TECHNICAL MEMORANDUM

SUBJECT: **Green River Basin Plan**

Available Ground Water Determination

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Introduction

This report provides a summary of the ground water resources of the Greater Green River Basin of Wyoming and a qualitative appraisal of the potential for development of ground water resources. This report was prepared for States West on behalf of the Wyoming Water Development Commission for the Green River Basin Plan. This report specifically addresses the requirements of Sub-Task 3E – Available Ground Water Determination.

Study Objectives

The objective of this study was to gather and summarize information relating to the location, size, quality, and yield potential of ground water aquifers located in the Greater Green River Basin of Wyoming. For purposes of this study, the boundaries of the Greater Green River Basin are as shown in Figure 1, and include the Green River drainage, the Little Snake River drainage, and adjacent areas of internal drainage, such as the Great Divide Basin. In particular, the goals of this sub-task were to investigate the following:

- Location and size of known aquifers;
- Aquifer yield potential;
- Relationships to surface water;
- Water quality.

Study Methods

The work consisted of a review of published literature on the geology and ground water conditions within the study area, inventory of records of wells maintained by the Wyoming State Engineers Office, inventory of records of wells and springs maintained by the U. S. Geological Survey (USGS), and inventory of water quality data maintained by the USGS. GIS datasets and coverages were developed to provide a useful tool for this and later analyses. There were no original investigations undertaken as part of this study. The goals of the study were to provide an overview of the information that is currently available concerning ground water resources, and on the basis of that information, assess the resource in terms of its current state of development and opportunities for future development.

GIS Tool

The following objectives provide the basis for developing a useful GIS groundwater analysis tool:

- Identify and locate existing wells and springs;
- Compile general geological information and aquifer descriptions;
- Plot reported hydrologic unit, yield, and water quality data to analyze spatial relationships, if they exist;
- Obtain and compile geologic map coverage.

The Wyoming State Engineers Office (WSEO) administers permitting and construction of water wells. That office maintains records of wells that have been permitted for construction. The database maintained by the WSEO includes information on well location, well yield (the amount permitted), status of adjudication, and other information relating to permitted use of the water. The WSEO database was queried as part of this investigation.

A second source of information on wells is the U. S. Geological Survey (USGS). The USGS maintains a database known as the Ground Water Site Inventory (GWSI). This database contains information on wells and springs collected by the USGS. Although there is some overlap between the GWSI inventory and the SEO inventory, no attempt has been made to merge, or otherwise reconcile these databases.

Unlike the WSEO database, the USGS database is not limited to water supply wells, but also includes information on exploratory wells, monitoring wells, and springs. The USGS database provides for recording of a broad range of information about a particular well, including geologic formation, water levels, well use, tested yield, elevation, and construction details. In most cases, the records for individual wells and springs are only partially complete, and limited to information on the main attributes of the well or spring (such as location, geologic formation, and use).

The USGS also maintains a database of information on the quality of water obtained from wells and springs. This database is a subset of the USGS's WATSTORE database. This database was queried for information on the quality of ground water in wells and springs.

Information stored in the two USGS databases and the Wyoming State Engineer's water well database pertain to specific geographic points, i.e. well locations. Therefore, their usefulness as a tool for understanding ground water issues can be greatly enhanced by placing them into a GIS format. GIS point coverages were created from both the GWSI databases and the State database showing the locations of the wells and springs. The attributes from the respective databases are assigned to each point in the GIS coverages. Some of the more useful attributes from the GWSI databases include the well yield, well aquifer name where available, well use code (i.e. domestic, irrigation, etc.), and sample results for total dissolved solids (TDS), Fluoride, Iron, Sulfate, Chloride, as well as other constituents where available. An additional database was compiled that provides descriptions of lithologic and aquifer characteristics coinciding with the well aquifer name in the USGS database. It also can be linked to the well coverage in a GIS environment.

Plate 1 is a generalized geologic map of the Greater Green River Basin in Wyoming, and includes correlation diagrams and descriptions of stratigraphic units. It has been clipped and edited from the original digital version developed by Green and Drouillard (1994) which was based on The Geologic Map of Wyoming by Love and Christiansen (1985).

The resulting GIS tool can be used to derive general conclusions concerning potential aquifer yield and likely water quality. Planners can use this tool to identify the aquifers that have been developed in the vicinity of proposed new developments, for example. Furthermore, GIS datasets are readily expandable upon acquisition of new information, yielding an enduring, robust tool. Hence, this GIS tool should be viewed as the beginning of a process always in development, and it is recommended that updates of information from the SEO and USGS, as well as other resources that may be identified, become a routine measure in the basin ground water planning process.

The GIS data is limited however, and provides only preliminary estimates of regional hydrogeologic conditions. A qualified hydrogeologist must still conduct professional investigations in order to determine site specific ground water development potential.

In summary, GIS tools, database analyses, and information from published reports provided the basis for accomplishing this appraisal of ground water resources of the Greater Green River Basin.

Principal Findings

Basin Overview

The Greater Green River Basin lies in the southwestern part of the state. The region is sparsely populated. Major towns include Rock Springs, Green River, Kemmerer, and Pinedale.

The Greater Green River Basin is bounded by the Gros Ventre Mountain Range to the north, the Wind River Mountains to the northeast, the Rawlins uplift to the east, the Wyoming State line to the south, and the mountain ranges of the Overthrust Belt to the west. Elevations range from about 6,000 feet in the basin's central interior to nearly14,000 feet in the Wind River Range. Rainfall varies with elevation, and ranges from less than 8 inches per year on the basin floor to over 50 inches per year in the surrounding mountain ranges.

There has been relatively little development of the ground water resources of the study area. As a result, information on well yield, aquifer properties, water quality, and recharge and discharge relationships is sparse. Well yield and aquifer data has had to be inferred from limited information from the relatively small number of wells.

Basin Structure and Basin Geology

The Greater Green River Basin lies in a structurally complex region. Tectonic forces have produced extensive faulting and folding within the basin, resulting in an estimated 27,000 feet of structural relief on the Precambrian basement rock surface (Keller and Thomaidis, 1971). Geologic formations range from Precambrian-age crystalline rocks to Recent-age alluvial sands and gravels. Plate 1 provides a generalized geologic map of the Greater Green River Basin, along with correlation diagrams, and descriptions of stratigraphic units.

Geologic and ground water conditions within the study area are a direct consequence of the structural geologic setting. Major structural elements within the basin are shown in Figure 1, and include the Darby Thrust Fault, the Moxa Arch, the Rock Springs Uplift, the Rawlins Uplift, and several unnamed structural features (Ahern, et al, 1981; Collentine, et al, 1981)**.**

The westernmost portion of the basin is referred to as the Overthrust Belt. This region is characterized by extensive folding and faulting of the underlying rocks. The extensive folding and faulting has produced a highly complex geologic setting characterized by areas in which sedimentary layers are tilted at steep angles or completely overturned (such that older beds now lie above younger beds), geologic sections are repeated, and rocks are displaced laterally by distances of many miles.

The Rock Springs Uplift (Figure 1) is a north-south oriented, doubly plunging anticline. The folded and uplifted sediments of the Rock Springs Uplift separate the Green River mainstem drainage basin to the west, from the Great Divide and Little Snake drainages to the east. The Rock Springs Uplift exposes progressively older rocks near its axis.

Both the Great Divide and Washakie basins (Figure 1) represent downfolded sediments (synclines), within which progressively younger rocks are exposed near the center of these downfolds. It is estimated that there may be as much as 25,000 feet of sediments overlying Precambrian basement in these basins. The basins' drainage boundaries are formed in part along the upturned edges of these folded sediments. The Rawlins uplift forms a portion of the easternmost boundary of the Greater Green River Basin.

