WIND/BIGHORN RIVER BASIN PLAN FINAL REPORT

PREPARED FOR THE:

Wyoming Water Development Commission

BY:

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IN ASSOCIATION WITH:

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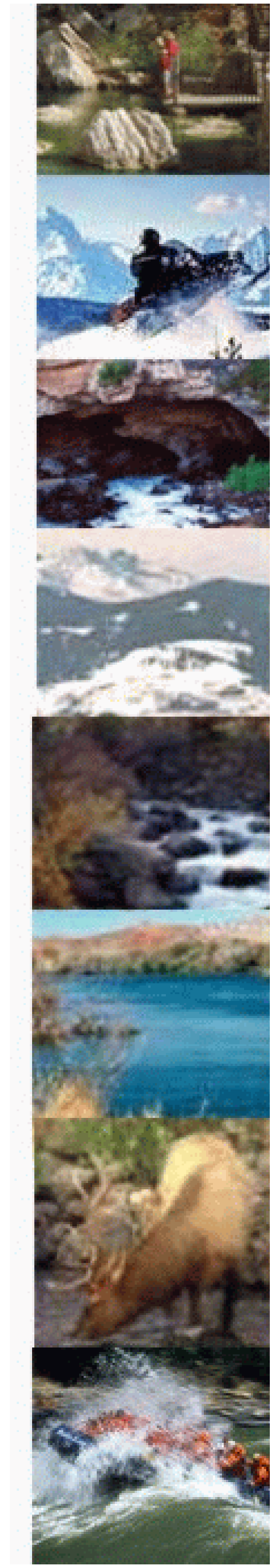
October 2003



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INTRODUCTION

Authorization

The Wind/Bighorn Basin (WBHB) Plan is one of a series of river basin plans prepared, or currently being prepared, for the Wyoming Water Development Commission (WWDC). The 2001 Wyoming Legislature authorized the Water Development Commission to complete this specific basin plan as part of the overall State Water Plan. River basin plans have been completed for the Bear River Basin, Green River Basin, the Northeast Wyoming River Basins and the Powder/Tongue River Basins. The Snake/Salt River Basin Plan is being completed contemporaneously with the WBHB. The Platte River Basin planning process is scheduled to begin in 2003 and is the final of the basin planning areas. It is the intent of the WWDC that the information presented in the plan documents will be reviewed and updated every five years to reflect changes and new concerns.

Project Scope

The WBHB includes the Wind River, the Clarks Fork of the Yellowstone River and the Bighorn River Basins and focuses on major water uses including: agricultural, municipal, domestic, industrial, environmental and recreational, and water use from storage. This basin plan documents current water uses, surface and ground water availability, and projects future use and/or demand for water, based upon various planning scenarios. In addition, institutional and legal constraints governing water development and management were reviewed and are summarized within this report. Subsequent to the initial scope of work, a review of power generation opportunities in the basin was requested by the WWDC. The power study included both hydropower and power generation from fossil fuels.

Basin Description

The Wind/Bighorn Basin planning area includes all of Bighorn, Park, and Hot Springs Counties, about 95% of Washakie County, approximately 85% of Fremont County, roughly 10% of Teton County, and the entire Wind River Indian Reservation, as shown in Figure I-1. Also included are small, relatively undeveloped portions of northwestern Natrona and western Johnson Counties. Approximately 80% of Yellowstone National Park is included in the planning area. Regionally, the planning area lies within the Missouri River drainage system and covers an area of approximately 20,500 square miles of federal, state, and privately owned land in central and northwestern Wyoming. Only 30%, the Wind River Indian Reservation being considered as non-private land, of the land within the planning area is privately controlled.

Elevations in the planning area are variable because the Wind River and Bighorn Basins are bordered by high alpine mountain ranges. Elevations range from roughly 3,500 feet above sea level, where the Bighorn River crosses the state line into Montana in Big Horn County, to 13,804 feet at the summit of Gannett Peak in Fremont County.

The climate of the planning area varies primarily as a function of altitude and ranges from semi-arid continental in the basin interiors to humid-alpine in the bordering mountain ranges. Annual precipitation varies from 6 to 8 inches in the basin interiors up to 60 to 70 inches along the peaks of the bordering mountain ranges, as shown in Figure I-2. Annual precipitation in the vicinity of Yellowstone National Park ranges from 13 to 70 inches. Most of the planning area receives the majority of its precipitation during the winter as snowfall, but the basin interiors primarily receive precipitation during occasional spring and summer thunderstorms.

There are several reservoirs located within the WBHB area. Capacity of the reservoirs, range from small one acre ponds to the larger reservoirs such as Boysen and Buffalo Bill. These storage facilities play a large role in water utilization within the planning area, as well as being important to down stream water users.

Unique water-related environmental features of the basin include the glaciers of the Wind River mountain range, a section of the Clarks Fork designated as a federal "Wild and Scenic" River, Sink's Canyon, the Thermopolis Hot Springs, and the numerous natural wonders of Yellowstone Park.

Within the Wind River, Clarks Fork and Bighorn Basins, surface water usage and flow is regulated by the Yellowstone River Compact of 1950 and the GENERAL ADJUDICATION OF ALL RIGHTS TO USE WATER IN THE BIG HORN RIVER SYSTEM (State Engineer's Office, 1999, www.seo.state.wy).

Previous reports have indicated that some 1,600,000 acre feet per year of surface water in the WBHB and some 424,000 acre feet per year of surface water in the Clarks Fork Basin is unappropriated (Ostresh, Marston, Hudson, 1990). The findings of this investigation substantially support these figures. However, despite this apparent surplus, many areas within the basins chronically experience water shortages. A challenge is presented to water planners due to the fact that the distribution and availability of the water resources in the WBHB, relative to the point of use, is highly variable.

The Final Report and Technical Memoranda are available through the Water Resources Data Systems (WRDS) (www.wrds.uwyo.edu) in either .PDF format or HTML format. A printed version is available for checkout through the WRDS library.

References and Additional Information

A substantial portion of information collected and developed as part of this project was developed as a Geographical Information System (GIS) product, which will be managed by WRDS. GIS products include, but are not limited to irrigated lands mapping and water right attribution, topography, climate, geology, hydrologic features and boundaries, and various man-made features such as points of diversion, storage, and distribution. In addition, a surface water model for the entire basin was developed as a spreadsheet model in the format requested by the WWDC. Finally, detailed technical data and descriptions of each component of the basin plan are provided in the Technical Memoranda prepared for this project, as follows:

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Addendum – Bibliography of Previous Water Use Studies
Addendum - Irrigation Diversion Operation and Description

Wind/Bighorn River Basin Plan, Power Study (separate cover)

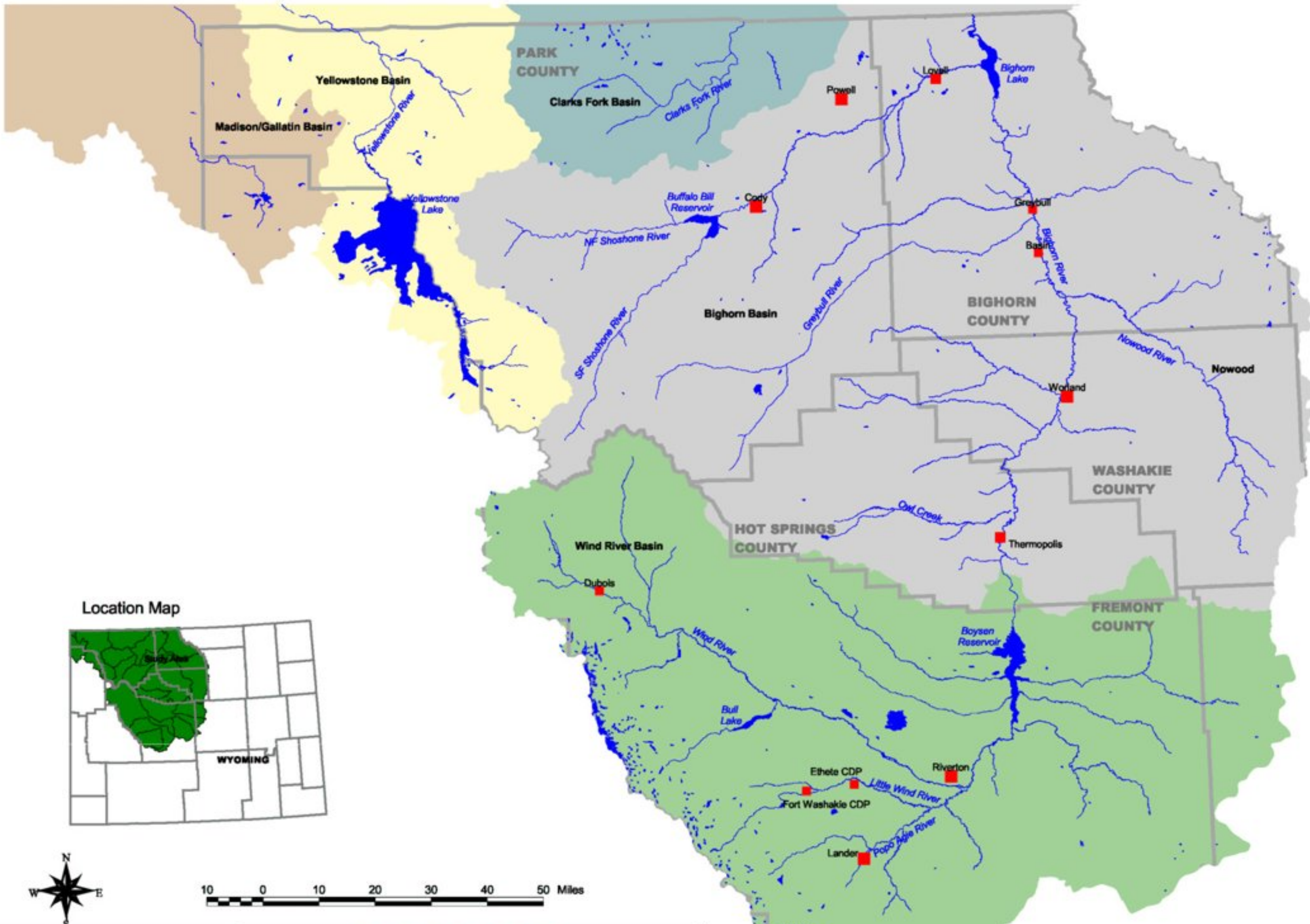

Figure 1
Study Area Map

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Wind/Bighorn River Basin Plan

