derive:

Annual groundwater deficit = (discharge + use) – recharge	7,000–15,000 acre-feet/yr

This 7,000 to 15,000 acre-feet per year represents about 0.01 percent to 0.02 percent of the estimated available groundwater stored in the GGRB, and depression of the groundwater surface of about 1 to 2 inches per year. (This rate of groundwater level depression could be masked by a gradual depression caused by drought, such as our regional 1999-2007 drought). However, this groundwater deficit estimate seems unrealistically high; the local changes implicit in such an average deficit would have been noted long ago. We believe that a smaller annual deficit is more probable.

Springs

Of the 1,202 recorded springs in the Wyoming GGRB, 947 are mapped on Cenozoic hydrogeologic units, 230 on Mesozoic units, 16 on Paleozoic units, and 9 on Precambrian units. Data for spring locations in Colorado and Utah were unavailable.

Summary

Geologic and hydrogeologic conditions across the GGRB are complex, and the quantity and quality of groundwater vary accordingly. In general, most aquifers and some confining units yield small to moderate quantities of water to shallow wells. Most of the water wells in the basin are low-yield wells less than 300 ft deep; approximately two-thirds of the existing WSEO groundwater permits in the Wyoming GGRB are for wells 100 feet deep or shallower, and with pumping yields of 25 gpm or less. Construction of similar shallow, low yield water wells is anticipated to continue in most rural areas of the basin for domestic and stock uses.

Except for some local areas in the Wyoming GGRB with a high density of existing wells, most of the basin area offers opportunities to develop additional groundwater resources. No areas have been identified in the GGRB with depletion (or "mining") of groundwater resources that would occasion the establishment of a groundwater control area. Some decline in groundwater levels was observed across Wyoming and adjacent states during the 8-year regional drought of 1999-2007.

In most GGRB areas, groundwater quality varies from good to poor for wells constructed into aquifers that are less than 1,000 ft deep. In some areas of the basin, groundwater quality is poor as shallow as 300 ft below land surface. Specific constituents and parameters have been shown to exceed USEPA drinking water standards in many GGRB aquifers. Groundwater quality concerns in most of the Wyoming GGRB will generally limit new water well construction to depths of 1,000 feet or shallower. Thus, potential groundwater development is generally limited to aquifer outcrop areas or within a distance from 1 to 5 miles of those areas.

Contamination of groundwater from point sources such as underground storage tank leaks or industrial releases are a concern. Many locations of former underground storage tanks for gasoline, diesel fuel, or oil have experienced past subsurface leaks into groundwater from the tanks or associated underground pipelines. Energy development activities may result in contamination of local groundwater, such as that indicated by volatile organic compounds (VOCs) detected in some multiple-use water wells near Pinedale in Sublette County.

The development of new, large-yielding wells with good quality water in the Wyoming GGRB is problematical. Tertiary conglomerate, conglomeratic sandstone, and medium- to coarse-grained sandstone lithologies that are relatively free of fine-grained (clay-silt-mud) material are optimum lithologies for the construction of large-yield wells in these target aquifers. Some of the members, tongues, and main body of the Wasatch Formation and the Battle Spring Formation in the Great Divide Basin contain these favorable and highly permeable gravel/sand lithologies. Mesozoic and Paleozoic aquifers may be developed on or near outcrop, where the aquifers are shallow enough and the water quality acceptable.

Although the estimates and conclusions in this report are the best we can generate at present, they must be used with caution in planning because (1) they are averaged over great areas; (2) they are based on data from different times with no way to extrapolate them to present time; (3) the data sets are incomplete; and (4) the effect of drawdown on recharge is not considered. Lack of data on groundwater production seriously affects the reliability of our conclusions. Therefore, the most valuable contribution to the reliability of future revisions of this memorandum would be accurate annual inventories of groundwater production and use.

References Cited

Fisk, E.P., 1967, Groundwater geology and hydrology of the Great Divide and Washakie Basins, south central Wyoming: M.S. thesis, Los Angeles, University of Southern California, 132 p.

