Snake/Salt River Basin Water Plan Update
Groundwater Study Level I (2011 - 2014)
Available Groundwater Determination
Technical Memorandum No. 7

Executive Summary

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INTRODUCTION

Between 2001 and 2006 the Wyoming Water Development Commission (WWDC) completed individual water plans for each of Wyoming's seven major river basins. Technical Memorandum S of the previous Snake/Salt River Basin Water Plan (Sunrise Engineering and others, 2003) contains a groundwater resource investigation that thoroughly examines the basin's resources and usage. The 2014 Available Groundwater Determination presented in this report updates and expands the previous technical memorandum with a new compilation of information and represents the most current assessment of the groundwater resources of the Snake/Salt River Basin. This technical memorandum has the following objectives:

- Identify the major (most widely used) aquifers in the Snake/Salt River Basin.
- Define the three-dimensional extent of the aquifers.
- Describe the physical characteristics, water chemistry, and potential contaminants of the aquifers and confining (hydrogeologic) units.
- Estimate the quantity of water in the aquifers.
- Describe the aquifer recharge areas.
- Estimate aquifer recharge rates.
- Estimate the "safe yield" potential of the aquifers and describe implications of hydrologically connected groundwater and surface water.
- Describe and evaluate existing groundwater studies and models.
- Identify future groundwater development opportunities to satisfy projected agricultural, municipal, and industrial demands.

SNAKE/SALT RIVER BASIN DESCRIPTION

This report examines groundwater resources that underlie the Snake/Salt River drainage basin in Wyoming as well as areas in Idaho that are tributary to the Wyoming part of this basin.

The Snake River is the major tributary to the Columbia River. The mainstem of the Snake River begins at the confluence of three small headstreams on the southwestern flank of Two Oceans Plateau in Yellowstone National Park. Primary tributaries that confluence with the Snake River in Wyoming include Buffalo Fork, Gros Ventre, Hoback, and Greys rivers. The headwaters of the Salt River flow from the slopes below Mount Wagner in the southern Salt Creek Range located in central Lincoln County. The Salt River confluences with the Snake River in Palisades Reservoir near Alpine, Wyoming.

The Snake/Salt River Basin in Wyoming covers approximately 5,113 square miles (3.27 million acres), or 5.2 percent of Wyoming's surface area. The tributary watershed in southeastern Idaho is small, about 432 square miles (0.28 million acres). In Wyoming, the Snake/Salt River Basin includes 81 percent of Teton, 28 percent of Lincoln, 8.5 percent of Sublette, and 1.7 percent of Fremont counties. In Idaho, the tributary watershed covers 4.5 percent of Bonneville, 18.3 percent of Caribou, 0.9 percent of Fremont, and 0.12 percent of Teton counties.

The Snake/Salt River Basin serves as home to approximately 34,500 people or about 6.0 percent of the state's current population (WDAIEAD, 2014). The basin contains five incorporated municipalities (Jackson, Afton, Star Valley Ranch, Alpine, and Thayne), 21 U.S. Census Designated Places (CDP), and a substantial rural population.

The landscape (**fig. 1**) of the Snake/Salt River Basin consists of deeply eroded landforms superimposed on the Overthrust Belt in the south, the Absaroka and Yellowstone Plateau volcanic systems to the north, Laramide and subsequent uplift structures to the north, and east and Basin and Range Province structures to the west. The landscape consists of several mountain ranges of the middle Rocky Mountains, valleys, rolling plains, plateaus, escarpments, bluffs, hills, drainage ways, and structural basins. Elevations in the Snake Salt River Basin in Wyoming range from 5,623 feet above mean sea level, where the Snake and Salt rivers enter the headwaters of Palisades Reservoir, to 13,779 feet at the summit of the Grand Teton.