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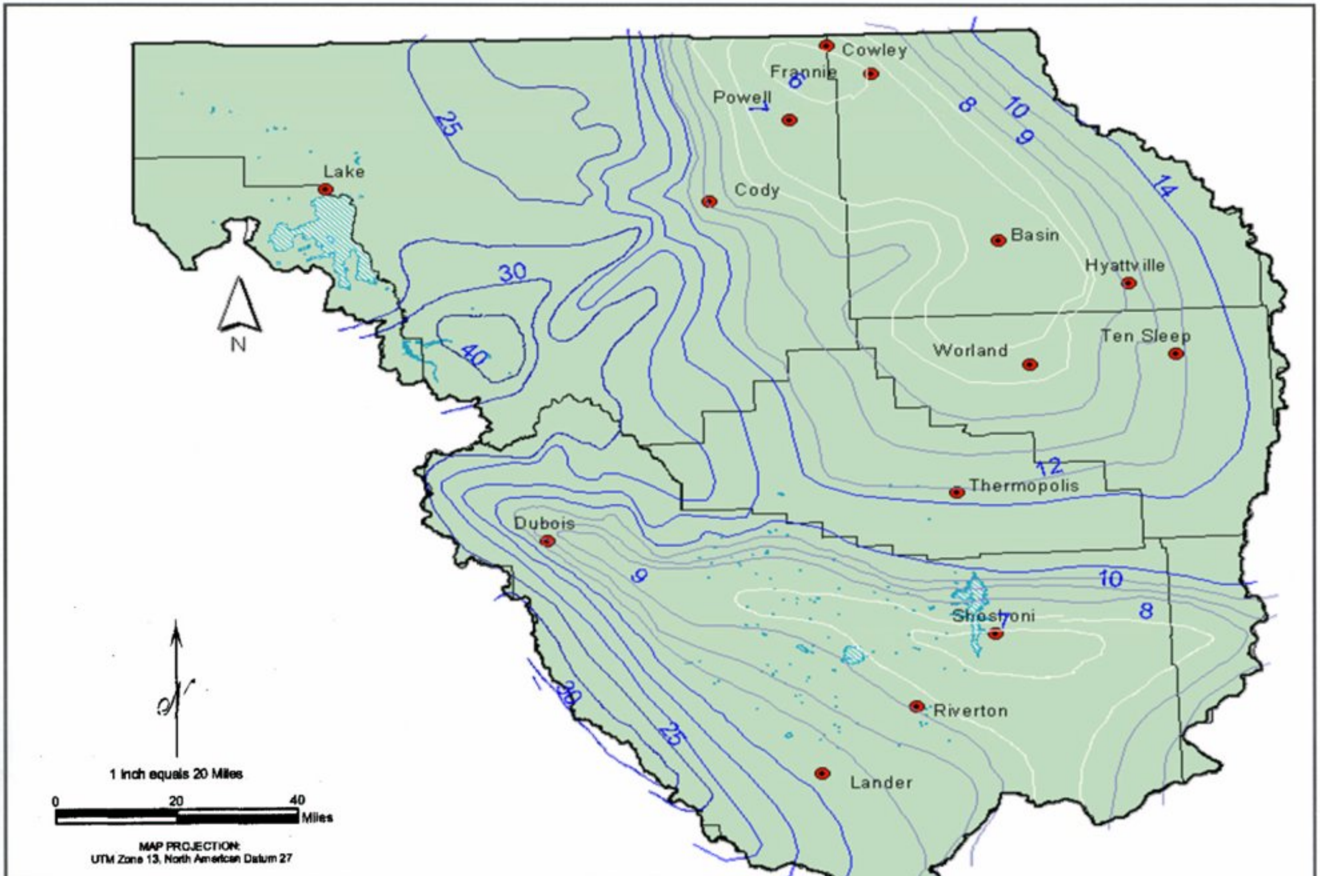


Figure 2
Precipitation

October 2003

Wind/Bighorn River Basin Plan

BRS ENGINEERING

MWH Denver, Colorado

TRIHYDRO corporation

CHAPTER 1
INSTITUTIONAL CONSTRAINTS

1.1 - Wyoming Water Law

Wyoming Water Law is founded on the doctrine of prior appropriation or **"first in time is first in right"**. This basic premise prevails throughout the statutes. Other basic precepts include:

- Water rights do not convey ownership of waters, but allow for priority use of the water for beneficial purposes.
- Beneficial use is the basis, measure, and limit to the right to use water at all times.

Use of water is administered by the State Engineer and the State Board of Control. The State Board of Control consists of the State Engineer and the superintendents of the four water divsions of the State.

1.2 - Compacts and Decrees

1.2.1 - Introduction

Within the Wind River, Clarks Fork and Bighorn Basins, surface water usage and flow is regulated by: the Yellowstone River Compact of 1950, the GENERAL ADJUDICATION OF ALL RIGHTS TO USE WATER IN THE BIGHORN RIVER SYSTEM, and State of Wyoming, in the District Court, Fifth Judicial District, Civil No. 4993.

1.2.2 - Yellowstone Compact

The interstate compact applicable to the WBHB is the Yellowstone River Compact, which apportions unappropriated flows after 1950 from the Wind River/Bighorn drainage system. The compact between the states of Wyoming, Montana, and North Dakota divides the waters of four tributaries to the Yellowstone River. To all tributaries the following rules apply:

- Existing rights as of January 1, 1950 are not affected.
- No water can be diverted out of the Yellowstone River Basin without consent from all states.
- Existing and future stock water reservoirs up to a capacity of 20 acre-feet are exempted from provisions of the compact.
- Supplemental supply to serve lands with water rights prior to 1950 is not counted against the State's apportionment.

The unappropriated waters in the tributaries, after meeting existing water rights (1950) and supplemental supply for existing rights, as measured at gages near the confluence, are allocated as follows:

Wind River/Bighorn	80% Wyoming, 20% Montana
Clarks Fork	60% Wyoming, 40% Montana

The Yellowstone River Compact is included in the **Technical Memorandum, Ch. 1,Tab 2, Appendix A.**

1.2.3 - Bighorn General Adjudication

The two million acre Wind River Indian Reservation, located in Fremont and Hot Springs Counties, is also located in the WBHB watershed. The Wind River and many of its tributaries originate on or run through the Reservation, making it an important factor in the WBHB's water management. The natural resources on the reservation are jointly owned by two tribes, the Shoshone and Arapaho, although some tribal members hold water rights individually. Tribal surface water rights date to 1868, the oldest water rights in the WBHB. Legal proceedings between the State of Wyoming and the Shoshone and Arapaho Tribes awarded the right to 500,000 acre feet of water from the Wind River system to the Tribes. The Wind River Reservation Tribes are allocated surface water annually for beneficial use. Within this allocation, approximately 290,000 acre feet is reserved for future developments on the reservation. Half of the allotment was intended for use in developing new irrigation projects. At the present time, the Tribes cannot beneficially utilize this much water. Downstream users, whose rights are junior to those of the Tribes, are accustomed to having this water available. Working out a management regime that will satisfy all parties is a formidable task. The Reservation not only incorporates within its boundaries private lands not owned by the Tribes, but also operates within a governmental context of tribal, federal, state and local authority and activity. The Bighorn General Adjudication relative to the Wind River Reservation and the Bighorn River system has a distinct impact on future water planning in the WBHB.

A summary of the Bighorn General Adjudication from the Wyoming State Engineer's Office 1999 Annual Report is included in the **Technical Memorandum, Ch. 1, Tab 2, Appendix B**.

1.3 - Institutional Considerations

1.3.1 - Introduction

Wyoming's culture and economy are largely shaped by the state's natural setting. All three of the state's major industries; mineral production, tourism and agriculture, are natural resource reliant. Much of the state's quality of life is founded on a tradition of easy access to open country rich in wildlife and relatively un-crowded natural vistas. Outdoor activities from skiing to hunting and fishing to off-road four-wheeling are integral to both the culture and economy of the state.

Management of land, water, wildlife and associated resources occurs within a multifaceted context of institutional constraints. Perhaps the most relevant of these constraints is fragmented ownership and control of land and natural resources. In Wyoming in general, about half the land is owned and managed by federal agencies. The management and ownership of the other half is divided among state, county, local and private entities. Given that the headwaters of most Wyoming streams are located on federal lands, federal oversight of water development and management is inevitable. These constraints also apply to the WBHB, where public lands constitute about 70% of the WBHB's territory.

Those regions of Yellowstone National Park east of the Continental Divide also lie within the WBHB watershed. Management of the waters within Yellowstone National Park falls within the purview of the National Park Service, although it remains the position of the State of Wyoming that national parks in the state need permits from the Wyoming State Engineer's Office to use water. The Clarks Fork River leaves Yellowstone National Park within Wyoming, and provides water for northern sections of Park County before going north into Montana. Yellowstone National Park draws around three million visitors per year, and three to four hundred thousand of these enter the Park through the East Entrance, west of Cody.