Basin Ground Water Conditions

An aquifer is defined as a formation or group of formations that can yield significant quantities of water to wells or springs. Eight major aquifer *systems* have been identified within the study area. Following the convention of Ahern (1981) an aquifer *system* is used to identify a group of water-bearing units with relatively similar hydrologic properties that are not significantly isolated from one another by regionally extensive low permeability zones. These aquifer systems (or in some cases individual aquifers) are identified by the geologic formation within which they occur. This definition allows for a somewhat simplified presentation of the relatively abundant and complex aquifers that underlie the Greater Green River Basin.

The eight major water-bearing systems are, in *ascending* order:

1. Flathead aquifer;

2. Paleozoic-age aquifer system (including the Madison Limestone);

3. (Sundance-) Nugget aquifer system;

4. Upper Jurassic-Lower Cretaceous age aquifers;

5. Frontier aquifer;

6. Mesaverde-Adaville aquifers;
7. Tertiary-age aquifers;
8. Quaternary-age sands and gravels associated with major river courses through the study area;

The major aquifer systems are also identified in Table 1, a Generalized Hydrostratigraphic Column. Extensive folding and faulting within the basin has resulted in the complex distribution of aquifers seen on the geologic map. (Plate 1). The majority of the study area is underlain by Cretaceous and Tertiary age rocks. These rocks are host to several important aquifers, including the Frontier aquifer (western part of the basin), the Mesaverde aquifer, and the Tertiary aquifer system. The Tertiary aquifer system in turn includes a number of water-bearing formations, including, but not limited to the Bridger Formation, the Green River Formation, and the Wasatch Formation.

The locations of wells and springs identified in the USGS database is represented in Figure 2, and Figure 3 is a graphical representation of the general distribution of primary uses, as permitted in the SEO database. The yields of wells and springs identified in the USGS database are shown on Figure 4, and the hydrologic units identified for USGS database wells are shown on Figure 5. These four figures represent a raw sampling of information available from these GIS datasets.

Basin Ground Water Quality

Water quality data was obtained from a ground water quality database maintained by the U.S. Geological Survey. Data was retrieved for 24 parameters including major cations, major ions, dissolved metals, dissolved solids, pH, and several other parameters that serve as useful indicators of the quality of water. The data obtained for this study contains reports for over 800 analyses obtained from a total of about 600 wells and springs. Wells and springs reporting TDS concentrations of over 10,000 milligrams per liter (mg/L) were excluded from the following statistical reports. For purposes of this resource assessment, water in excess of 10,000 mg/L TDS is assumed to be unusable without significant and costly treatment.

The State of Wyoming has identified standards for different classes of water, as follows:

- Class I ground water is defined as water suitable for domestic use. A partial list of standards for Class I water is contained in Table 2.
- Class II ground water is defined as water suitable for agricultural use where soil conditions and other factors are favorable.
- Class III ground water is defined as water suitable for livestock.
- Class IV ground water is defined as water suitable for industry.
- Class Special (A) ground water is defined as water suitable for fish and aquatic life.

- Class V ground water is defined as ground water found closely associated with commercial deposits of hydrocarbons and/or other minerals, or which is considered a geothermal resource.

- Class VI ground water is defined as ground water which may be unusable or unsuitable for use.

Since agriculture, livestock and domestic and municipal uses are the primary uses in the basin, a comparison was made between water quality measurements for wells in the database and the standards for Classes I through III. This comparison is shown in Table 2.

Table 2.
Comparison of Ground Water Quality with Ground Water Standards

	Water Quality Standards			**Results of Analyses**		
Parameter	**Class I Domestic (mg/L)**	**Class II Agricultural (mg/L)**	**Class III Livestock (mg/L)**	**Number of Wells Sampled**	**Range (mg/L)**	**Mean (mg/L)**
Chloride	250	100	2,000	546	0.1-3,700	72
Iron	0.3	5.0	-	284	0-34	0.33
Sulfate	250	200	3,000	544	0-4,600	363
TDS	500	2,000	5,000	594	70-9,710	982

Notes: TDS (total dissolved solids) estimated by multiplying specific conductance by 0.64 (Hem, 1970).

Domestic water quality standards are exceeded in:

- 25 out of 546 wells tested for chloride (5 percent);

- 20 out of 284 wells tested for iron (7 percent);

- 177 out of 544 wells tested for sulfate (33 percent); and

- 333 out of 594 wells tested for TDS (56 percent).

Agricultural standards are also exceeded for chloride (9 percent), iron (2 percent), sulfate (38 percent), and TDS (11 percent). Livestock standards are exceeded for chloride (<1 percent), sulfate (1 percent), and TDS (2 percent).

TDS is a measure of the total dissolved chemical content and is a general indicator of the suitability of water for various uses. The Federal Drinking Water secondary standard, and the Wyoming Ground Water Standard for TDS in public water systems is 500 milligrams per liter (mg/L). The Wyoming ground water standard for agricultural uses is 2,000 mg/L and for livestock uses 5,000 mg/L. Table 3 lists the U.S. Environmental Protection Agency's recommended guidelines for TDS in irrigation water.

Table 3. Recommended Guidelines for TDS in Irrigation Water

TDS Concentration (mg/L)	Guideline/Effects
<500	Water for which no detrimental effects are usually noticed.
500 – 1,000	Water that can have detrimental effects on sensitive crops.
1,000 – 2,000	Water that can have adverse effects on many crops; requires careful management practices.
2,000 – 5,000	Water that can be used for tolerant plants on permeable soils with careful management practices.

Source: National Academy of Science and Engineering, 1973.

Table 4 shows the most recent TDS sample results from wells completed in various geologic formations within the study area. Values for TDS were in some cases estimated from values reported for electrical conductivity (specific conductance) by multiplying reported conductance by a factor of 0.64 (Hem, 1970).

Table 4. Range of TDS Concentrations for Wells and Springs

Formation	Number of Wells/Springs Reporting	Wells/Springs Within Range Of:				
		<500 mg/L	500 – 1,000 mg/L	1,000 – 2,000 mg/L	>2,000 mg/L	Unknown
Alluvial Aquifers	84	45	19	10	9	1
Bedrock Aquifers	398	159	122	76	44	2
Unknown Aquifers	112	60	29	11	6	6

Source: USGS Ground Water Quality Database

A detailed breakdown of TDS by aquifer is shown in Table 5. The distribution of TDS concentrations within the basin is shown in Figure 6. There are no apparent tendencies in terms of the concentration of TDS by aquifer, nor does there appear to be a conspicuous tendency in the distribution of TDS concentrations across the basin. Water quality likely varies by location within an aquifer, in relation to the depth of a well, and by aquifer.

Table 5. Tabulation of Total Dissolved Solids Concentration by Aquifer (GWSI Database)