Climate types in the basin range from semi-arid continental within the basin interior, to humid-alpine in the bordering mountains. The mountain ranges capture much of the atmospheric moisture through orographic uplift, increasing annual precipitation in the mountainous regions while substantially decreasing precipitation in the basin interiors. Air temperatures vary by season from below -50°F in the winter, to more than 100°F in the summer. Annual precipitation increases with surface elevation (**fig. 3-3, main report**) and can exceed 95 inches a year in the high mountain headwater areas of the Tetons; average annual precipitation for the entire basin is 33 inches (PRISM, 2013). Most precipitation within the basin occurs as snowfall during the winter and early spring and as convective thunderstorms during the late spring and summer months (Ahern and others, 1981).

Land use in the Snake/Salt River Basin is controlled primarily by elevation, climate, precipitation, and land ownership. Above timberline, the alpine lands are generally used for recreational purposes. At lower elevations, thickly forested areas are utilized for recreation and limited logging. Grazing is the dominant use for rangelands, foothills, and riparian areas. Agriculture plays a significant role in the basin; approximately 3 percent (99,071 acres) of the basin's surface area consists of irrigated cropland (Sunrise Engineering and others, 2003).

Approximately 90 percent of the land area of the Snake/Salt River Basin is federally owned. In general, federal land in the basin is managed by the U.S. Forest Service (~2.26 million acres), the National Park Service (655,521acres), and the Bureau of Land Management (8,056 acres). Privately owned lands, concentrated along rivers and streams, constitute about 7.8 percent of the land in the basin; 0.4 percent is owned by the state of Wyoming; and less than 2 percent is owned or managed by other entities. A map of state, federal, and private land ownership in Wyoming is available online via the Wyoming Water Development Office's 2007 Statewide Water Plan Online Presentation Tool:
http://waterplan.wrds.uwyo.edu/fwp/figures/pdf/Fig3-2_3-3.pdf.