1.3.2 - Land Ownership

In the WBHB, the Wyoming pattern of diverse land ownership is carried to the extreme, the majority of the WBHB's 14.1 million acres is publicly owned, 63% by the federal government. See Table 1.3-1 for a detailed listing of land ownership. Privately owned land totals nearly three million acres, the Bureau of Land Management alone controls about 4.3 million acres in the WBHB, while the Forest Service owns more than 2.9 million acres. Other federal agencies controlling large areas include the National Park Service and the Bureau of Reclamation. Much of Yellowstone National Park is in the WBHB, and there are wilderness areas in the national forests (Bighorn and Shoshone) in the mountains. Bighorn Canyon, where the Bighorn River leaves Wyoming for Montana, is a national recreation area. Federal agencies play a major role in the what, when, where, how and why of water management and development. The necessity of dealing with diverse land ownership can complicate water development planning.

Table 1.3-1: Land Ownership in WBHB (acres)

County	Bureau of Indian Affairs	Federal	Private	State	Water	**Total**
Hot Springs County	220,948	542,728	433,262	84,736	3,056	1,284,730
Natrona County	0.00	136,301	152,828	38,217	0	327,346
Park County	0.00	3,548,712	746,760	159,546	0	4,455,018
Washakie County	0.00	941,213	351,300	98,044	1,324	1,391,881
Fremont County	1,323,871	2,083,832	977,048	159,732	42,161	4,586,644
Bighorn County	0.00	1,616,215	328,184	72,879	2,551	2,019,829
WBHB	1,544,819	8,869,001	2,989,382	613,154	49,092	14,065,448

(All County/Landownership area calculations based on data projected to UTM, Zone 12, NAD27. The Landownership file was acquired from the BLM, its scale is 1:24,000.)

Table 1.3-2 Percent Land Ownership in the WBHB

County	Bureau of Indian Affairs	Federal	Private	State	Water
Hot Springs County	17.2%	42.2%	33.7%	6.6%	0.3%
Natrona County	0.0%	41.6%	46.7%	11.7%	0.0%
Park County	0.0%	79.6%	16.8%	3.6%	0.0%
Washakie County	0.0%	67.6%	25.2%	7.0%	0.2%
Fremont County	28.9%	45.4%	21.3%	3.5%	0.9%
Bighorn County	0.0%	80.0%	16.2%	3.6%	0.2%
WBHB	11.0%	63.0%	21.3%	4.4%	0.3%

(Percents based off of Table 1.3-1 Land Ownership in the WBHB)

1.3.3 - Wyoming Water Development

The Wyoming Water Development Program was established in 1975, with a mandate to foster, promote, and encourage the optimal development of the state's human, industrial, mineral, agricultural, water and recreation resources....The program shall encourage development of water facilities for irrigation, for reduction of flood damage, for abatement of pollution, for preservation and development of fish and wildlife resources, for protection and improvement of public lands, and shall help make available the water of this state for all beneficial uses, including but not limited to municipal, domestic, agricultural, industrial, instream flows, hydroelectric power and recreational purposes, conservation of land resources and protection of the health, safety and general welfare of the people of the State of Wyoming. The Wyoming Water Development Commission (WWDC), was established in 1979 to implement the water development program, set goals, provide technical support, and to offer grants and loans to public entities for construction projects directly related to water needs.

Wyoming statutes do not require that publicly funded water development projects include provision for instream flows. However, the WWDC, through its founding legislation, is able to consider instream flows, though it is not mandatory in every case. Under Wyoming law, only the state can hold Instream Water Rights.

The presence of threatened or endangered wildlife species is a trigger for instream flow consideration or action by the state. Examples of fish species that seem to be under pressure are the Yellowstone Cutthroat Trout in the western drainages of the WBHB, and sauger and sturgeon chubs in the Bighorn River. State action initiatives can simplify remedial actions that might be made more complex by federal intervention. However, 94% of the more than 9.4 million acres of public land in the WBHB is federally owned, so federal involvement or participation is likely in most water projects of any size.

Other state agencies involved in water management include the State Engineer's Office (SEO), the Department of Environmental Quality (WDQ-DEQ), the Wyoming Game and Fish

Commission (WGFC) and the Wyoming State Parks and Cultural Resources Department. Water rights are administered by the State Engineer's Office.

1.3.4 - Impact of Environmental and Cultural Concern on Regulation and Legislation

During the last four decades, a rising concern about the condition of the physical environment has sparked many regulatory initiatives. A much broader spectrum of value is now applied to natural entities, including the delineation of "existence" or "passive" uses of natural amenities. Numerous environmental activist groups now exist, seeking a voice in policy-making, and use econometric methods to enable comparisons of intangible benefits attached to natural phenomena. The rise of these advocacy groups has moved other types of interest groups to be more active in areas of environmental and development policy.

Along with the growing environmental concerns, there is a growing concern about historic, archaeological, and cultural sites. As a consequence, surveys to determine effects of development projects on cultural values are necessary. The Cultural Resources Division of the Department of State Parks and Cultural Resources provides surveys of areas to ascertain whether or not cultural resources might be put at risk.

These factors have played a role in producing more active participation in public land, water, and wildlife policy-making and management than was observed in the past. In response to this political evolution, since the late 1960's, government at all levels has proliferated studies, laws, regulations, and policies aimed at environmental protection. Water development must incorporate a variety of needs including agricultural, industrial, municipal, domestic and recreational uses. At the same time, the relevance of ecological values in policy-making has greatly expanded. One consequence of increased and widespread public concern, beyond whatever ecological or cultural benefits may be produced, is an increase in the complexity, cost, and time required to evaluate, plan, fund, carry out, and maintain projects. Perhaps the most obvious consequence of this trend is the increasing range, number, and complexity of laws, regulations, agencies, and policies governing water use and development, adding to the overall complexity in water management.

1.3.5 - Environmental Legislation

Prior to 1948, the federal government's role in water pollution regulation was minimal. However, in 1956 the federal government began to assume primary responsibility for water quality (Freeman, 1991). Since then, federal and state legislation and regulation have created many constraints for water and water-related development efforts. A broader spectrum of issues exist and water development projects are not necessarily driven primarily by consumptive needs. A change of emphasis from "wise use" to "conservation" and then toward "preservation" has occurred, carrying many implications for water planning and development. The consequence is higher levels of costs and longer time periods for planning and construction. Almost all water development actions fall under the purview of federal environmental laws and the agencies that administer them. The WWDC has reported (Wyoming Water Development Commission, "2002 Legislative Report, Situation Analysis", http://wwdc.state.wy.us):

> *"…the federal permitting processing is more costly, time consuming and restrictive than it was in 1982. For example, in 1985 the federal 404 permit for the Sulphur Creek Dam was obtained in nine months at a cost of approximately $50,000. In 1996, after three and one-half years, we received the 404 Permit for the Buffalo Municipal Dam, a smaller and less complex project than the Sulphur Creek Dam. The actual costs related to permit acquisition were approximately $650,000. New federal requirements for wetlands mitigation, criteria involving purpose and need, and alternative analyses are the major reasons for the increased costs"*

Major national environmental legislation pertinent to water management and development includes the National Environmental Policy Act (NEPA), the Clean Water Act (CWA) and the Endangered Species Act (ESA). These three laws (first enacted in 1969, 1972, and 1973, respectively) are the source of most federal authority for regulating water and the ecosystems relevant to water supply and quality. Agency rules, regulations, and policies are derived from these congressional roots. The headwaters of most WBHB streams are within the boundaries of U.S. Forest Service or Park Service lands and most reservoirs are managed by the U.S. Bureau of Reclamation. Other federal agencies, such as the U.S. Department of Agriculture's Natural Resource Conservation Service, are concerned with riparian areas, crop and pasture land. Outside the national parks, wildlife management, including fisheries, is within the domain of the WGFC, although the U.S. Fish and Wildlife Service plays a major role in issues involving threatened, endangered, migratory species and threatened habitat.

Federal environmental protection laws are very inclusive in their reach. The Endangered Species Act (1973), for instance, covers both animal and plant species and requires that the Department of the Interior, often through the U.S. Fish and Wildlife service, determine whether or not an action may affect some species. No federal agency can take any action deemed threatening to any endangered or threatened species, or any "sensitive" species such as raptors. These laws require that project planners avoid or minimize impacts viewed as ecologically negative. Most judgments are vested in lead agencies, the U.S. Fish and Wildlife Service for the ESA and the U.S. Corps of Engineers for the CWA. NEPA is a broad piece of legislation, requiring compliance with federal agencies and regulations for all proposed projects.

As noted in the WWDC Green River Basin Plan, the "only water development activity not subject to federal environmental laws is drilling a well with non-federal funds on non-federal lands outside the banks of rivers, streams, and wetlands. However, piping the water from such wells across federal lands or rivers, streams and wetlands could initiate a federal environmental review" (Purcell, 2001). Any project involving public lands requires special use and right-of-way permitting, and ecological reviews will be required in most cases. In cases where an Environmental Assessment finds that there are no serious issues involved, an Environmental Impact Statement may not be necessary, expediting the process. This national legal and institutional framework means that any Basin water project will be reviewed by multiple agencies, unless the proposal is a very clear cut and unmistakably beneficial. Considerations such as water quality, instream flows, riparian habitat, threatened or endangered species and human access are particularly pertinent within the WBHB.

In Park County's Shoshone National Forest, a 20-mile reach of the Clarks Fork River running through a deep canyon, is Wyoming's only federally designated Wild and Scenic river. The Wild and Scenic status severely limits development possibilities. Other WBHB waters, outside of Yellowstone National Park, that have been mentioned as deserving protected status include the Porcupine drainage in Big Horn County, the Shoshone River within the Bighorn Canyon National Recreation Area, and the Wiggins Fork in Fremont County (U.S. National Park Service, Nationwide Rivers Inventory, http://www.nps.gov). These streams could be considered for inclusion under several categories: wild and scenic or recreational. However, none of them have yet to reach candidate status.