			Range of Total Dissolved Solids Concentration				
USGS Code	Aquifer	No of wells	<500	500-1000	1000-2000	>2000	unknown
111ALVM	Holocene Alluvium	60	28	16	7	8	
111EOLN	Eolian Deposits	1	1	0	0	0	
111HLCN	Holocene Series	1	0	0	1	0	
111LDLD	Landslide Deposits	3	3	0	0	0	
111SNDD	Sand Dune Deposits	3	1	0	2	0	
111TRRC	Terrace Deposits	10	7	2	0	1	
112GLCL	Glacial Deposits	5	4	1	0	0	
112TRRC	Terrace Deposits	1	1	0	0	0	
120EXTV	Extrusive Rock	1	1	0	0	0	
120TRTR	Tertiary System	8	6	1	0	1	
121BRPK	Browns Park Formation	4	3	0	0	0	1
121NRPK	North Park Formation	4	4	0	0	0	
121PLCN	Pliocene Series	1	1	0	0	0	
122ARKR	Arikaree Formation	1	1	0	0	0	
122BSHP	Bishop Conglomerate	9	7	2	0	0	
124ANGL	Angelo Member of Green River Formation	1	0	0	0	0	1
124BRDG	Bridger Formation	22	9	5	2	1	5
124BSPG	Battle Springs Formation	10	6	2	0	0	2
124CDBF	Cathedral Bluffs Tongue of Wasatch Formation	11	3	7	0	0	1
124EOCN	Eocene Series	8	0	4	2	1	1
124FSLB	Fossil Butte Member of the Green River Formation	5	5	0	0	0	
124GRRV	Green River Formation	9	0	1	4	3	1
124LNEY	Laney Shale Member of Green River Formation	44	3	14	11	13	3
124NFRK	New Fork Tongue of Wasatch Formation	8	2	3	2	1	
124TPTN	Tipton Shale Member of Green River Formation	18	3	10	3	2	
124WKPK	Wilkins Peak Member of Green River Formation	9	3	2	2	1	1
124WSHK	Washakie Formation	1	0	0	0	1	
124WSTC	Wasatch Formation	118	34	41	31	8	4
125EVNS	Evanston Formation	2	1	1	0	0	
125FRUN	Fort Union Formation	10	0	6	1	3	
211ALMD	Almond Formation	12	5	4	3	0	
211BLDB	Blind Bull Formation	1	1	0	0	0	
211BLIR	Blair Formation	2	1	1	0	0	
211BXTR	Baxter Shale	3	2	1	0	0	
211ERCS	Ericson Sandstone or Formation	5	2	1	1	0	1
211FRNR	Frontier Formation	8	2	4	2	0	
211HLRD	Hilliard Shale or Formation	4	2	1	0	1	
211LWIS	Lewis Shale	4	0	2	1	0	1
211MVRD	Mesaverde Formation or Group	14	5	1	4	3	1
211RKSP	Rock Springs Formation	5	0	0	3	1	1
211STEL	Steele Shale	1	1	0	0	0	
217ASPN	Aspen Shale or Formation	5	2	1	0	1	1
217BRRV	Bear River Formation	3	2	1	0	0	
217GNNT	Gannet Group	4	3	0	0	0	1
224TCRK	Twin Creek Limestone	2	2	0	0	0	
227NGGT	Nugget Sandstone	6	5	0	0	1	
231ANKR	Ankareh Formation	1	0	1	0	0	
237DNDY	Dinwoody Formation	2	2	0	0	0	
237TYNS	Thaynes Limestone	3	3	0	0	0	
311PSPR	Phosphoria Formation	1	0	0	1	0	
317WLLS	Wells Formation	2	2	0	0	0	
331MDSN	Madison Group (Upper and Lower Mississippian)	1	1	0	0	0	
361BGRN	Bighorn Dolomite	3	3	0	0	0	
400PCMB	Precambrian Erathem	1	1	0	0	0	

Existing Ground Water Development

Ground water resources of the basin are largely undeveloped at this time. Ground water is currently used for domestic supply, public supply, industrial uses including mining, and for irrigation. The two principal uses of ground water in the basin are for drinking water supplies and industry. Population in the basin is relatively sparse, and concentrated around the communities of Rock Springs, Green River, Kemmerer, and Pinedale. The majority of the supplies are developed from Quaternary and Tertiary aquifers. Current levels of pumping are difficult to quantify, since there are few direct measurements of pumping or consumption. Current ground water use within the Greater Green River Basin is estimated to be between 5,300 and 7,200 acre feet per year for all uses (Purcell, 2000).

Ground Water Development Potential

The opportunities for developing wells of sufficient capacity for a particular use are highly site dependent. The types of rocks that underlie a specific location vary across the basin. The lithologic and hydrogeologic properties of the formations within the basin also vary spatially, and equivalent geologic units at two locations may have profoundly different potentials for well development. As a result, opportunities for future development of the ground water resources in the Greater Green River Basin vary from favorable to limited, depending on location in the basin. The highest yielding well locations will be found in the Paleozoic aquifers lying on the western margins of the basin in the Overthrust Belt, and in the alluvial aquifers associated with the mainstem and major tributaries of the Green River. In these fairly limited areas, properly located and constructed wells should be capable of yielding from several hundred to over one thousand gallons per minute. However, in most areas of the basin, well yields will vary from several gallons per minute to several hundred gallons per minute depending on the aquifers that underlie the area. Yields of wells completed in the Tertiary aquifer system, the most laterally extensive aquifer system within the basin, are typically in the range of several tens to several hundreds of gallons per minute. There are also some areas of the basin in which well yields are inadequate for all but domestic (household) supplies.

Ground water quality is also highly variable by location and by aquifer. Concentrations of TDS exceed the secondary drinking water standard in over one-half the wells sampled. Concentrations of sulfate exceed the secondary drinking water standards in about one-third of the wells sampled. Although these conditions do not necessarily prevent use of the water, there may be limitations on the types of uses for which this water is suitable. The quality of water at several locations is considered poor, and would require extensive treatment to render it suitable for drinking. There is insufficient data available to assess whether alternate ground water sources of better quality might be available at these locations.

Basin Yield

The "safe" yield of the basin as a whole is herein defined to be the level of ground water development which can be sustained without significant adverse effects on the basin or on wells and springs within the basin. Determination of safe yield requires reliable information on basin inflows, outflows, and basin storage capacity. It also requires that adverse effects be reasonably well defined (e.g. the level of dewatering of an aquifer which is acceptable). There is virtually no information on the overall ground water basin water budget, such that major inflow and outflow components may be quantified. Accordingly, it is difficult to evaluate the basin's safe, long-term yield for purposes of defining future ground water development potential. In the case of the Quaternary-age alluvial aquifers, any future development of ground water resources may be expected to have a direct and near-immediate impact on the adjacent rivers and streams within the alluvial system. Further, evaluating the impacts of development of some of the more isolated and deeply buried aquifer systems, such as the Paleozoic aquifers of the Overthrust Belt is made difficult by a number of factors including: a) the subsurface limits of the aquifers are unknown, b) hydrologic properties are not well understood; c) the interrelationships between the various aquifers and the surface water system are poorly understood.

An indirect estimate of basin yield can be related to the estimated recharge to the ground water basin, assuming that all such recharge could be developed, and that this could be accomplished in a way that causes no unacceptable impacts. Accordingly, basin yield may be estimated as:

Basin Yield = Estimated Recharge = Basin Area x Effective Precipitation,

where effective precipitation is defined as the fraction of precipitation that recharges the ground water system.

The basin has a total area of about 20,000 square miles (12.8 million acres). However, there are large areas of the basin in which potential evapotranspiration (ET) significantly exceeds average rainfall. For purposes of this analysis, it is assumed that recharge is effectively zero in areas where ET significantly exceeds rainfall. In the remaining parts of the basin, mainly the mountain and foothills areas, rainfall exceeds potential (ET). These areas have been mapped (Marston, 1990) and are estimated to have an area of approximately 925,000 acres. The average “surplus” rainfall (where annual rainfall exceeds annual ET) is assumed to be about 6 inches. It is also assumed that approximately 10 percent of the surplus rainfall recharges the ground water system. This approach yields an estimate of about 50,000 acre-feet per year of ground water recharge, and is considered to be an approximation of basin yield. These estimates neglect the potential for interbasin movement of ground water. They also neglect the large quantity of ground water in storage that could potentially be developed without experiencing significant basin-wide impacts.

By comparison, the USGS (Martin, 1996; Glover, et al, 1998) estimates approximately 100,000 acre-feet per year of ground water recharge by precipitation to the Tertiary-age rocks. For planning purposes, it is concluded that basin yield is on the order of between 50,000 and 100,000 acre-feet per year.

Currently, there is no evidence to suggest over-development of the principal aquifer systems. It may be concluded that there is significant potential for additional development of these aquifer systems, with little risk of depleting this resource. However, there are many factors that may affect future development and availability of ground water resources. One such factor is the potential development of ground water associated with the coal bed methane (CBM) extraction industry.