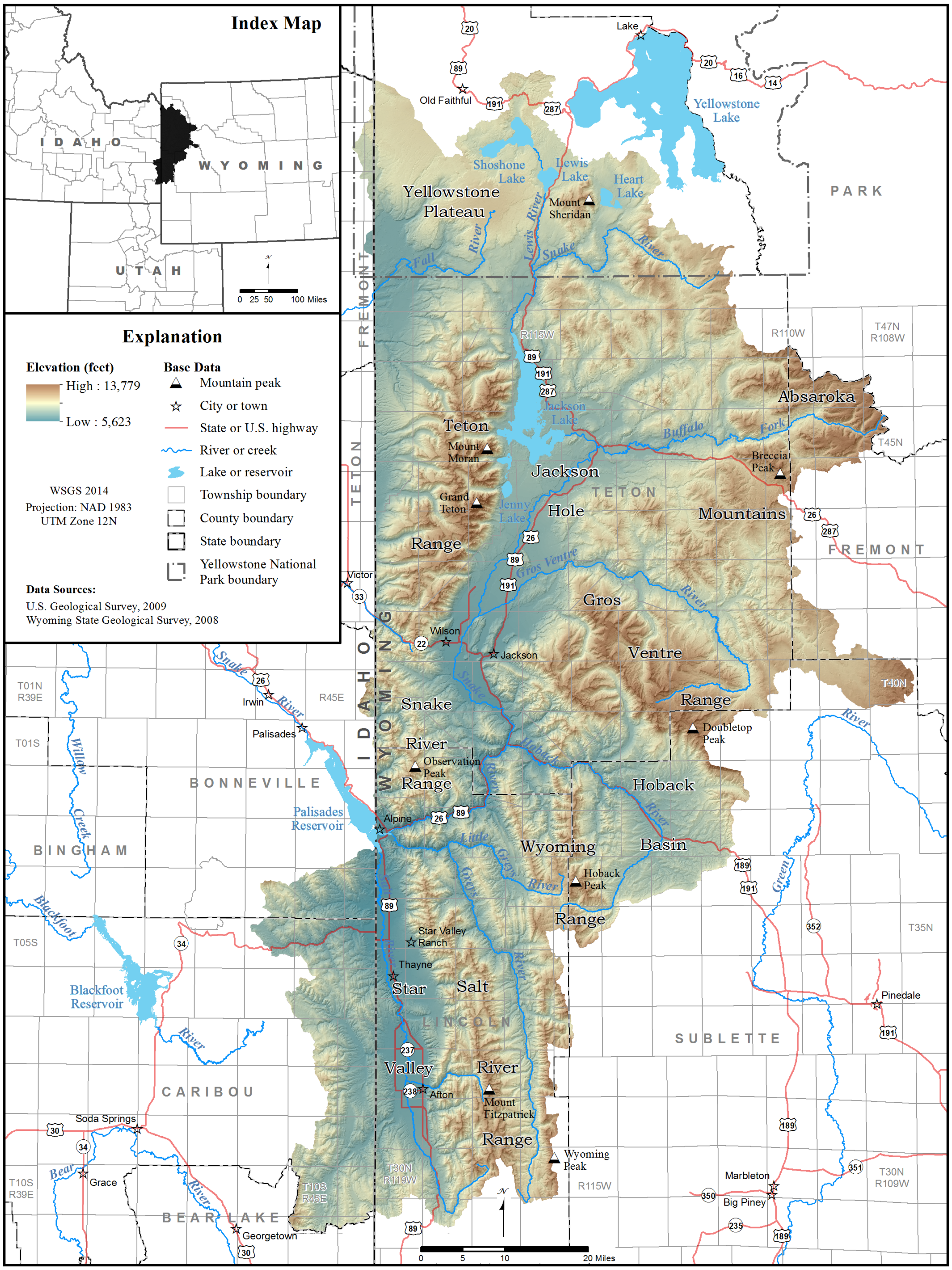

Figure 1. Physiographic features, drainages, and bodies of water, Snake/Salt River Basin.

SNAKE/SALT RIVER BASIN GEOLOGY

The Snake/Salt River Basin encompasses three characteristic structural provinces: 1) continental shelf deposits, which include the Teton and Gros Ventre ranges; 2) west of the shelf zone, structurally deformed passive margin Paleozoic and Mesozoic units that include the Wyoming, Salt and Snake River ranges (i.e., the Overthrust Belt); and 3) the volcanism of the Yellowstone Plateau and Absaroka Province. The dominant structural features that form the backbone of the Teton and Gros Ventre ranges consist of basement core, broad, asymmetrical anticlines, northeast dipping thrust faults, and parallel folds. The initial stages of forming Teton and Gros Ventre structures were concurrent with the early phases of the Laramide deformation. These major structures controlled the character and trend of the later, Snake, and Salt River structures in Wyoming. The structural architecture of the Salt River and Snake River Ranges are also the result of the Sevier "thin-skinned" deformation. The Overthrust Belt located in southwestern Wyoming and neighboring areas of Idaho and Utah, is a north-south trending, elongate fold and thrust belt that encompasses structurally deformed Paleozoic and Mesozoic units. The complex structural deformation in this region includes folding, imbricated thrust faults, and reverse faulting. During the Sevier Orogeny, thrust sheets were pushed eastward, resulting in the formation of parallel thrust faults with the younger thrust belts to the east.

Beginning in the Tertiary and continuing to the present day, some Laramide and Sevier structural features have been overprinted or transected by north-south trending, high-angle normal faults due to Neogene Basin and Range extension. Normal faults are coincident with north-northwest trending folds and thrust fault bounded uplifts that define a complex set of half-grabens. Holocene-age displacement is apparent on some of the normal faults.

The topography of the Snake/Salt River Basin is reflected by major structural features that uplifted, folded, faulted, and eroded Precambrian basement and Phanerozoic sedimentary and volcanic deposits. The insert map in **plate 1** (main report) is a structural contour map of the Precambrian basement surface in the Snake/Salt River Basin that shows a general northwest-southeast lineament trend. The geologic cross-sections in **figures 4-2** through **4-7** (main report) show Precambrian basement rocks overlain by varying thicknesses of Phanerozoic formations, all deformed by large-scale folding and faulting.