1.3.6 - Water Development Projects and Proposals

In arid Wyoming, water tends to be somewhat scarce and therefore a valuable and controversial commodity. Proposed projects must receive broad support if they are to be funded and implemented. Since the foundation of Wyoming Water Law is the doctrine of prior appropriation, junior rights may not be entitled to divert water until senior rights are satisfied. This means that the first water management issue to be resolved is whether or not there is adequate water available for junior uses under a worst-case scenario. If it is thought likely that in dry years the water supply could be inadequate, then consideration needs to be given to the possibility of building storage facilities. As a project study proceeds, legal, institutional, and economic issues are identified. An important factor may be whether or not additional benefits, such as environmental or recreational opportunities, are there to strengthen the project. The evaluation completed, the overall economic feasibility of a proposed project can be assessed.

CHAPTER 2
WATER USE

2.1 – Wind/Bighorn Lands Mapping and Water Rights Data

2.1.1 – Introduction

The majority of the appropriated water in the WBHB has been appropriated for the irrigation of land. Therefore, an estimate of water used for irrigation is central in the development of a comprehensive water use inventory for the WBHB. Mapping the irrigated lands within the WBHB is a principal task in developing the water use inventory. The methodology can be divided into four general steps:

1. Identification and Delineation of Irrigated Lands
2. Attribution of Water Rights to Delineated Irrigated Lands
3. Creation of a Digital Irrigated Lands Map
4. Verification of Delineated Irrigated Lands

Figure 2.1-1 shows the overall irrigated lands mapping for the WBHB.

2.1.2 – Identification and Delineation of Irrigated Lands

Two data sources were used in the identification and delineation of irrigated lands, the United States Geological Survey (USGS) black and white digital orthophotograph quarter quadrangles (DOQQs) published in 2000 and 2001, and the 1999 Landsat color-infrared satellite imagery.

Once the data sources were obtained, hard copy maps corresponding to the extents of 7.5 minute USGS quadrangle maps were created of the DOQQ and Landstat color-infrared imagery. Both a DOQQ map and a Landsat color-infrared map were produced for those areas within the WBHB that were determined to possibly contain irrigation practices. Maps were not produced for those quadrangles fully contained in areas previously mapped by the State of Wyoming. Each created map was then closely examined and potential irrigated lands were identified and delineated. After the completion of the identification and delineation process, the delineated areas were transcribed onto a corresponding 7.5 minute USGS hardcopy topographic map.

Transcribing the delineated irrigated lands onto the 7.5 minute USGS topographic maps accomplished two necessary objectives. First, the transcription provided a means to crosscheck and assemble the delineated lands from the two source maps. Second, the transcription provided a Public Land Survey System (PLSS) land description base. The water rights records maintained by the Wyoming State Engineer and the State Board of Control reference land based on the PLSS, therefore the same base was required for the assignment of water rights to the delineated lands.

As mentioned above, portions of the irrigated lands within the WBHB were previously mapped by the State of Wyoming. The previously mapped areas include irrigated lands within the boundaries of the Wind River Indian Reservation and lands that irrigate with water from the Bighorn River or tributaries of the Bighorn River. Within the Wind River Reservation, water awards for the "future" development of irrigated lands were also mapped. The water awards were determined for three different circumstances and are therefore referred to with three different names – Reserved Right Awards, Walton Awards, and Remand Awards. The lands covered under each of the water awards may or may not be currently irrigated, however the water awards have an 1868 priority and therefore play an important role in determining the water use or potential water use of the WBHB.

2.1.3 – Attribution of Water Rights to Delineated Irrigated Lands

Water rights attribution is the process of assigning water right information to the delineated irrigated land areas or polygons. A complete description of irrigated lands includes a definition of the water rights granted to allow for the irrigation of the lands. The water right information most relevant to this project include: permit number, source of water supply, facility name, priority date, amount of appropriation, permitted number of acres and type of supply. Specifically these water rights attributes provide an overview and insight into the supply sources, the permitted area of land and the types of irrigation systems.

The identification and attribution of water rights was addressed upon the completion of the irrigated lands mapping. The water rights assigned to the irrigated land polygons were identified from the original records on file in the offices of the Wyoming State Engineer and State Board of Control. As a water right was determined to be associated to an irrigated land polygon, an identification number was assigned to the topographic map clearly referencing the appropriate polygon. The identification number created a link between the irrigated polygon or polygons and the water rights database. If a delineated land polygon was found not to contain a water right, the polygon was reclassified to sub-irrigated land. Sub-irrigated land is land that receives water from a semi-saturated subsurface zone and not directly from an irrigation source. An assumption of "officially permitted water right use" was made throughout the mapping process. Therefore, any lands that appeared to be receiving water yet did not have an appropriated water right were assigned to the sub-irrigated category.

Throughout the water rights attribution process of the WBHB it was discovered that historic water rights still exist within some town boundaries (i.e. Otto and Greybull). To maintain consistency with previously completed basin plans, these water rights were excluded from the final irrigated lands map.

2.1.4 – Creation of a Digital Irrigated Lands Map

Upon the completion of the water rights attribution, the delineated lands and water rights attributes were converted into a digital format, such that the data could then be presented in a GIS format. AutoCAD Map software was used to both register the maps and digitize the delineated lands. After the maps were digitized, the AutoCAD map files were converted into ArcView shapefiles. Utilizing custom-built ArcView tools created for this project, the irrigated land polygons were attributed with the appropriate water rights. The creation of an ArcView point file representing the points of diversion was also created and attributed in the same manner as the irrigated land polygons. The GIS product developed digital irrigated lands and points of diversion. Figure 2.1-2 shows a typical 1:24,000 scale irrigated lands map.

2.1.5 – Verification of Delineated Irrigated Lands

Throughout the delineation process, inquiries were made to irrigation districts and landowners in order to verify the accuracy of the information obtained from the DOQQs and the Landsat color-infrared imagery. In cases where the accuracy was questioned, field-truth verification was performed by members of the Wind/Bighorn project team, landowners, or irrigation district personnel. A second iteration of field verification took place upon completion of the digital data conversion process. The second verification involved the creation of maps illustrating the irrigated lands and the points of diversion. These maps were delivered to Mr. Craig Cooper, retired Wyoming State Engineer's Office Division III Superintendent, and Mr. Gary Collins, with the Office of the Wind River Reservation Tribal Water Engineer, who both acted as primary project field verification contacts. The pertinent additions and changes from the second field verification process were incorporated into the final mapping products using the same procedures outlined in the previous section.

2.1.6 – Explanation of the Irrigated Lands Geographic Information System (GIS)

The final products from the irrigated lands mapping tasks include the following GIS data themes or digital datasets and database tables:

GIS Data Themes	Database Tables
Irrigated Lands (polygons)	Water Rights Table
Points of Diversion (points)	Linking Table

The GIS data themes are located in the Latitude and Longitude coordinate system based on the North American Datum of 1927. File formats of the data themes include both the ArcView shapefile format (*.shp) and the ArcInfo export file format (*.e00). Descriptions of the GIS data theme attributes and the database table fields are detailed in **Chapter 2, Section 5 of the Technical Memorandum "Wind/Bighorn Lands Mapping and Water Rights Data"**.

2.1.7 – Water Right Type of Supply Related Terminology

Original Supply: Original supply is a ground or surface water right attached to land or uses where there is no other water right of record. It is the first priority water right attached to and to be used on the identified land.

Supplemental Supply: Direct flow water from a different source and different point of diversion to augment or supplement the available water for an existing appropriation (water right) for which the original source does not provide a full supply constitutes a supplemental supply. The amount of supplemental water which may be diverted, is the amount available, in priority, to bring the total water diverted from all sources up to the appropriated amount of 1.0 cubic foot per second (cfs) for every 70 acres to be irrigated. (W.S. 41-4-317 through 41-4-324)

Additional Supply: Additional supply is additional ground water for irrigation use which is appurtenant to lands that already have a direct flow supply of surface water or have an original supply from another ground water source.

2.2. – Agricultural Water Use and Diversion Requirements

2.2.1 – Introduction

A key component of the WBHB Plan is the development of a river basin model for the study area. The primary purposes of the river basin model effort are to identify and quantify water uses that experience shortages during dry, average and wet years; to determine the impact of Tribal futures projects; and to identify and quantify the amount of water that is available for future water development. The model runs on a monthly time step and utilizes dry, average, and wet-year hydrology developed from a 1973-2001 period-of-record.

This section discusses the development of agricultural water use and diversion requirements that were used in the model. Agricultural water use represents the vast majority of water use within the WBHB planning area. Because of this, accurate estimation of agricultural water use within the WBHB is essential in producing an accurate model and calculating water availability. Water use by agriculture is a function of many physical and managerial functions including the quantity of land irrigated, crop types, soil types, precipitation, conveyance mechanisms, irrigation types and management styles.

The model requires the historical diversion requirement for each point of diversion. Then, the model calculates the historical amount of consumptive use using irrigation efficiencies and returns non-consumptive demands back to the river according to surface water accumulation functions, or lags. Then, because the amount of land historically irrigated is less than the amount of land with water rights, full supply diversions are modeled, where all irrigated lands with water rights are supplied from the existing water supplies. The development of historical diversions, both measured and estimated, as well as fully supply diversions, are discussed in the following sections.

2.2.2 – Historical Diversions

Historical diversions are used as input for the model calculation and calibration process. Therefore, based upon criteria used in previous river basin plans, historical diversion records were obtained for all diversions greater than 10 cfs. Diversions greater than 10 cfs are explicitly included in the model as separate diversions, while those less than 10 cfs are "lumped" with other small diversions less than 10 cfs that divert in the same reach of stream. Diversion records and the reduction of the diversion records for use in the model are discussed in this section. Estimated historical diversions for those diversions without diversion records are discussed in Section 2.2.3, Estimated Historical Diversions.