Coal Bed Methane Development

The CBM industry is relatively new, although the technology for the methane extraction process is well established. High quality methane gas is often associated with coal, where the coal exists in a hydraulically confined environment. The methane gas is trapped in micropores within the coal, and maintained in that state by naturally occurring water pressure. The methane gas can be recovered using standard oil and gas field recovery and production technologies. The gas is extracted using wells, which are used to lower the water pressure responsible for trapping the methane gas. As the water pressure is lowered, the methane gas desorbs from the coal, and can be recovered from the well along with the water.

Conditions favorable to CBM development are (DeBruin, Rodney H., et al, 2000):

- Known, thick, abundant, and laterally continuous coal beds;
- Coal-bearing areas with coals of appropriate rank;
- Adequate conditions for accumulation and preservation of coalbed methane;
- Depth to the coal bed, which influences economic and mechanical limits on development; and
- Other evidence such as presence of fracturing and faulting, geothermal gradient, high pressure in the subsurface, and the presence of gas fields producing from known coal-bearing rocks.

Such conditions exist in the Greater Green River Basin. There is direct evidence of methane within coals occurring primarily in the Almond and Wasatch Formations as well as in the Mesaverde Group (See Plate 1 for the locations of these rocks). It is estimated that there are over 3 trillion cubic feet of recoverable gas resources in the Green River coalfield. The Green River is ranked second in the State, behind the Powder River Basin for recoverable gas resources (DeBruin, Rodney H., et al, 2000). Development of CBM resources in the Greater Green River Basin would reduce the ground water resource available for development for other uses, although to date, there has been no commercial CBM development within the Greater Green River Basin (Harju, 2000; Neuman, 2000).

There is a high degree of uncertainty as to the extent to which CBM resources are likely to be developed statewide, as well as within individual basins. The extent to which CBM resources are developed depends on a number of factors, including current and forecasted energy costs, and the economics of the CBM projects. One important factor affecting a project’s economics is the quality of water co-produced in the recovery process. In the Powder River Basin, the quality of water associated with the methane-yielding coals is generally good. This allows for surface discharge of the co-produced water. Development of CBM resources in the Powder River Basin has been significant. As of September of 2000, there are over 3,000 CBM wells (Wyoming Oil and Gas Conservation Commission, 2000). And, although there is a high degree of uncertainty as to the number of wells which are eventually drilled to recover the resource, as many as 30,000 to 40,000 wells may be eventually be constructed for CBM recovery in the Power River Basin (Harju, 2000).

In the Gillette area, in an environmental assessment released in October 1999, the U. S. Bureau of Land Management (BLM) estimated drilling and operation of approximately 3,000 CBM wells over a 17-year project life on Federal leases. The development envisioned up to 16 wells per square mile, based on a 40-acre well spacing. The rate of water production varies over the life of the well, generally declining over time. The USBR estimated an average rate of production of about 12 gpm per well over the project life. Water level declines associated with this level of CBM development are estimated to be over 300 feet in localized areas. Water level declines of at least 5 feet are projected to extend from 15 to 24 miles from the center of the CBM project. (Bureau of Land Management, 1999). These estimates have since been revised, concluding that as many as 5,000 wells may be required (Harju, 2000) illustrating the uncertainty as to level of development which is likely to occur. The BLM assessment does however provide a measure of the level of ground water impacts which may accompany CBM development.

There are significant differences between CBM resources of the Powder River Basin and those of the Greater Green River Basin including the quality of water associated with the coals (Harju, 2000) and limitations of the quality of water which may be discharged to the surface (Harju, 2000; Neuman, 2000). The quality of water associated with the coals is reportedly significantly worse in the Greater Green River Basin than in the Powder River Basin (Harju, 2000). Limitations imposed by interstate compact on the quality of water which is discharged in the Green River may require that the co-produced water be treated or reinjected. The BLM's current policy on federally developed CBM resources in the Greater Green River Basin is that all co-produced water must be re-injected or treated prior to discharge on the surface (Neuman, 2000). The impacts of the added costs of treatment or reinjection are unclear, but may render some CBM projects uneconomical. At this time, it appears unlikely that the level of development of CBM resources in the Greater Green River Basin will match the levels of development anticipated in the Powder River Basin given current market and environmental conditions.

List of Plates, Figures, and Tables

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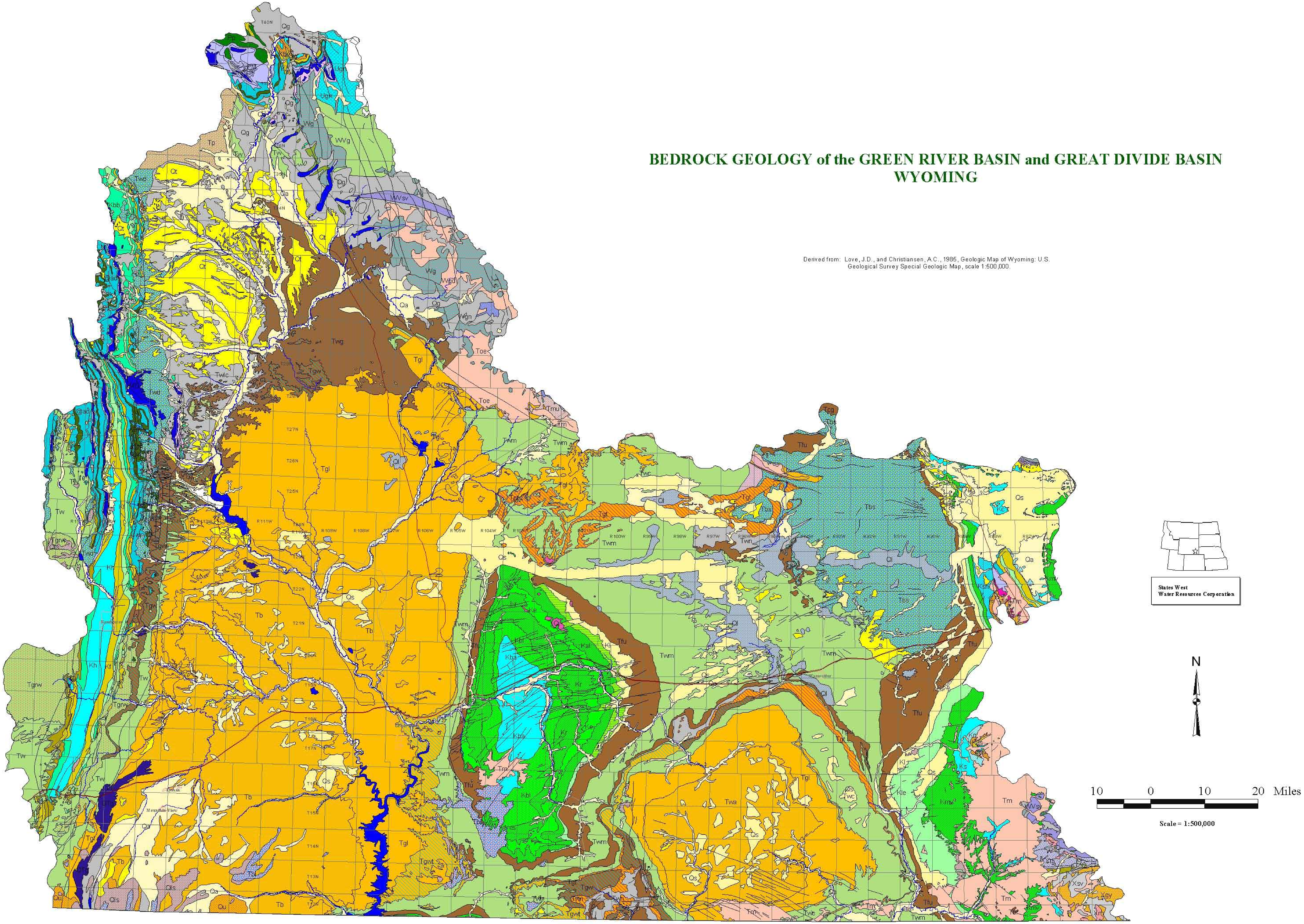
Other Resources