The major structural elements of the Snake/Salt River Basin (**fig. 4-1, main report**) comprise:

- Multiple phases of folding and faulting that involved Precambrian basement rocks,
- Folding and faulting of the Overthrust Belt during the Sevier Orogeny,
- Extension of the Basin and Range Province,
- Volcanism that created the Yellowstone Plateau and the Absaroka Range,
- Uplifted mountain ranges that surround and separate the basins, including the Gros Ventre, Teton, Wyoming, Salt River and Snake River mountains. And Subsidence of structural basins including Jackson Hole, Hoback Basin, and Star Valley.

Mineral resources

There have been no significant quantities of oil and natural gas developed in the Snake/Salt River Basin. Wyoming Oil and Gas Conservation Commission (WOGCC) records indicate that the three gas fields shown in **fig. 5-4** (main report) contained only exploratory wells that never produced economically recoverable amounts of oil or natural gas and were subsequently plugged and abandoned.

Mapped coal, sand, and gravel mines consist predominantly of historic pit mines. A single, historic phosphate mine is located near Afton and a single uranium mine is located in the Absaroka Mountains near the Gros Ventre River. A historical metal mine is sited on the western flanks of the northern Teton Range.

Currently, there is no active coal mining in the Snake/Salt River Basin. Sand, gravel, and limestone have been extensively mined within the Snake/Salt River Basin, and continue to be produced in some localities.

BASIN HYDROGEOLOGY

Groundwater circulation, availability, and development

The following sections discuss groundwater circulation in Quaternary, Thrust Belt, Laramide structural, and volcanic aquifers.

In terms of the volume of water withdrawn and the number of wells permitted, the most widely used aquifer system in the Snake/Salt River Basin is the Quaternary alluvial aquifer that lies along the Snake and Salt rivers and their tributaries (Sunrise Engineering and others, 2003). Nearly all of the basin's irrigation wells, as well as most of the wells permitted for livestock, municipal, and domestic uses are located within the Quaternary system. Nolan and Miller (1995) report that the alluvial aquifer system is recharged primarily by direct infiltration of precipitation, discharge from bedrock aquifers, recharge from irrigation, and infiltration of streamflows in losing reaches of headwater streams. Evapotranspiration, groundwater discharges into surface water flows, and withdrawals from wells constitute the principal forms of aquifer discharge. Groundwater flows within this system generally follow the topography of the watershed drainages, that is, toward or parallel to the channels of the Snake/Salt River and its tributary streams (Nolan and Miller, 1995).

In the Thrust Belt, Tertiary, Mesozoic, and Paleozoic bedrock aquifers are exposed on the flanks of the mountain ranges that border the Salt River. The Tertiary aquifer group is extensively utilized and includes the Salt Lake, Wasatch, and Evanston aquifers. Ahern and others (1981) note that groundwater circulation in these aquifers is primarily controlled by local topography and that artesian discharge is common only along stream drainages. Recharge to these aquifers consists of infiltration of rainfall and snowmelt and streamflow seepage in ephemeral streambed reaches. Natural discharge occurs primarily at gravity-driven springs and seeps and as direct flows into alluvial sediments. Ahern and others (1981) noted that groundwater circulation in highly fractured, Mesozoic and Paleozoic aquifers is heavily controlled by faults and fracture sets especially in the Salt River drainage, where numerous north-south parallel systems of reverse and normal faults occur typically in relatively close proximity to one another.

Extensive volcanic exposures are found in the portion of the Snake/Salt River Basin confined within the boundaries of Yellowstone National Park, in northeastern and northwestern Teton County, and in northwestern Fremont County. With the exception of northwestern Teton County, few wells are completed in volcanic aquifers because most volcanic units outcrop within wilderness areas. Cox (1973) noted that brecciated zones at the contacts of individual extrusive flows, heavily fractured units, and volcanic rocks with high levels of well-connected vesicular porosity, exhibit the most vigorous groundwater circulation and are capable of discharging “a few tens of gallons per minute.” Wells and springs in volcanic aquifers that lack these features generally yield “only a few gallons per minute.” Natural recharge to volcanic aquifers consists of infiltration by precipitation and snowmelt, streamflow seepage in ephemeral streambed reaches, and inflows from adjacent aquifers. Natural discharges occur at gravity driven springs and seeps and as direct flows into alluvial sediments.