Diversion records were collected from the State Engineer's Office Division III Hydrographer's Reports and USGS published data, as included in the addendum to the **Technical Memoranda**

Wind/Bighorn River Basin Plan – Irrigation Diversion, Operation, and Description. Two types of records are available, daily flow data available from USGS or SEO gaging stations and instantaneous flow data from SEO spot checks of diversions. The reduction of daily data simply used the daily average diversion flow rate and converted it to a volumetric amount. Any missing daily data was estimated from the available data before and after the missing data using linear interpolation. Then, the daily volumetric amounts were summed for a monthly diversion. For most data in the Hydrographer's reports, this was already done and these values were used.

The reduction of spot data involved a similar process. Data for days not measured was linearly interpolated from the available data. Starting and ending dates for irrigation seasons were taken from <u>Consumptive Use and Consumptive Irrigation Requirements in Wyoming</u> (Pochop et.al., 1992). The daily flow values were then converted to monthly volumes and summed for each month.

Monthly diversions estimated from the daily and spot data were used to develop dry, average, and wet year diversions. The development of dry, average, and wet years, as well as the index gages for each basin are described in Chapter 3, Section 1, Surface Water Hydrology. In general, the 1973-2001 period-of-record was used for hydrologic calculations. Based upon selected index streamflow gages, which generally represent undepleted flows, dry years were defined as the driest 20 percent of years, average years were the middle 60 percent, and wet years were the wettest 20 percent of years, as defined by the total annual flow at the gage.

To reduce diversion data, the monthly average of all available diversion data was taken for all years within the hydrologic condition. Unlike the gaged flow records, years without data were not filled. Therefore, occasionally, there are diversions with records in one hydrologic condition and not another. In this case, the estimated actual diversion methodology was used for the missing data. This primarily occurred only for smaller diversions.

Occasionally, calibration of the model required that the measured historical diversions be reduced to maintain mass balance in the model. This was accomplished using the same techniques as described in Section 2.2.4 – Full Supply Diversion Requirements.

2.2.3 – Estimated Historical Diversions

Because diversion records were not available for many of the smaller diversions within the study area, and because some diversion records were not obtained (those that did not meet the 10 cfs criteria), estimated historical diversions were developed. The quantification of estimated historical diversions for those irrigated lands without historical diversion records took place in two parts:

- Develop the potential estimated historical diversion for the point of diversion given the irrigated lands and the consumptive use/diversion requirement calculations using the following methodologies.

- Adjust the estimated historical diversion using the model calibration procedures as follows.

The development of estimated historical diversion requirements for input into the model was performed in the same manner as described in Section 2.2.4 - Full Supply Diversion Requirements.

The calibration procedure, as more fully described in Chapter 2, Section 1 "Wind/Bighorn Lands Mapping and Water Rights Data", Spreadsheet Model Development and Calibration, was used to adjust the estimated historical diversions. This calibration procedure utilizes the estimate of water availability at the point of diversion and compares it with the estimated historical diversion. If the estimated historical diversion is less than the amount of water available at the point of diversion, then the estimated historical diversion is not adjusted. If the estimated historical diversion is more than the available flow at the point of diversion, then the estimated historical diversion is adjusted so that it can take no more than the available streamflow. These adjustments are shown on the "Historical Diversions" worksheet within each model.

2.2.4 – Full Supply Diversion Requirements

Full supply diversion requirements are based on the theoretical consumptive use and system efficiencies for each of the points of diversion. In general, the full supply diversion requirement is equated to the theoretical maximum diversion requirement as given in the following equation:

Full Supply Diversion Requirement = (Area x CIR)/Overall Efficiency

Where: Area = Area of Land that is Irrigated (acres)–Described in Section 2.2.5
CIR = Crop Irrigation Requirement (feet)–Described in Section 2.2.6
Overall Efficiency = Overall Irrigation Efficiency(%)–Described in Section 2.2.10

Each of these factors is described in the following sections.

2.2.5 – Irrigated Lands

Mapping of irrigated lands within the WBHB was performed by the project team. Irrigated lands mapping is discussed more thoroughly above in Section 2.1, Wind/Bighorn Lands Mapping and Water Rights Data. This mapping was used for determining the area of land irrigated in each sub-basin model.

The irrigated lands mapping was attributed in the GIS as Irrigated Land (IRR), lands with Water Rights (Water Rights), man-made riparian (MM RIP) and sub-irrigated (SUB IRR). Islands of non-irrigated lands within larger irrigated areas, or polygons within polygons in the GIS database, were also mapped.

A summary of the irrigated lands is shown in Table 2.2-1. As shown in Table 2.2-4 (Section 2.2.7, chapter 2, page 12 of this report), the USDA estimates approximately 354,000 acres of irrigated lands while the Wyoming Agricultural Services estimates approximately 344,000 acres of irrigated lands within the study area. Table 2.2-1 shows approximately 561,000 acres of irrigated lands with an additional 125,000 acres of lands with tribal water awards. There are many reasons for the differences in estimates, including the non-reporting of irrigated lands by many farmers, and the fact that some of the lands could have been fallow during the reporting year.

Table 2.2-1 Summary by Attribute of Irrigated Lands Mapping

County	Irrigated Lands (acres)	Man-Made Riparian (acres)	Sub-Irrigated (acres)	Lands with Tribal Awards (acres)	Total (acres)
Big Horn	167,669	0	9,915	0	177,583
Fremont	154,829	2,385	3,155	122,330	282,700
Hot Springs	24,389	0	32	3,131	27,552
Natrona	551	0	183	0	734
Park	162,772	0	6,440	0	169,212
Washakie	50,934	0	0	0	50,934
Total	561,144	2,385	19,725	125,461	708,715

Notes:

1. Source: Reduction of Irrigated lands database (TriHydro, 2003).
2. Definitions:
   Irrigated Lands – Lands irrigated with a valid water right.
   Man-Made Riparian – Non-farmed riparian areas receiving irrigation return flows as classified by the USBR (these were classified as sub-irrigated in the final GIS attribution).
   Sub-Irrigated Lands – Lands irrigated from a sub-surface source due to water received from neighboring irrigated lands.
   Lands With Water Awards – Water futures awarded with an 1868 priority.
3. Acreages shown in table include those in the Popo Agie Basin.
4. Based on 1999 Landsat.

Table 2.2-2 presents a summary of the mapped irrigated acreage by county within the Wind/Bighorn River Basin Plan study area as used in the model. The following should be noted regarding the development of the modeled acreage:

- For purposes of the modeling analysis, sub-irrigated lands were not explicitly included within the model. The consumptive use of sub-irrigated lands is simply accounted for in the gain/loss calculations. Therefore, their consumptive use is implicit within the model calculations.
- The Popo Agie River Basin was not included within the modeling of the Wind/Bighorn River Basin Plan, as it was already covered by another planning project.
- Based upon the scenarios run by the model, the Tribal Futures lands were separated out from the historically irrigated lands and included separately. Tribal Futures projects are discussed in Chapter 4, Section 4.2.2.1, Tribal Futures.
- Man-made riparian areas were modeled because they are a consumptive use within historical diversions (in other words, historical diversion records include diversions made to meet consumptive use requirements of man-made riparian areas). Therefore, man-made riparian areas should be accounted for in the historical diversion requirements and in the Full Supply

diversion requirements. The man-made riparian areas are all mapped within the Midvale Irrigation Project.

The remaining portion of this section discusses historical and full supply diversion requirements for existing irrigated lands. Full Supply diversion requirements for Tribal Futures projects and any other potential irrigation development are discussed in Chapter 4, Section 4.2.3, Available Flow for Agricultural Development.

Table 2.2-2 Modeled Irrigated Acreage

County	Irrigated Lands for Full Supply Scenario [(2)] (acres)	Futures Projects (acres)	Total (acres)
Big Horn	164,404	0	164,404
Fremont [(1)]	196,502	52,667	249,169
Hot Springs	27,465	0	27,465
Natrona	551	0	551
Park	161,099	0	161,099
Washakie	50,405	0	50,405
Total	600,426	52,667	653,093

Notes:

(1) Source: Reduction of Irrigated lands database (TriHydro, 2003) as used in

(2) Irrigated lands derived as follows:
530,606 acres: Irrigated lands within model study area
2,385 acres: Man-made riparian within model study area
67,435 acres: Lands with water rights within model study area minus Futures Projects

2.2.6 – Theoretical Crop Irrigation Requirement

Crop consumptive use requirement is the maximum water use of a well-watered crop under optimum growing conditions (Pochop; et al, 1992). A portion of the crop consumptive use is met by effective rainfall (or rainfall that reaches the root zone and meets a portion of the consumptive water requirement before occurring as surface runoff). The portion of the crop consumptive use that is not met by rainfall is referred to as the Crop Irrigation Requirement (CIR). Actual conditions often vary from the theoretical CIR for a variety of reasons, such as the micro-climates at the site that may be different from the climate station, variations in genetics of different strains of the same crop, and more likely, varying soil types. However, CIR gives an estimate of the amount of water that is required to produce a crop under ideal conditions on a system-wide basis.

As has become a standard for use in the WWDC river basin plans, the crop irrigation requirements presented in Consumptive Use and Consumptive Irrigation Requirements – Wyoming (Pochop, et al, 1992) were used in this analysis. The study utilizes 1951 – 1990 climatic data to calculate CIR for several crops and climate stations throughout the study area.

Because climatic dry, average, and wet periods in summer months during irrigation are often different than the dry, average, and wet periods in the winter that produce runoff, the average CIR was used for all three hydrologic conditions.