Hahn, W.F., and Jessen, C.A., 2001, Available ground water determination, Green River Basin plan, Technical memorandum: Technical memorandum included with the States West Water Resources Corporation, 2001 Green River Basin Plan, prepared for the Wyoming Water Development Commission by Boyle Engineering Corporation and States West Water Resources Corporation, 24 p., 1 pl.

Hamerlinck, J.D. and Arneson, C.S., editors, 1998, Wyoming ground water vulnerability assessment handbook, Volume 2. Assessing ground water vulnerability to pesticides: Laramie, University of Wyoming, Spatial Data and Visualiztion Center Publication SDVC 98-01-2, various pagination.

Hintze, L.F., Willis, C.G., Laes, D.Y.M., Sprinkel, D.A., and Brown, K.D., 2000, Digital geologic map of Utah: Utah Geological Survey, 2 sheets, scale 1:500,000; *and at* http://geology.utah.gov

Love, J.D., and Christiansen, A.C., compilers, 1985, Geologic map of Wyoming: U.S. Geological Survey, 3 sheets, scale 1:500,000.

Love, J.D., Christiansen, A.C., and Ver Ploeg, A.J., compilers, 1993, Stratigraphic chart showing the Phanerozoic nomenclature for the state of Wyoming: Geological Survey of Wyoming Map Series 41 (MS-41).

Martin, L.J., 1996, Geohydrology of Tertiary rocks in the Green River structural basin in Wyoming, Utah, and Colorado: U.S. Geological Survey Water-Resources Investigations Report 92-4164, 43 p.

PRISM Climate Group at Oregon State University, Precipitation: Annual Climatology (1971–2000), *at* www.prism.oregonstate.edu

Purcell, Mike, 2000, Green River Basin Plan, Water use profile – Domestic, industrial, and municipal technical memoranda: Purcell Consulting, P.C., variously paginated.

States West Water Resources Corporation, 2001, Green River Basin water planning process, Final report: Consultant's report prepared for the Wyoming Water Development Commission Basin Planning Program, by States West Water Resources Corporation, Cheyenne, Wyoming, in association with Boyle Engineering Corporation, Purcell Consulting, P.C., Water Right Services, L.L.C., and Watts and Associates, Inc., paginated by section; *and at*
http://waterplan.state.wy.us/basins/green/green.html

Stoeser, D.B., Green, G.N., Morath, L.C., Heran, W.D., Wilson, A.B., Moore, D.W., Van Gosen, B.S., 2005, Preliminary integrated geologic map databases for the United States – Central states – Montana, Wyoming, Colorado, New Mexico, Kansas, Oklahoma, Texas, Missouri, Arkansas, and Louisiana: U.S. Geological Survey Open-File-Report 2005-1351.

WWC Engineering, Inc., forthcoming, Green River Basin Plan: Consultant's report for the Wyoming Water Development Commission, Cheyenne, by WWC Engineering, Inc., Laramie, in association with AECOM and ERO Resources Corp; *and at*
http://waterplan.state.wy.us/