The Gros Ventre Range and the Jackson Basin are Laramide geologic structures. Few wells are sited in Laramide aquifers, however, due to the ready availability of groundwater in alluvial aquifers. Groundwater circulation in Laramide geologic structures is controlled by large-displacement thrust faults, reverse-fault-cored anticlines and associated fractures (Huntoon, 1993). Groundwater circulation is not only controlled by the Laramide structures, but also alters the hydrogeology of them where circulation has enhanced permeability through the development of karst along pre-existing fractures and bedding planes. Natural recharge to Laramide aquifers consists of direct infiltration of precipitation and snowmelt, streamflow seepage in streambed reaches, and inflows from adjacent aquifers. Natural discharges occur at gravity driven springs and seeps, and as direct flows into alluvial sediments.

The conceptual models of groundwater circulation, described above have been utilized in groundwater development projects throughout the Snake/Salt River Basin. **Appendix B** lists Wyoming Water Development projects that have implemented for this exploration model.

The Wyoming Statewide Framework Water Plan (WWC Engineering, Inc. and others, 2007) classified the Snake/Salt River Basin geologic units as follows:

Major Aquifer – Alluvial - Quaternary alluvium

Major Aquifer – Sandstone – Teewinot and Salt Lake formations; Nugget Sandstone

Major Aquifer – Limestone - Tensleep Formation; Madison Group; Bighorn Dolomite

Minor Aquifer - Quaternary non-alluvial deposits; Twin Creek and Thaynes limestones; Frontier and Phosphoria formations

Marginal Aquifer - Volcanic rocks, Camp Davis, Colter, Sohare, Harebell and Hoback formations; Woodside Shale; Dinwoody Formation

Major Aquitard (Confining Unit) - Cody Shale, Niobrara Formation, Steele Shale, and Baxter Shale; Precambrian rocks

Natural groundwater quality and hydrogeochemistry

For this report, groundwater-quality data were gathered from the U.S. Geological Survey (USGS) National Water Information System (NWIS) database (USGS, 2012), the USGS Produced Waters Database (PWD) (USGS, 2010), the WOGCC database (WOGCC, 2013), the University of Wyoming Water Resources Data System (WRDS) database, and other sources such as consultant reports prepared in relation to development of public water supplies.

Groundwater quality in the Snake/Salt River Basin varies widely, even within a single hydrogeologic unit. Water quality in any given hydrogeologic unit tends to be better near outcrop areas where recharge occurs, and tends to deteriorate as the distance from these areas increases (and residence time increases). Correspondingly, the water quality in a given hydrogeologic unit generally deteriorates with depth.

This report contains statistical analyses and trilinear diagrams of groundwater quality for numerous "environmental water" samples and for two "produced water" samples. Environmental water samples are from wells of all types except those used for resource extraction (primarily oil and gas production) or those used to monitor areas with known groundwater contamination. Produced-water samples are from wells related to natural resource exploration and extraction (primarily oil and gas production). Physical characteristics, major-ion chemistry, nutrients, trace elements, and radiochemicals are summarized for both environmental and produced waters in **appendices E** and **F** of the main report.

Aquifer sensitivity and potential sources of groundwater contamination

This report uses Geographic Information Systems (GIS) analysis of aquifer sensitivity (Hamerlinck and Arneson, 1998) to evaluate potential contamination threats to groundwater resources in the Snake/Salt River Basin. Potential contaminant sites were identified from Wyoming environmental regulatory agency databases and include facilities that handle substantial volumes of substances that if released to the environment could migrate to the water table. These facilities are generally located in and near municipal, manufacturing, and mineral resource areas in the basin.