There are 13 climatic stations within the Wind/Bighorn River Basin at which CIR is reported. CIR continually varies between these stations based on localized climate, topography, elevation, etc. However, normally, these variations are small and for regional planning efforts, the CIR values can be extended to areas outside of the exact climatic station location. For purposes of this analysis, the Theissen polygon method was utilized to determine the "influence area" for each climatic station. This method draws lines between each station, then bisects them midway with a perpendicular line. The intersections of these bisection lines makes up polygons for which all irrigated lands within the polygon uses the CIR at the climatic station. The climatic stations and their associated acreages within each basin are presented in Table 2.2-3, while a map showing the climate stations and the climatic areas developed using the Theissen polygon method is presented in Figure 2.2-1.

Table 2.2-3 Area within Climate Station Theissen Polygon

CIR Station	Irrigated Acres within Station Polygon by Basin			Total Irrigated (acres)
	Bighorn	Clarks Fork	Wind	
Basin	106,434	0	0	106,434
Boysen Dam	0	0	23,242	23,242
Cody	49,927	4,563	0	54,490
Dubois	0	0	20,185	20,185
Fort Washakie	0	0	49,483	49,483
Lander	0	0	11,603	11,603
Lovell	40,507	0	0	40,507
Powell	73,435	13,735	0	87,170
Riverton	0	0	91,528	91,528
Sunshine	28,962	0	0	28,962
Ten Sleep	18,395	0	0	18,395
Thermopolis	24,365	0	1,278	25,643
Worland	42,784	0	0	42,784
Grand Total	384,809	18,298	197,319	600,426

Notes:

1. Does not include Tribal Futures projects or Popo Agie Basin.

2.2.7 – Cropping Patterns

Cropping patterns are available from two sources: the United States Department of Agriculture (USDA) 1992/1997 Census of Agriculture (USDA, 1997) and the Wyoming Agricultural Statistics for 2000 (WASS, 2002). A summary of the published cropping patterns and distributions are presented in Table 2.2-4, while the USDA cropping distribution by county is shown in Figure 2.2-2.

In general, for purposes of the modeling effort, the USDA values were used to determine the cropping pattern for the irrigated lands. The USDA values were used because they represent averages of more than one year within the study period (1973-2001), as compared with the Wyoming Agricultural Statistics, which represent only one year at the end of the study period. In addition, for certain climatic stations such as Sunshine and Dubois, it is recognized that many of the crops that are shown in the county-wide cropping patterns are not grown. Therefore, within these two polygons, it was assumed that only hay and alfalfa are grown (at the same distribution as without the remaining crops). Then, the cropping patterns for the remaining stations were modified so that the county-wide cropping pattern remains consistent.

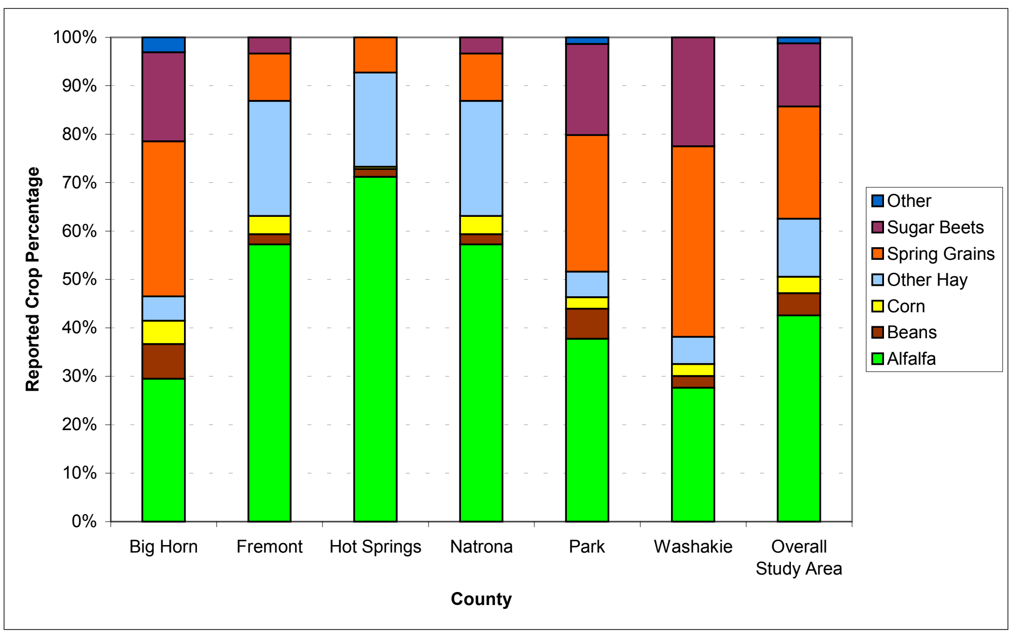


Figure 2.2-2. County-Wide Cropping Pattern for Study Area (USDA, 1997)

Table 2.2-4. Reported Acreage and Cropping Patterns within Wind/Bighorn Basin

County	Crop	Wy. Ag. 2002 (1) (acres)	Wy. Ag. 2002 (1) (percent)	USDA 1992/1997 (2) (acres)	USDA 1992/1997 (2) (percent)
Big Horn	Alfalfa	26,000	31%	25,286	29%
	Beans	7,500	9%	6,145	7%
	Corn	7,200	8%	4,116	5%
	Other Hay	6,000	7%	4,321	5%
	Spring Grains	24,100	28%	27,476	32%
	Sugar Beets	14,400	17%	15,740	18%
	Other		0%	2,661	3%
Sub-Total		85,200	100%	85,745	100%
Fremont	Alfalfa	66,000	63%	65,349	57%
	Beans	2,000	2%	2,441	2%
	Corn	6,000	6%	4,282	4%
	Other Hay	20,000	19%	27,143	24%
	Spring Grains	5,700	5%	11,136	10%
	Sugar Beets	5,100	5%	3,836	3%
	Other		0%		0%
Sub-Total		104,800	100%	114,187	100%
Hot Springs	Alfalfa	10,000	60%	12,235	71%
	Beans	300	2%	274	2%
	Corn		0%	80	0%
	Other Hay	5,000	30%	3,335	19%
	Spring Grains	1,300	8%	1,255	7%
	Sugar Beets	0	0%		0%
	Other		0%		0%
Sub-Total		16,600	100%	17,179	100%
Park	Alfalfa	35,000	36%	36,378	38%
	Beans	8,000	8%	5,945	6%
	Corn	5,700	6%	2,283	2%
	Other Hay	8,000	8%	5,132	5%
	Spring Grains	23,700	25%	27,137	28%
	Sugar Beets	16,200	17%	18,100	19%
	Other		0%	1,332	1%
Sub-Total		96,600	100%	96,307	100%
Washakie	Alfalfa	13,000	32%	12,211	28%
	Beans	1,700	4%	1,065	2%
	Corn		0%	1,095	2%
	Other Hay	1,000	2%	2,471	6%
	Spring Grains	16,700	41%	17,369	39%
	Sugar Beets	8,800	21%	9,932	22%
	Other		0%		0%
Sub-Total		41,200	100%	44,143	100%
Total	Alfalfa	150,000	44%	151,459	43%
	Beans	19,500	6%	15,870	4%
	Corn	18,900	5%	11,856	3%
	Other Hay	40,000	12%	42,402	12%
	Spring Grains	71,500	21%	84,373	24%
	Sugar Beets	44,500	13%	47,608	13%
	Other	0	0%	3,993	1%
Total		344,400	100%	353,568	100%

Notes:

1. From Wyoming Agricultural Services (WASS, 2002)
   Spring Grains: Irrigated Spring Wheat = Barley, Oats, Spring Wheat (a majority is Barley)
   Other Hay: All Hay (-) Alfalfa Hay
2. From USDA 1997 Census of Agriculture (USDA, 1997)
   Other Hay: Grass Hay, Small Grain Hay, Other Tame Hay, Wild Hay, Grass Silage
   Other: Field Seed, Fruits

2.2.8 – Full Supply Crop Irrigation Requirement (CIR)

Based on the cropping patterns and crop irrigation requirements for the climatic station polygons, the CIR for each of the irrigated lands polygons was calculated. A summary of the CIR for the lands within the Wind/Bighorn River Basin Plan is shown in Table 2.2-5. These CIR values represent the theoretical maximum crop irrigation requirement, calculated using the methodology above, and is considered the full supply irrigation requirement for purposes of the model.

Table 2.2-5 CIR for Irrigated Lands with Wind/Bighorn River Basin Plan by Model Sub-Basin

Model Sub-Basin	Irrigated Acres	Monthly CIR (acre-feet)								Unit CIR (ac-ft/ac)
		Apr	May	Jun	Jul	Aug	Sep	Oct	Annual	
Upper Wind	138,863	10,561	33,354	60,572	80,813	63,577	26,875	1,149	276,901	1.99
Little Wind	45,536	1,842	8,887	18,442	26,128	20,646	8,755	617	85,317	1.87
Lower Wind	12,919	1,913	3,870	6,317	8,198	6,385	2,950	219	29,852	2.31
Owl Creek	17,839	2,334	4,326	6,849	9,107	7,043	3,182	307	33,148	1.86
Nowood	21,725	1,360	4,204	9,104	12,053	7,335	2,925	156	37,137	1.71
Upper Bighorn	63,150	5,979	16,883	30,534	36,846	22,846	10,552	967	124,607	1.97
Greybull	98,046	8,042	24,528	43,862	56,399	38,320	18,034	2,023	191,208	1.95
Shoshone	158,187	13,547	36,759	65,870	91,206	59,951	26,728	3,355	297,416	1.88
Lower Bighorn	25,862	2,789	7,338	12,854	16,247	10,490	4,995	581	55,293	2.14
Clarks Fork	18,299	1,637	4,251	7,642	10,539	6,957	3,113	440	34,579	1.89
Yellowstone	0	0	0	0	0	0	0	0	0	0.00
Madison/Gallatin	0	0	0	0	0	0	0	0	0	0.00
Total	600,426	50,003	144,400	262,046	347,536	243,550	108,109	9,814	1,165,458	1.94

Notes:

1. Does not includes Tribal Futures projects or Popo Agie Basin.
2. Average values are reported; analysis does not distinguish between dry, normal or wet year hydrologic conditions for consumptive use calculations.