Water Resources Data Systems (WRDS) at The University of Wyoming maintains a web site entitled *"Geohydrologic Expansion of WRDS in the Little Snake River Basin."* This site, developed jointly with the Wyoming State Geological Survey, and in cooperation with the Wyoming State Engineer's Office, the Spatial Data and Visualization Center at the University of Wyoming, the Wyoming Oil & Gas Conservation Commission, and the Institute for Energy Research at the University of Wyoming covers a major portion of the Little Snake River Basin (see outline of project area on Plate 1 Part A) and provides information on generalized basin structure (depths to formations and potential aquifers) at any location, as well as generalized aquifer characteristics and water quality information. Online viewing of State Engineer's Office well completion reports within the study area is also available. Although there are a number of limitations set forth that should be heeded in the use of this web product, it may be considered a useful tool for groundwater exploration in the Little Snake River Basin. The site link may be found at: http://www.wrds.uwyo.edu/

BEDROCK GEOLOGY of the GREEN RIVER BASIN and GREAT DIVIDE BASIN WYOMING

Derived from: Love, J.D., and Christiansen, A.C., 1985, Geologic Map of Wyoming: U.S. Geological Survey Special Geologic Map, scale 1:500,000.



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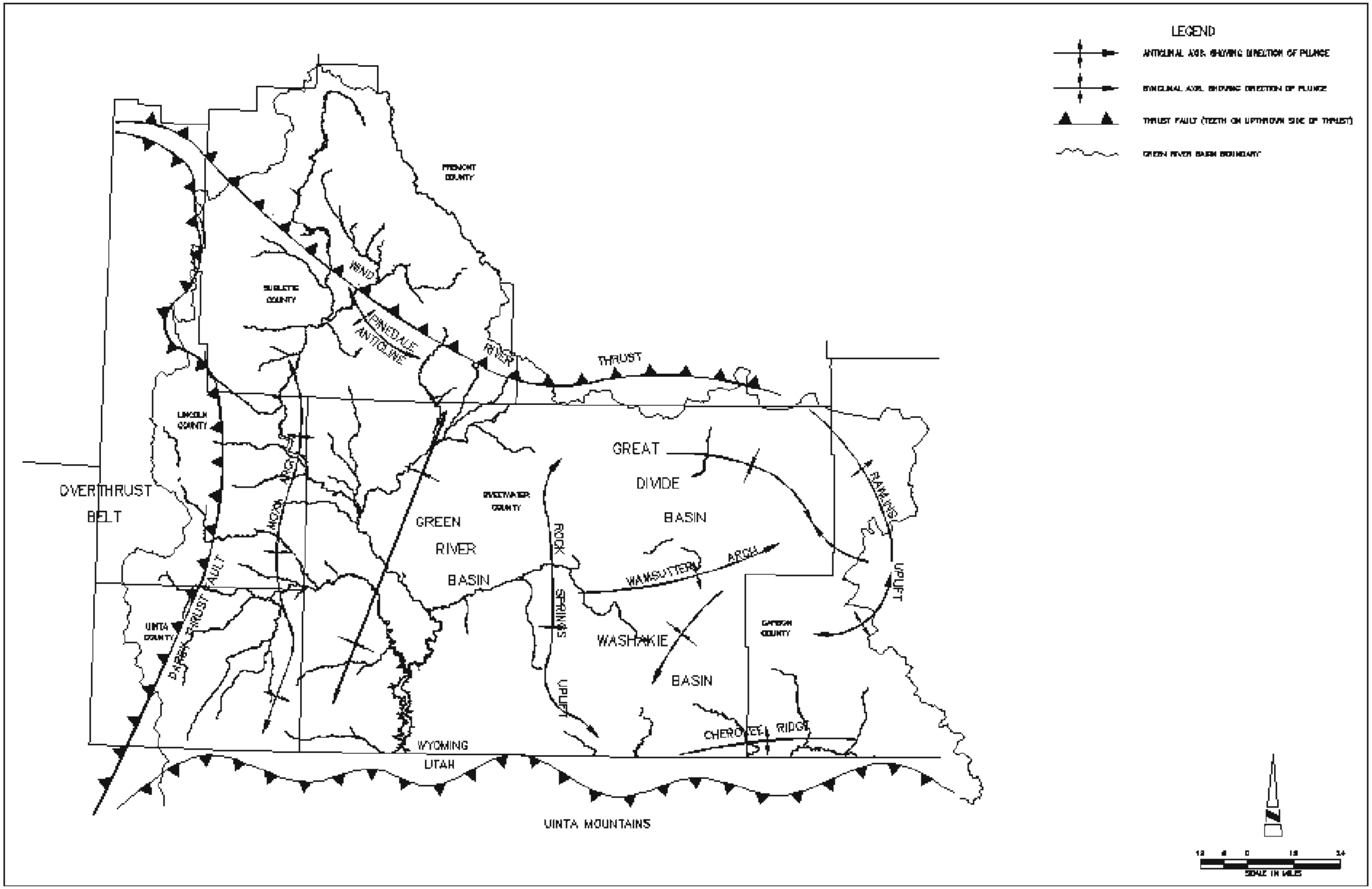
[##] = thickness in feet

^{1}Utah and Northwest Colorado terminology, used in Wyoming only in the subsurface.