Estimated recharge in the Snake/Salt River Basin

The hydrogeologic units in the Snake/Salt River Basin range in geologic age from Quaternary to Precambrian, and are variably permeable. The basin's complex geology does not permit the use of the general assumptions regarding aquifer geometry, saturated thickness and hydraulic properties commonly employed by hydrogeologists in other settings that would be required to calculate a plausible estimate of total and producible groundwater resources. In this report, groundwater resources are evaluated by using previous GIS based estimates of average annual recharge (Hamerlinck and Arneson, 1998) to the outcrop zones of the basin's identified aquifers. Aquifer recharge zones, based on geologic age were generated as GIS shapefiles; these are: 1) Quaternary, 2) Tertiary, 3) Mesozoic, 4) Paleozoic 5) Precambrian, and 6) volcanic aquifers. Total recharge volume for each aquifer recharge zone was calculated as the cell-by-cell product of the surface area within each aquifer recharge zone by the estimated average annual recharge.

Total average annual precipitation in the Wyoming portion of the Snake/Salt River Basin for the 1981-2010 period of record was estimated as 9,137,284 acre-feet; the best estimate of average annual recharge to Wyoming's Snake/Salt River Basin's sedimentary aquifers is 2,247,974 acre-feet per year.

GROUNDWATER USES AND BASIN-WIDE WATER BALANCE

Chapter 8 contains a discussion of current groundwater uses in the Snake/Salt River Basin. Seven maps (**figs. 8-1** through **8-7, main report**) were prepared for this study to illustrate the geospatial distribution of groundwater permits according to use in the Snake/Salt River Basin. Only permits for wells that were likely to have been drilled (including abandoned wells) are included on the maps. Figures are provided for irrigation, stock watering, municipal, domestic, industrial, monitoring, and miscellaneous permits. Groundwater permits are mapped relative to their date of issue (before or after January 1, 2003) and by total well depths on basin scale maps. The figures indicate the following trends for groundwater permits by use:

- Most **irrigation** permits appropriate water from wells located near the Snake and Salt rivers, likely targeting alluvial deposits adjacent to the river.
- **Livestock wells** are generally located in close proximity to the Snake and Salt rivers and other surface drainages.
- **Municipal wells** are located within or close to the municipalities that they supply and produce water from both bedrock and alluvial aquifers.
- Most **domestic wells** are located in rural areas, generally outlying population centers along surface drainages. Most wells are completed in Quaternary and Tertiary geologic units; however, domestic-use wells have also been permitted over a wide range of depths within virtually all hydrogeologic units, including confining units.
- The few **Industrial wells** are generally sited at light industries located near population centers.
- **Monitoring wells** are generally located near population centers, areas with industrial facilities, and along rivers and other large surface drainages, where facilities that require groundwater monitoring are concentrated.
- **Miscellaneous-use** and **test wells** are located near population centers, in mineral development areas, rural areas, and generally along rivers and larger surface drainages.

Chapter 8 (**table 8-2a, main report**) also contains a basin-wide water balance based on the mass balance equation:

Evapotranspiration = (precipitation + surface inflow + imported water + groundwater inflow) – (surface water outflow + groundwater outflow + reservoir evaporation + exported water + recharge) ± changes in surface water storage ± changes in groundwater storage.

For this analysis, geospatial precipitation data was obtained from PRISM Climate Group (PRISM, 2013) for the Snake/Salt River Basin. The USGS Daily Streamflow website, http://waterdata.usgs.gov/nwis/rt, was accessed for surface water outflow data. Consumptive use estimates for irrigation and stock watering, industry, municipal, domestic, and recreational and environmental uses were obtained from previous Snake/Salt River Basin Water Plans (Sunrise Engineering and others, 2003; WWDO, 2014). Finally the water budget analysis was based on the annual recharge estimate calculated in **chapter 6** of the main report. The results of the water balance analysis, shown in **table 1**, indicate that evapotranspiration (ET) accounts for about 30

Table 1. Summary water balance statistics.