2.2.9 – Full Supply Diversion Requirements

The CIR represents the theoretical amount of water that is needed by the crop. Water is transported from the river to the crop through a series of conveyance facilities and on-farm facilities. These facilities lose a portion of the water that is transmitted through them before the water reaches the crops due to headgate leakage, evaporative losses, seepage, etc. These inefficiencies must be accounted for in determining the monthly diversion requirement for any crop.

2.2.10 – Overall Efficiencies

Overall efficiency is typically represented as the product of the conveyance efficiency and the on-farm efficiency. Conveyance efficiencies represent the efficiencies of the canals and/or pipelines that transmit the water from the diversion headgate to the farm turnout. Conveyance efficiencies typically vary from 65 to 90 percent, with unlined open channel distribution systems generally having lower efficiencies and pipe systems generally having the highest efficiencies (SCS, 1992 and WWDC, 1999). The distribution systems' length, soil types, lining types, and the canal cross-section and condition of structures, can all have an effect on conveyance efficiencies. The on-farm efficiency represents the efficiency of applying water to the field from the farm turnout to consumptive use by the crop. On-farm efficiencies typically vary from less than 30 to nearly 65 percent, based upon the type of irrigation practices (SCS, 1992). Flood irrigation typically experiences lower efficiencies while sprinkler systems represent higher efficiencies.

Overall efficiencies are typically difficult to estimate. This study has relied upon overall efficiencies estimated from previous reports and from standard sources. For the Wind River Indian Reservation (WRIR) area, efficiencies are taken from a study conducted by the Soil Conservation Service (SCS) (1992), which estimated efficiencies for several areas within and in the vicinity of the Wind River Reservation. The SCS developed both annual and monthly overall efficiencies. For the remaining study area, efficiencies were based upon conveyance efficiencies reported by water users within the Basin (WWDC, 1999), and typical field and application efficiencies estimated by the SCS (1992). Efficiencies typically vary by month due to antecedent moisture in banks (there is more moisture in the banks later in the season, thus there is less seepage from the canal), operational conditions, etc. Therefore, the efficiencies were varied by month using the same distribution as the monthly efficiencies calculated by the SCS for the Reservation. Table 2.2-6 presents the monthly and annual overall efficiencies used in the diversion requirement calculations.

Table 2.2-6 Monthly and Annual Overall Efficiencies

Area	**Overall Efficiency by Month**								**Annual**
	March	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Average**
Dubois[1]	(4)	(4)	18%	26%	34%	34%	34%	34%	30%
Lander[1]	(4)	17%	17%	24%	37%	35%	22%	22%	28%
Other, Large [2]	(4)	27%	27%	38%	58%	55%	35%	35%	39%
Other, Small [3]	(4)	19%	19%	27%	42%	40%	25%	25%	28%
Owl Creek[1]	19%	19%	21%	28%	36%	41%	21%	17%	25%
Reservation[1]	(4)	18%	18%	25%	33%	34%	21%	21%	24%
Riverton[1]	(4)	20%	24%	39%	52%	52%	27%	27%	34%

Notes:

(1) From (SCS, 1992).

(2) Based on average conveyance efficiencies from 1999 Irrigation System Survey Report (WWDC, 1999), large blocks with some lined canals and pipelines, and adequate management (SCS, 1992). Monthly distribution from (SCS, 1992)

(3) Based on average conveyance efficiencies from 1999 Irrigation System Survey Report (WWDC, 1999), small systems with unlined canals and sufficient management (SCS, 1992). Monthly distribution from (SCS, 1992)

(4) No consumptive use within month.

2.2.11 – Full Supply Diversion Requirement

Based upon the crop irrigation requirements and overall irrigation efficiencies, full supply diversion requirements were calculated for the irrigated lands. The diversion requirement is calculated as the crop irrigation requirement divided by the efficiency of the system. The estimated full supply diversion requirements by sub-basin are shown in Table 2.2-7. As expected with the wide variations in efficiencies, the unit full supply diversion requirements expressed as acre-feet per acre also vary.

Table 2.2-7 Full Supply Diversion Requirements for Irrigated Lands within Wind/Bighorn River Basin Plan by Model Sub-Basin

Model Sub-Basin	Irrigated Acres	Monthly Diversion Requirement (ac-ft)								Unit DR (ac-ft/ac)
		Apr	May	Jun	Jul	Aug	Sep	Oct	Annual	
Upper Wind	138,863	52,990	148,602	171,535	172,482	134,611	102,584	4,465	787,269	5.67
Little Wind	45,536	10,235	49,374	73,769	79,175	60,722	41,692	2,939	317,907	6.98
Lower Wind	12,919	9,564	16,124	16,198	15,766	12,278	10,924	811	81,666	6.32
Owl Creek	17,839	12,282	20,600	24,462	25,298	17,178	15,153	1,804	116,776	6.55
Nowood	21,725	6,808	21,019	32,189	27,630	17,780	11,296	607	117,327	5.40
Upper Bighorn	63,150	24,750	68,152	87,259	69,516	45,400	33,940	3,206	332,223	5.26
Greybull	98,046	31,053	99,224	126,122	106,124	77,173	57,435	6,379	503,512	5.14
Shoshone	158,187	52,322	142,958	181,860	163,473	113,701	80,601	9,984	744,901	4.71
Lower Bighorn	25,862	13,143	34,599	42,899	35,225	24,039	18,191	2,113	170,209	6.58
Clarks Fork	18,299	7,765	20,260	25,860	23,152	16,156	11,494	1,605	106,293	5.81
Yellowstone	0	0	0	0	0	0	0	0	0	0.00
Madison/Gallatin	0	0	0	0	0	0	0	0	0	0.00
Total	600,426	220,913	620,912	782,154	717,841	519,040	383,310	33,912	3,278,082	5.46

Notes:

(1) Does not include Tribal Futures projects or Popo Agie Basin.

2.2.12 – Summary and Conclusions

The purpose of the analysis summarized in this section was to document the status of historical and current agricultural water use within the WBHB and to document the methodologies used to develop data necessary for the river basin simulation models. A summary of the irrigated lands identified in this study as well as those documented in the 1972 Water Plan (SEO) is presented in Table 2.2-8. The current estimate of irrigated lands is approximately 54,000 acres (10%) greater than the estimate of irrigated lands in the 1972 Water Plan. In addition, the estimate of idle lands is approximately 44,000 acres (150%) greater than the estimate of idle lands in 1972. The differences could be due to increased lands under irrigation, but are more likely a difference in estimation techniques. For instance, the definition of idle lands in the 1972 Water Plan (lands purposely left idle for any given year or lands on which a crop was planted but not harvested) is much more strict than used in this study (basically any land with a water right not currently irrigated but that has shown any signs of past irrigation). Another factor is that the current basin plan considered all lands in the Wind River Irrigation Project that were given water rights as either irrigated or idle, whereas the 1972 Water Plan may have not.

Direct comparisons of consumptive use are not as easy because the current basin plan did not calculate consumptive use for the Popo Agie Basin, as it was already included in another water study. However, a comparison of unit consumptive use (ac-ft/ac) can be made. The 1972 Water Plan calculated a total consumptive use for the 538,830 acres as 1,028,500 acre feet, or approximately 1.91 acre feet per acre. As shown in Table 2.2-5, the current basin plan calculated a consumptive use of 1,165,000 acre feet for the 600,400 acres used in the model, or approximately 1.94 acre feet per acre, which agrees very closely to the consumptive use calculated in the 1972 Water Plan.

A major purpose of the irrigated lands and consumptive use calculations in this study was to provide data for overall basin planning, therefore a conservative approach was taken. The conservative approach ensures that all lands with currently or recently active water rights are considered in the water needs analysis and are considered when available surface water is determined. More detailed analyses could be performed once specific projects are identified.

Table 2.2-8 Summary of Irrigated Lands

Category	1972 Water Plan (SEO)		2002 Wind/Bighorn Basin Plan[3]
	Current (1972)	Projected (2000)	
Irrigated Lands (acres) [1] [2]	509,640	516,330	563,529
Idle Lands [1]/Lands with Water Rights (acres) [2]	29,190	22,500	72,794
New Land Development [1] /Tribal Future Projects (acres) [2]	---	102,670	52,667
Total	538,830	641,500	688,990

Notes:
(1) Term used in 1972 Water Plan
(2) Term used in Wind/Bighorn Basin Plan
(3) From Irrigated Lands Mapping (Includes Popo Agie Basin)
Irrigated Lands = Mapped Irrigated Lands + Man-Made Riparian
Idle Lands = Lands with Water Rights – Tribal Futures Projects
New Land Development = Tribal Futures Projects

2.3 – Municipal Water Use Profile

2.3.1. – Introduction

According to the U.S. Environmental Protection Agency (EPA), there are currently 58 active municipal and non-municipal community public water systems in the WBHB (Lamb, 2002). Through its water system surveys, the Wyoming Water Development Commission (WWDC) has acquired detailed information on approximately 40 of these public water systems. Information provided in the 2002 Water System Survey (WWDC:WSS, 2002) indicates these systems are capable of storing more than 36.7 million gallons of water obtained from rivers, streams, wells, reservoirs, and lakes to serve more than 59,000 people, or roughly 87% of the WBHB population. The average daily municipal water use for the WBHB is approximately 12.2 million gallons per day (MGD), or roughly 207 gallons per day per person (WWDC, 2002). Figure 2.3-1 shows the location of public water supplies in the WBHB.