Geologic Age	Overthrust Belt	Northwest Green River Basin	South & East Green River Basin	Great Divide, Washakie, and Little Snake River Basins	Hydrologic Unit	Description/Properties
Quaternary	Aluvial, terrace, glacial, landslide dep., slopewash and talus material. [50-410]	Alluvial, terrace, and glacial deposits [0-200]	Alluvial, floodplain, terrace, and glacial deposits [0-100]	Alluvial, dune, lacustrine, and glacial deposits [0-70]	Quaternary Aquifers	Discontinuous, major aquifer
Tertiary	Salt Lake Fm. [0-1000]	Camp Davis/Teewinot Fms. [2250-5200]	South Pass Fm. [0-200]	North Park/South Pass Fms. Browns Park/Bishop Conglomerate [0-1200]	Tertiary Aquifer System	North Park/South Pass is discontinuous, minor aquifer (topographically high and well-drained, predominantly).
		Browns Park/Bishop Conglomerate [~4400]	Browns Park/Bishop Conglomerate [0-200+]			
	Fowkes Fm. [500-2600]	Bridger Fm. [1700-2300]	Bridger Fm. [500-2300]	Bridger/Uinta Fms. [0-3200]		Complex intertonguing fluvial and lacustrine sediments. The Wasatch Formation, the Fowkes/Bridger Formations in the southwest Overthrust and Green River Basins near outcrop, as well as Ft Union in Great Divide, Washakie, and Little Snake Basins are major aquifers. Ft Union elsewhere, Evanston Formation, and Fox Hills SS are minor aquifers.
	Green River Fm. [400-600]		Green River Fm. (Wasatch-Cathedral Bluffs) [100-2800]	Green River Fm. (Interfingers with Wasatch) [0-1500]		
	Wasatch Fm. [2500-3600]	Wasatch Fm. [4100-5250]	Wasatch Fm. (Main Body) [0-7000]	Wasatch (South & West)/Battle Springs (Northeast) Fms. [0-4700]		
	Evanston Fm. [1350-2900]	Hoback Fm. [8000-18500]	Ft Union Fm. [0-2700]			
Upper Cretaceous		Harebell Fm.	Lance Fm./Fox Hills SS [0-4900]			
	Meeteetse Fm.		Lewis Shale [0-2700]		Aquitard	
		Mesaverde Fm.	Almond [0-1000] Mesaverde Group	Mesaverde Fm. [0-5600]	Mesaverde Aquifer	Major aquifer: Rock Springs and Ericson formations are the most permeable units, as is the basal member of the Adaville Formation (Lazeart Sandstone).
			Ericson SS [400-700]			
			Rock Springs [900-1700]			
	Adaville Fm. [1400-5000]		Blair [900-1800]			
	Hilliard Shale [3000-6800]	Baxter Shale [2700-4500]		Cody Shale (Great Divide)/Baxter Shale (West)/Steele Shale & Niobrara Fm. (East) [2000-5000]	Aquitard (Recent, unpublished work by the Wyoming State Geological Survey suggest the possibility that a number of wells yield a reasonable water supply from portions of the Hilliard Shale).	
	Frontier Fm. [1100-3000]	Frontier Fm. [1800-2700]		Frontier Fm. [190-900]	Frontier Aquifer	Minor aquifer, greatest potential in Overthrust Belt and Western Green River Basin.
Lower Cretaceous	Aspen Shale [400-2200]		Mowry/Muddy/Thermopolis Fms. [100-1000]	Mowry/Muddy/Thermopolis Fms. [200-900]	Aquitard	
	Bear River Fm. [800-1500]				Upper Jurassic-Lower Cretaceous Aquifers	Discontinuous, minor aquifer; Cloverly major aquifer (esp. sandstones & conglomerates of lower member) near recharge area in Great Divide & Washakie Basin.
	Gannett Group "Lakota Conglomerate" [800-5000]	Cloverly Fm. "Dakota Sandstone"		Cloverly Fm. "Dakota Sandstone," "Lakota Conglomerate" [45-240]		
Jurassic		Morrison Fm. [170-450+]			Aquitard	
	Stump-Preuss Fms. [160-530]	Curtis Fm./Entrada SS [35-530]		Sundance Fm. [130-450+]	(Sundance-) Nugget Aquifer System	Nugget Sandstone is the major aquifer throughout the area, although the Nugget is absent in the far southeast. The lower part of the Twin Creek Limestone, and the Thaynes Limestone are minor, regional aquifers in the Overthrust Belt.
	Twin Creek LS [150-725]	Gypsum Spring Fm. [0-725]				
	Nugget SS [750-1300]	Nugget SS [400-700]		Nugget SS (absent SE) [0-650+]		
Triassic	Ankareh Fm. [330-500]	Chugwater [900-1500]		Chugwater Group [900-1500]		
	Thaynes LS [0-500]					
Lower Triassic	Woodside Shale/Dinwoody Fm. [600-1300]	Dinwoody Fm. [250-450]		Dinwoody/Phosphoria Fms. (Goose Egg Fm.) [170-460]	Aquitard	
Permian	Phosphoria Fm. [200-400]				Paleozoic Aquifer System	Major aquifers are the Bighorn Dolomite, Darby Formation, Madison Limestone, Tensleep Sandstone, and Phosphoria Formation. These are primarily carbonate, so significant yields occur where there are solution openings and fractures, especially in the Madison with its well-developed paleokarst. The Amsden and Phosphoria are locally confining, minor aquifers.
Pennsyl-vanian	Wells Fm. [450-1800]	Tensleep SS [350-700]	Weber SS/Morgan Fm./Round Valley LS [650-1300]^1	Tensleep SS [0-840]		
Mississip-pian	Amsden Fm. [300-700]			Amsden Fm. [0-260]		
	Madison LS, Darby Fm., Bighorn Dolomite [780-1800]		Madison LS, Darby Fm. [650-1300]	Madison LS [5-325]		
Devonian						
Ordovician						
Cambrian	Gallatin LS [0-200]			Undifferentiated Cambrian/Flathead SS [0-800]		
	Gros Ventre Fm. [500-1000]				Aquitard	
	Flathead SS [175-200]				Flathead Aquifer	May be good source to exploit due to characteristic permeable sandstone, basal conglomerate and secondary permeability along bedding plane partings in outcrop and where the rocks are highly fractured.
Pre-cambrian	Precambrian Rocks					Minor aquifer where highly fractured and weathered in outcrop, or near the surface.

Table 1 - Generalized Hydrostratigaphic Column of the Greater Green River Basin, Wyoming

Modified from Ahern, et al, 1981, Collentine, et al, 1981, and Love, et al, 1993.



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BASIN BOUNDARIES AND MAJOR STRUCTURAL ELEMENTS
OF THE GREATER GREEN RIVER BASIN