WATER BALANCE PARAMETERS[a]		**Average Annual Volume (ac-ft)**
Precipitation (1981 - 2010 - Figure 3-3)[b]		9,137,300
Total surface water inflows[c]	+	43,700
Total surface water outflows[c]	-	4,643,100
Evaporation from reservoirs[d]:	-	72,200
Surface water and groundwater depletions from municipal/domestic, livestock, and industrial uses[d]	-	9,800
Total estimated Snake/Salt River Basin recharge (Table 6-3)	-	1,706,300
Basin-wide evapotranspiration	=	2,749,600

Comparative estimates

Estimated evapotranspiration in the Snake/Salt River Basin from the USGS climate and land-cover data regression[e] ; 4,150,900 acre-feet

[a] Fetter , C. W., 2001
[b] PRISM Climate Group, 2012
[c] USGS, 2014
[d] Wyoming Water Development Office, 2014
[e] Sanford and Selnick, 2013

percent of precipitation losses in the basin; the USGS estimate places ET losses at 45 percent of precipitation. The large discrepancy between the two estimates suggests that a significant portion of recharge in the semi-humid Snake/Salt River may return to streamflows in the form of baseflow. The Wyoming State Geological Survey (WSGS) believes that the USGS estimate is more accurate. Current estimated consumptive uses of surface water and groundwater constitute about 0.1 percent of annual precipitation.

FUTURE WATER DEVELOPMENT OPPORTUNITIES

Table 2 summarizes the general potential for development of the Snake/Salt River Basin's major aquifers, grouped by geologic age.

Table 2. Generalized groundwater development potential for major regional aquifer systems in the Snake/Salt River Basin (modified from WWC Engineering and others, 2007; WWDO, 2014).

Age	**System**	**Location**	**Well yields**	**Major aquifers**	**General potential for new development**
Quaternary	Alluvial	Throughout Snake/Salt River Basin	Small to large	Unconsolidated deposits	Good to very good
	Non-alluvial	Throughout Snake/Salt River Basin	Small to moderate	Primarily unconsolidated terrace deposits but locally can include glacial deposits	Good to very good
	Volcanic rocks	Yellowstone Volcanic Area and Northern Ranges	Small to moderate	Undifferentiated volcanic deposits	Fair to good – deposits generally located distant from population centers
Tertiary	Late	Scattered small outcrops from southern to east central basin	Small to large	Salt Lake, Teewinot	Fair to very good
	Early	Scattered small outcrops eastern basin	Small to moderate	Wind River, Wasatch	Fair - outcrops generally located distant from population centers
Mesozoic	Late Cretaceous	Outcrops throughout basin	Small to moderate	Mesaverde, Frontier	Poor to fair – little yield data
	Early Cretaceous	Outcrops throughout basin	Small to moderate	Thomas Fork	Fair to good - some marginal yields
	Triassic/Jurassic	Outcrops on upland flanks of south basin	Small to large	Twin Creek, Nugget	Fair to good –yield data from springs in Snake/Salt Basin
Paleozoic	Late	Outcrops throughout basin	Small to very large	Madison, Tensleep, Wells	Fair to very good – some marginal water quality
	Early	Outcrops throughout basin	Small to large	Flathead, Bighorn, Gallatin	Good – some marginal water quality

Future groundwater development projects in the Snake/Salt River Basin are largely affected by the issues of water availability, funding, stakeholder involvement, water quality, and environmental regulation.

CURRENT WWDC GROUNDWATER DEVELOPMENT PROSPECTS

Neither the WWDC nor the State Engineer's Office (SEO) is currently conducting large scale groundwater development projects in the Snake/Salt River Basin. Applications submitted to the SEO are usually for domestic well permits.

Recent WWDC groundwater projects in the Snake/Salt River Basin include evaluations of water systems in Afton (2006), Alpine (2009), Alta (2007), Kennington Springs (2003), North Alpine (2009), Squaw Creek (2012), Star Valley (2009), and Star Valley Ranch (2008).

SUMMARY

This WSGS study evaluated available groundwater resources in the Snake/Salt River Basin of Wyoming and a small upstream watershed in Idaho. The potential for future groundwater development in the basin is fair to very good in Quaternary through early Paleozoic aquifers.

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