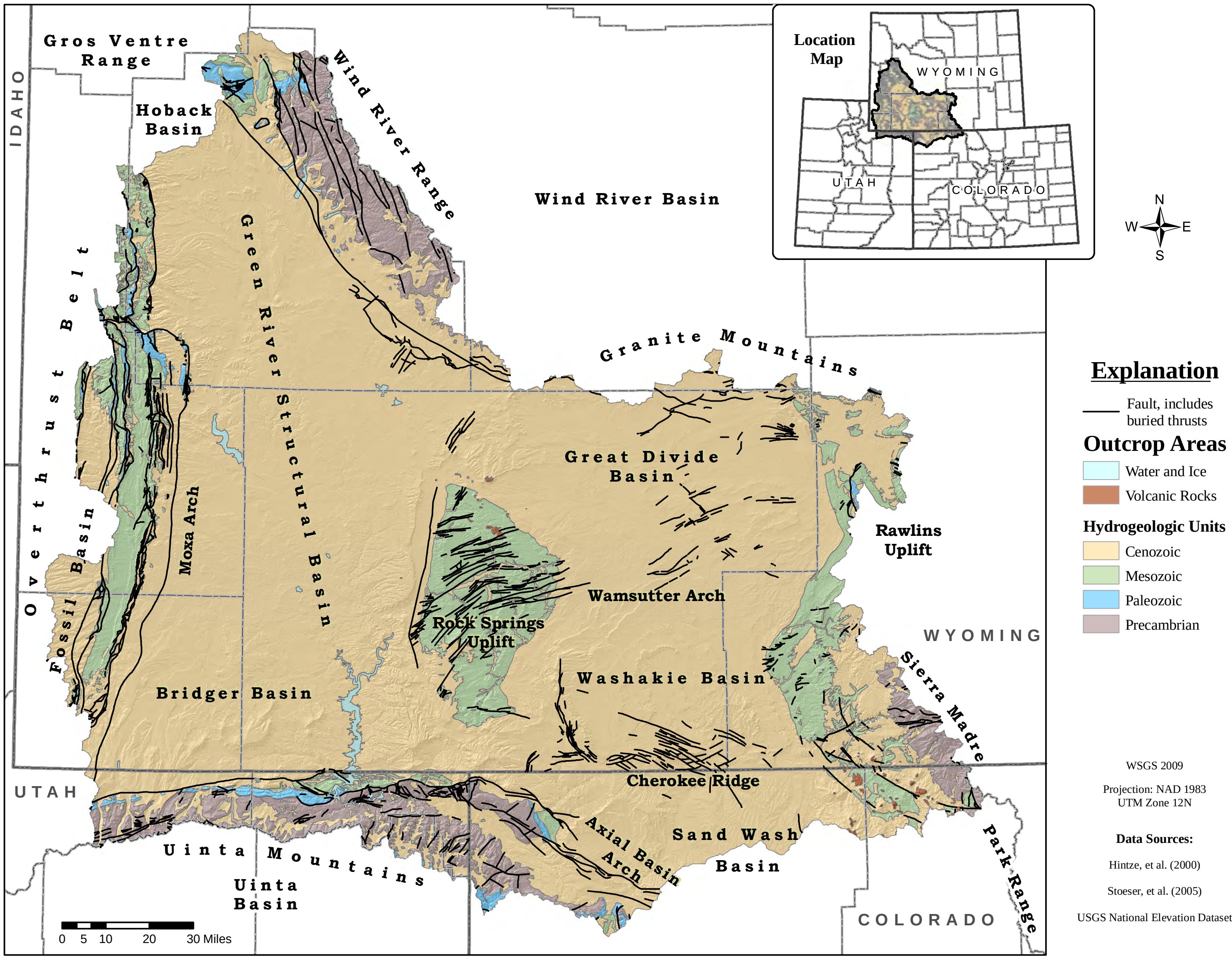
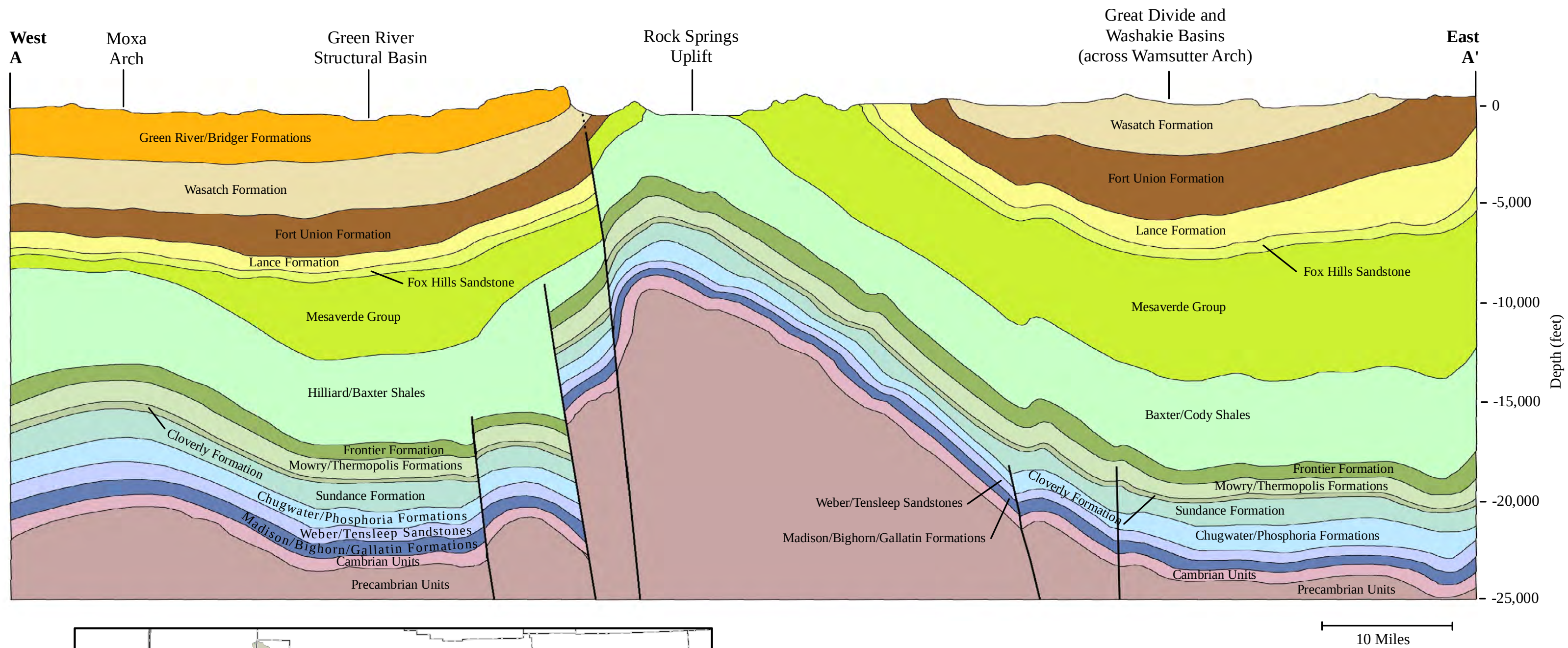
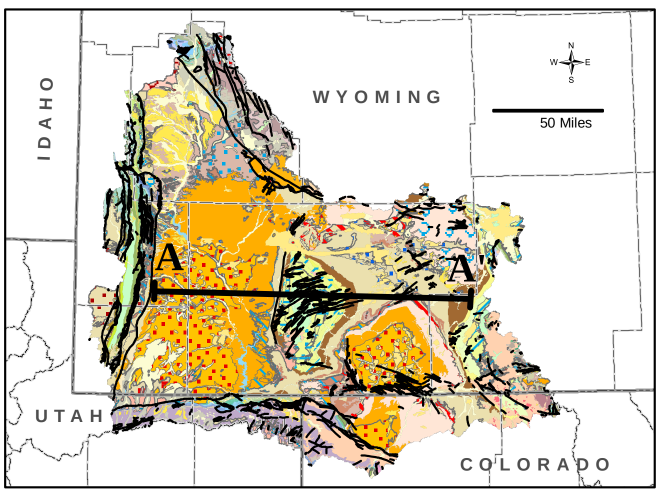