FIGURE 1

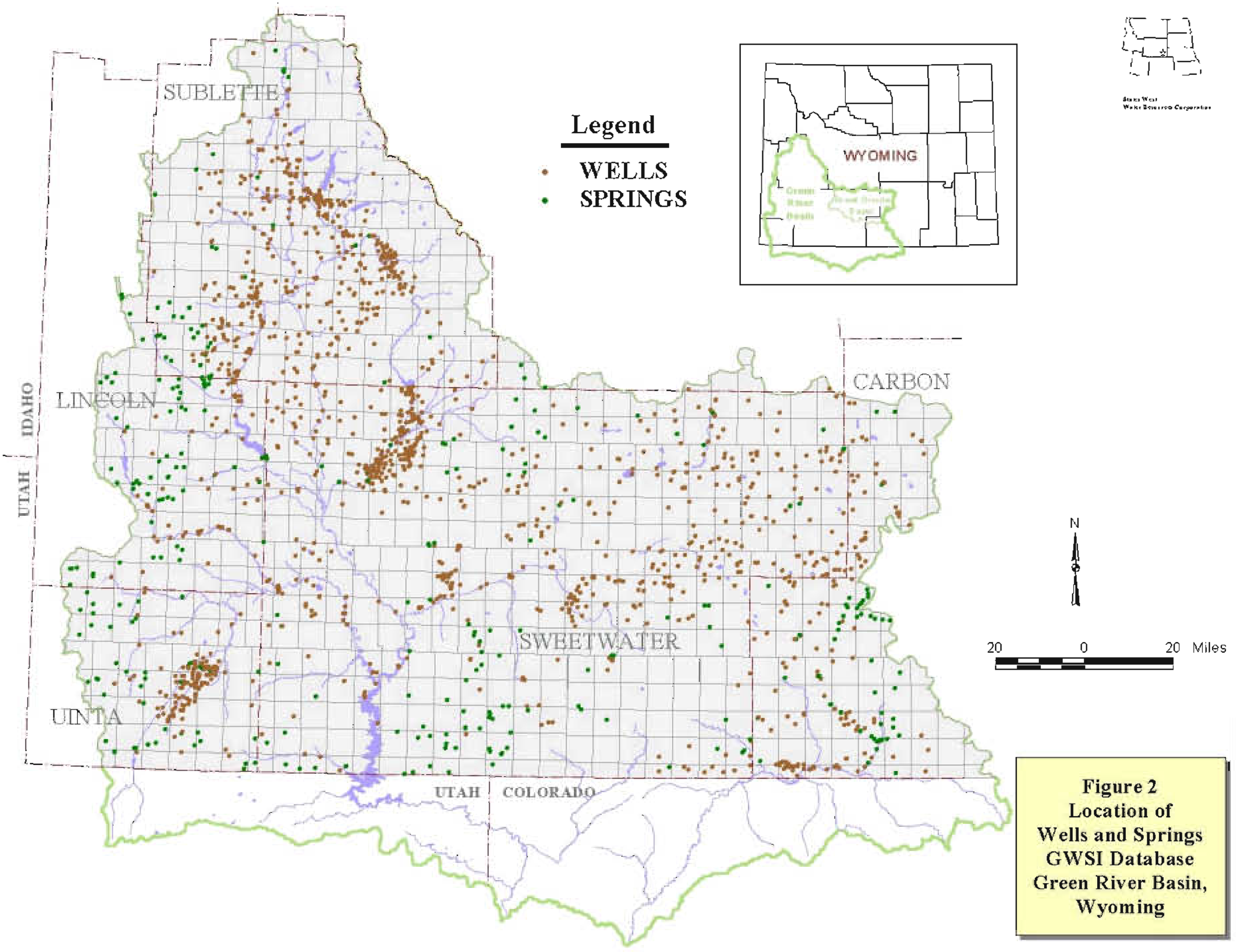

Figure 2
Location of
Wells and Springs
GWSI Database
Green River Basin,
Wyoming

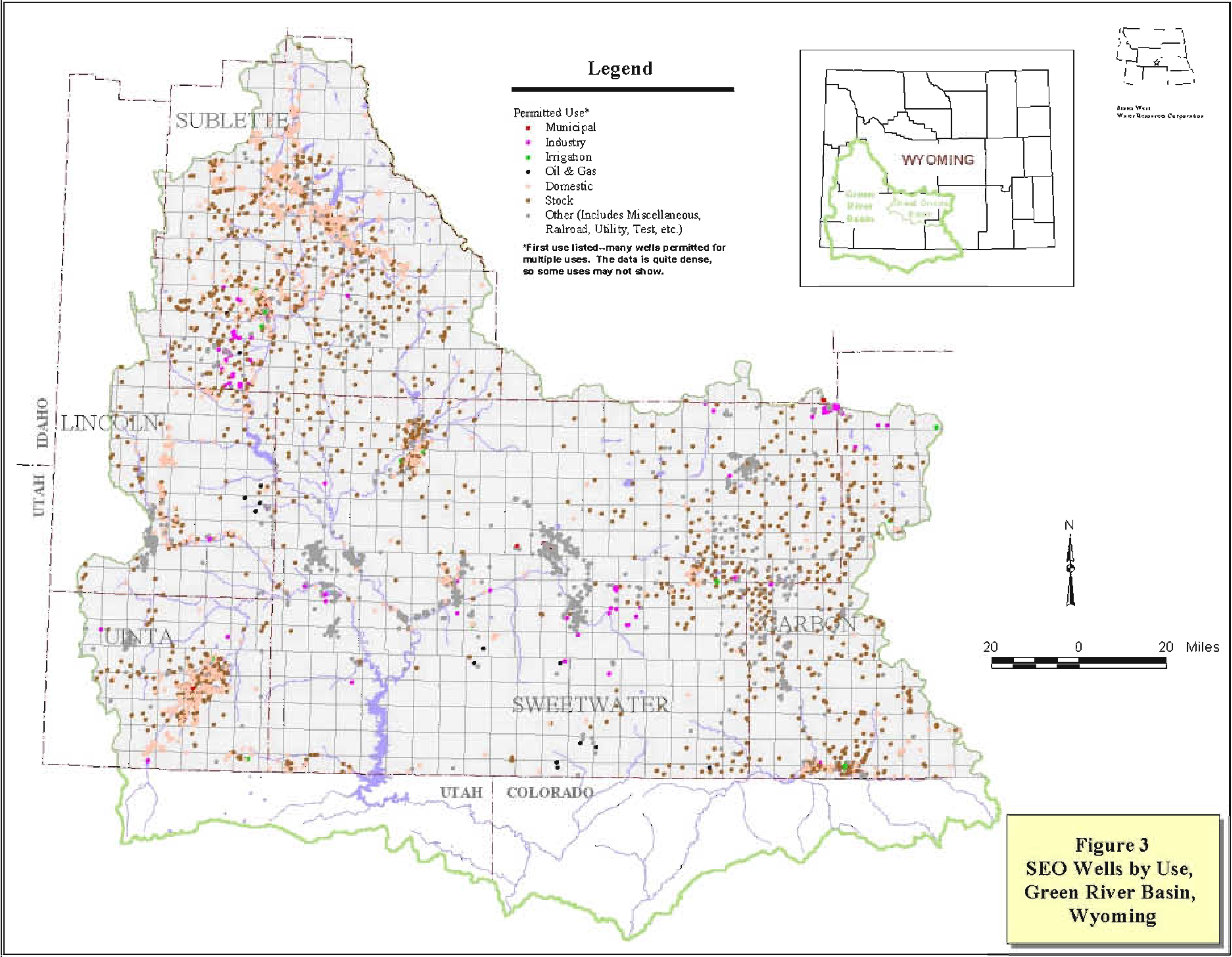

Figure 3
SEO Wells by Use,
Green River Basin,
Wyoming

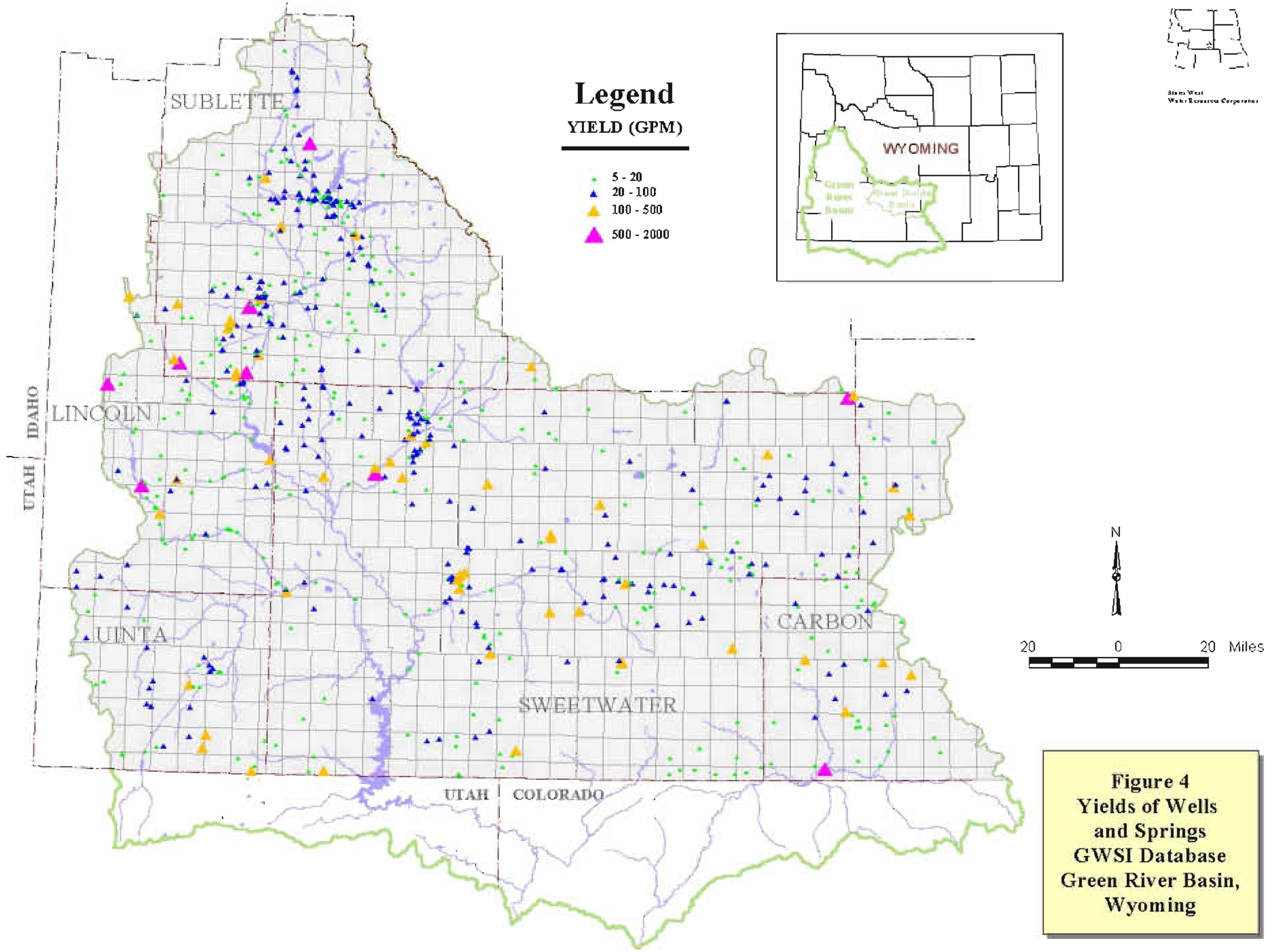

Figure 4
Yields of Wells
and Springs