Figure 1. Geologic features, Greater Green River Basin. [Memorandum Figure 2-2.]





Index Map and Line of Section

WSGS 2009

Projection: NAD 1983
UTM Zone 12N

Data Sources:

WSGS unpublished data

Hintze, et al. (2000)

Stoeser, et al. (2005)

Figure 2. West–east geologic cross section, Wyoming Greater Green River Basin. Seismic velocity profile, vertical exaggeration ~7×. *Cross section by Fred McLaughlin and Yuriy Ganshin, WSGS.* [Memorandum Figure 2-5.]

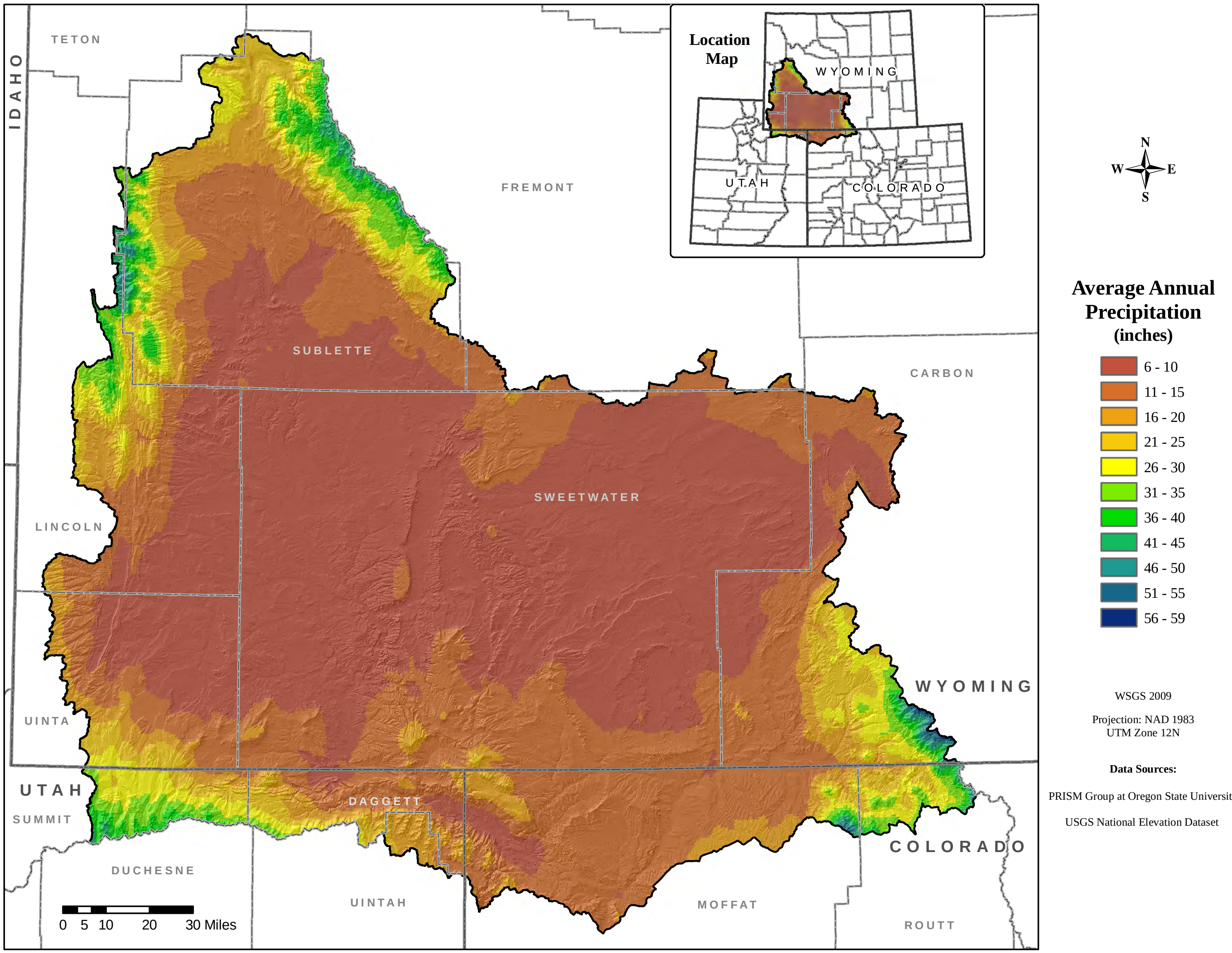


Figure 3. Average annual precipitation, Greater Green River Basin. [Memorandum Figure 2-3.]

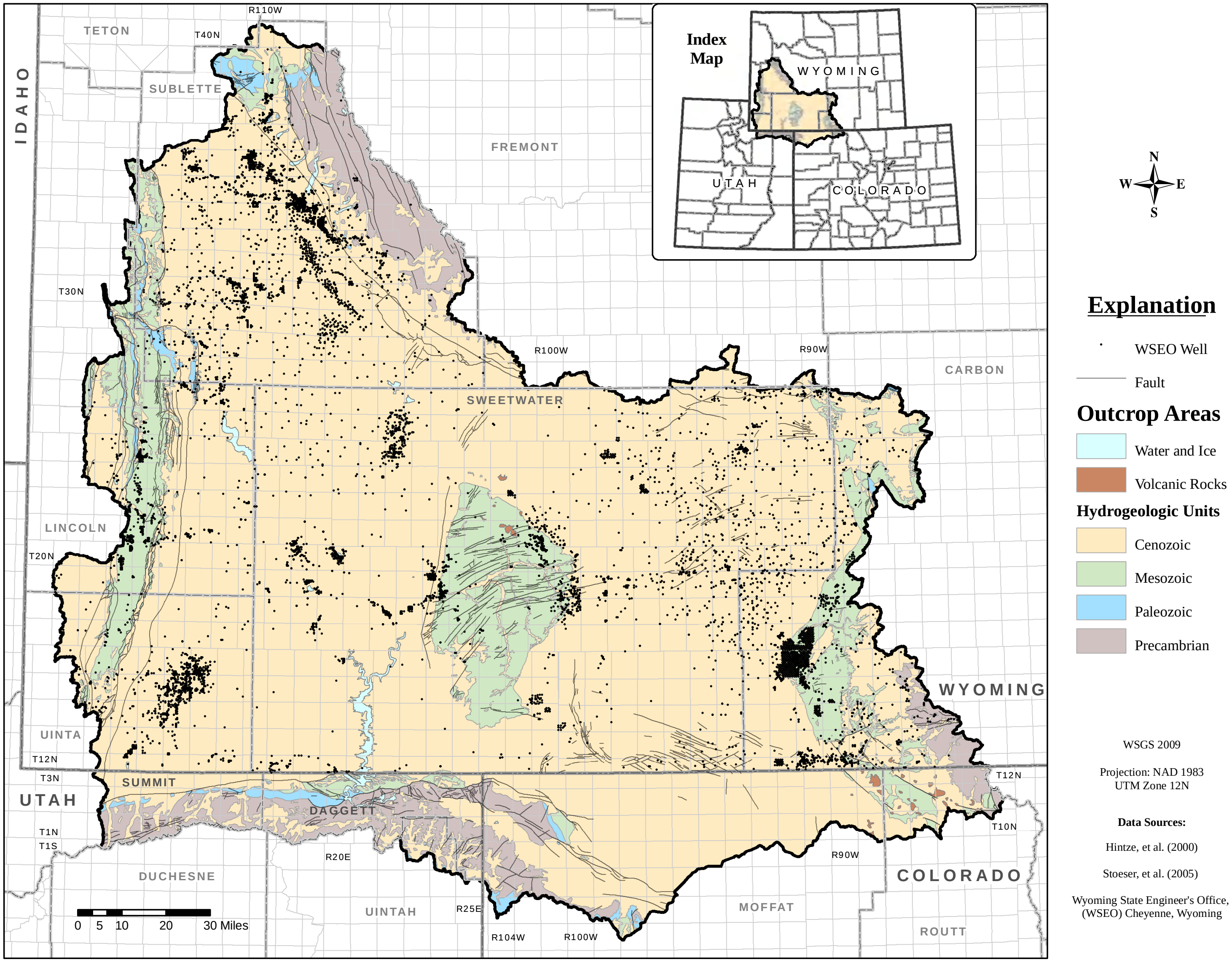


Figure 4. Wells permitted by the Wyoming State Engineer's Office, Wyoming Greater Green River Basin. [Memorandum Figure 3-7.]