GWSI Database
Green River Basin,
Wyoming

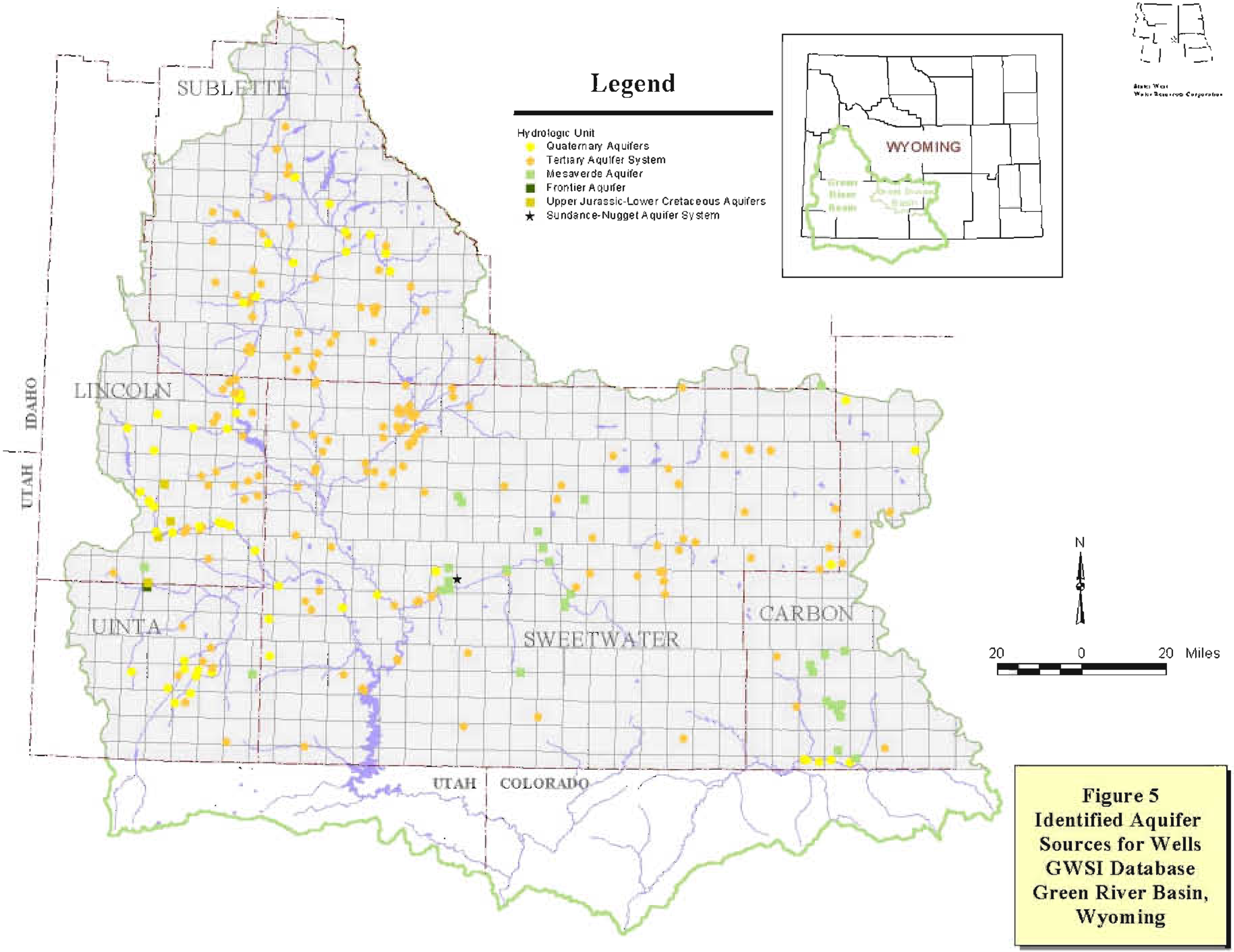

Figure 5
Identified Aquifer Sources for Wells GWSI Database Green River Basin, Wyoming

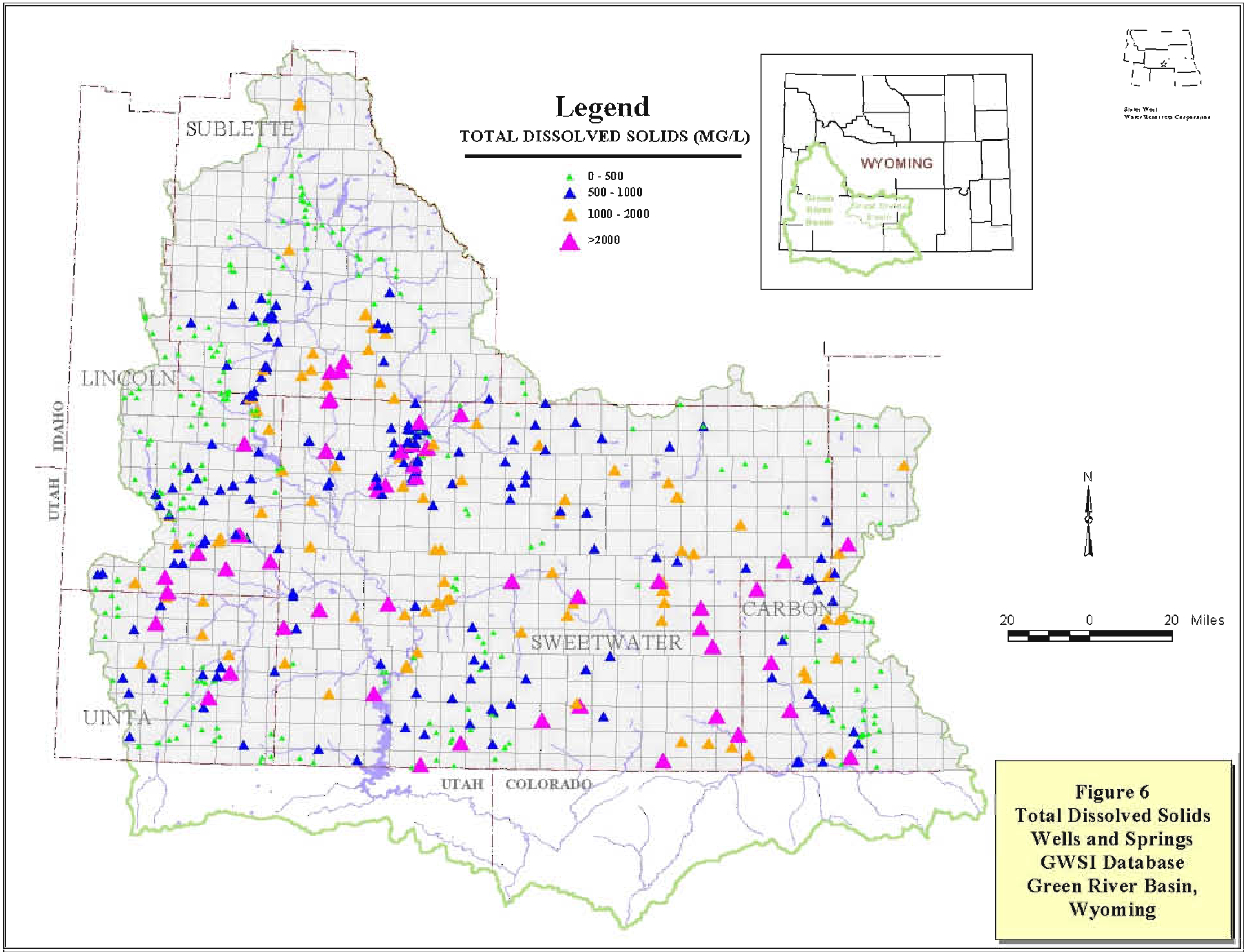

Figure 6
Total Dissolved Solids
Wells and Springs
GWSI Database
Green River Basin,
Wyoming