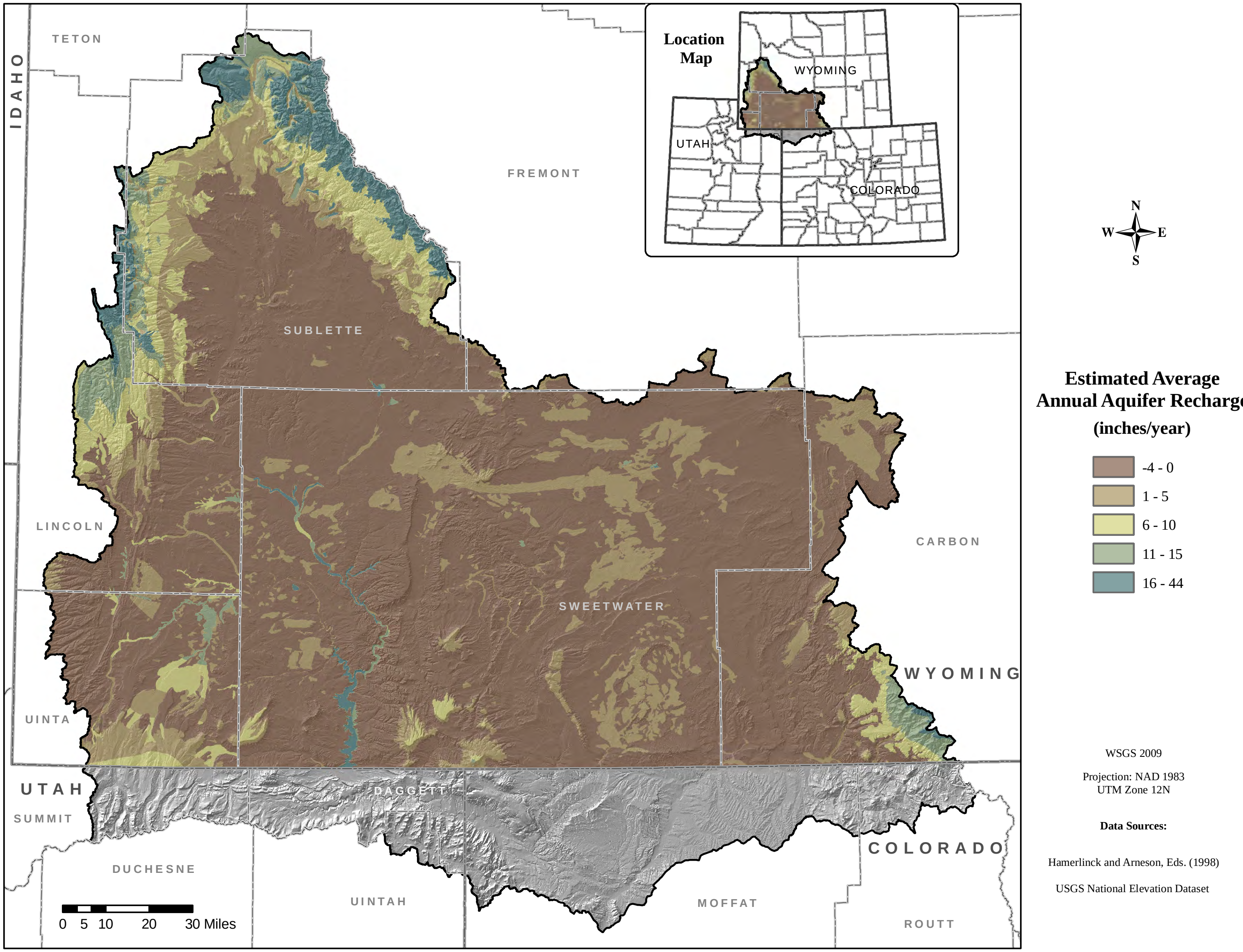


Figure 5. Estimated aquifer recharge, Wyoming Greater Green River Basin. [Memorandum Figure 4-2.]