This section provides water use and capacity information for these 58 municipal and non-municipal community public water systems that are located in the WBHB. Of the following 25 municipalities in the WBHB, only 11 serve more than 1,000 people. Surface water is the primary source for most of these larger population centers and is utilized to supply 68% of the average water use in the WBHB. Ground water is the source of supply for the larger populated areas of Greybull, Dubois, Basin, and Worland, and is utilized to supply 32% of the average water use in the WBHB. The following municipalities primarily use ground water sources of supply:

- Burlington
- Manderson
- Greybull
- Hyattville
- Dubois
- Hudson
- Pavillion
- Shoshoni
- Ten Sleep
- Worland
- Basin

The following municipalities utilize surface water sources as their principal supply:

- Lander
- Riverton
- Thermopolis
- Meeteetse
- Byron
- Deaver
- Powell
- Frannie
- Lovell
- East Thermopolis
- Kirby
- Lucerne
- Cody
- Cowley

Within the vicinity of these municipalities are various subdivisions, mobile home parks, water and sewer districts, and water users associations that utilize surface and ground water sources for community public water systems. Riverton supplements its surface water supply with ground water from the Wind River Aquifer, and it represents their sole supply during the non-irrigation season. In addition, Yellowstone National Park utilizes surface water for its visitors to the park.

Information used in the preparation of this section was acquired from several different sources and is tabulated in the **Technical Memorandum, Chapter 6, Appendices A and B**. For the community public water systems in the WBHB that provided information to the WWDC, the 2002 Water System Survey Report provided the basis for establishing their water system capacity and existing use. The EPA public water system database provided the basis for information on the remaining community water systems. To acquire additional information, these systems were contacted by telephone and were asked to complete a brief questionnaire about their system. In a few cases, information obtained on the water system or the data in the WWDC 2002 Water System Survey Report, as reported to the WWDC, could not be confirmed.

2.3.2 – Ground Water Use

Based on the listing of public water systems registered with the EPA in the WBHB, more than 16,000 people rely on ground water sources of supply for their community water systems. Some of these systems obtain water from shallow alluvial wells and/or springs, which may be regulated as ground water under the direct influence of surface water. Roughly 75% of these people are served by ground water delivered from the Towns of Greybull, Dubois, and Worland, and the South Big Horn County Joint Powers Board. More detailed usage information is included in

Chapter 2, Section 6 of the Technical Memorandum "Municipal Water Use Profile", Appendix A. Locations of wells that are used for municipal supply and produce more than 50 gpm can be found in **Technical Memorandum "Municipal Water Use Profile", Chapter 2, Section 6**.

Of the 58 municipal and non-municipal community public water systems that are located in the WBHB, 36 of these systems are serviced by ground water derived from high quality sources in the WBHB. These community systems use at least 3.9 MGD on average based on information provided to the WWDC. Peak ground water usage is more than double that amount at 8.8 MGD. Several small communities report low average per capita use ranging from 40 to 70 gallons per capita per day (GPCD), while the Towns of Greybull and Ten Sleep reportedly use the most on average ranging from 450 to 500 GPCD. Peak usage per capita ranges from 48 GPCD in the North Riverton Water & Sewer District to 1,500 GPCD in the Town of Ten Sleep. Several of these systems are unmetered and per capita usage could not be verified.

2.3.3 – Surface Water Use

Based on the listing of public water systems registered with the EPA in the WBHB, at least 43,000 people in the WBHB rely on surface water sources of supply for their community water systems. While 22 public water systems service residents of the WBHB with surface water, only seven sources that are controlled by various entities are utilized for supply. These sources include the Middle Popo Agie River, Wind / Bighorn River, Wood River, Buffalo Bill Reservoir (Shoshone River), Gardner Creek, Panther Creek, and the Firehole River. Lander and Thermopolis divert water for their own use and supply other entities. The largest surface water diversion is the Shoshone Municipal Pipeline that obtains water from Buffalo Bill Reservoir and distributes water to roughly 21,000 people downstream along the Shoshone River. Riverton, Meeteetse, and Yellowstone National Park all divert surface waters for their own water supply use. Of the municipalities in the WBHB, Riverton is unique in that the town supplements with ground water during the summer months and exclusively uses ground water for municipal supply during the non-irrigation season. The location, population served, and source for these community public water systems are listed in **Chapter 2 of the Technical Memorandum, "Municipal Water Use Profile"**. More detailed usage information is included in the **Technical Memorandum, Chapter 2, Section 6, Appendix A**.

The 22 municipal and non-municipal community public water systems that are located in the WBHB utilize a substantial amount of water to supply both average and peak demands. These community systems use an average of 8.3 MGD based on information provided to the WWDC by the community public water systems. As with ground water sources, peak surface water usage is almost more than double average use and is approximately 16.2 MGD. On a per capita basis, the Mammoth Hot Spring system within Yellowstone National Park reportedly uses the least amount of water at an average rate of 10 GPCD, while the City of Thermopolis uses the most on average at 530 GPCD. Peak usage per capita ranges from 100 GPCD at Mammoth Hot Spring to 1,136 GPCD in Meeteetse. Again, several of these systems are unmetered and per capita use could not be verified.

While 7 entities obtain their municipal water supply from surface water sources, most of the 22 community water systems that are actually served return water from their wastewater treatment facilities to the stream from which they obtained their supply. The impact of this practice upon surface waters can best be determined by assuming that depletions in streamflow are equal to the unit amount of the diversion minus the unit return flow to the stream. In several instances, municipal return flows, however, actually augment streamflow because those municipalities obtain their water supply from non-tributary ground water sources. Estimated surface water depletions were calculated on a monthly basis to accommodate the modeling efforts for this planning study. These estimates of monthly diversion and wastewater discharge were developed from information provided by each community system. Only actual wastewater point source discharges have been considered in this analysis.

2.3.4 – Conclusions

Surface and ground water resources within the WBHB are utilized to serve more than 59,000 people, or roughly 87% of the basin's population. The average daily municipal water use for the WBHB from all sources is nearly 12.2 MGD, or roughly 207 GPCD. Surface water is utilized to supply 68% of the average water use for 22 municipal and non-municipal community public water systems in the WBHB. Ground water is used to supply 32% of the average water use for 36 public water systems, including the Towns of Greybull, Dubois, Basin, and Worland.

Based on EPA and WWDC data, it appears that the majority of the municipal and non-municipal community public water systems in the WBHB have sufficient water to meet their current needs. However, it appears that Lander and Hudson may have insufficient water treatment and potentially water storage based on peak usage volumes. While it appears the municipal entities have sufficient water, Lander and other entities have expressed concern about the susceptibility of their water resources to drought periods. Certain ground water dependent towns are concerned about declining water levels, storage capacity, well interference, and most importantly, well redundancy. For this reason, several municipalities have sought alternative water sources to supplement their existing sources.

2.4 – Domestic Water Use Profile

2.4.1 – Introduction

The purpose of this section is to estimate overall domestic water use in the Wind/Bighorn River Basin planning area, which includes all or portions of the following counties: Big Horn, Washakie, Hot Springs, Natrona, Johnson, Fremont, Park and Teton. Within this area the principal users of domestic water supplies are rural homes and non-municipal public water systems that are regulated by the U.S. Environmental Protection Agency (EPA). These public water systems are utilized by a wide variety of users, including the following: commercial establishments, national forests and recreational areas, state and national parks, campgrounds, rural schools, businesses, ranches, rest areas and other small water users.

Within the planning area, both surface and ground water sources are used to provide domestic water supplies. Ground water from wells is used almost exclusively to provide domestic supplies to rural homes and supplies virtually one half of the water used by all non-municipal public water systems. Surface water sources provide the other half of the water used by these public water systems, and are used exclusively to provide domestic supplies at Canyon and Grant Villages in Yellowstone National Park. Surface water is also used on a limited basis by many rural homes to irrigate lawns and gardens.

2.4.2 – Non-Municipal Public Water System Usage

In order to estimate domestic water use by non-municipal public water systems, the EPA was contacted to obtain a listing of systems in the planning area. By definition, a public water system may be publicly or privately owned, and must serve at least 25 people or 15 service connections for at least 60 days per year. For the purposes of this report, only transient non-community and non-transient non-community public water systems were considered. Community systems that include municipalities and subdivisions were considered in Section 2.3, Municipal Water Use. EPA records indicate there are 115 non-municipal public water systems within the project area. The users of non-transient non-community systems generally obtain water from a municipal system or domestic well, and transient non-community systems generally only supply a relatively small amount of water to their users. These systems are distributed throughout the area as follows: 13 in Big Horn County, 30 in Fremont County, 3 in Hot Springs and Natrona Counties combined, 52 in Park County, 13 in Teton County, and 4 in Washakie County.

EPA reported the population served by these non-municipal public water systems was 34,287 people, of which 74.1% were located in Yellowstone National Park in Teton County. It is anticipated that they only use a limited amount of water, and that this usage is seasonal given the high population percentage attributable to Yellowstone National Park. To estimate domestic water usage from these 115 public water systems, an estimated usage rate of 75 gallons per capita per day (gpcpd) was assumed. This assumption yields an estimated domestic water usage of 2.57 million gallons per day (MGD).

Both ground and surface water supplies are utilized to meet daily domestic demands in the planning area. Of the estimated 2.57 MGD that are used, roughly 45% is supplied by surface water sources while 55% is supplied by ground water. Yellowstone National Park is the primary surface water user and obtains most of its water supplies from the Yellowstone River and Yellowstone Lake. Due to the population served, Yellowstone National Park is also the largest user of non-municipal ground water in the planning area and accounts for 53% of the overall ground water used by non-municipal public water systems in the planning area.

2.4.3 – Rural Domestic Water Usage

Because ground water is the predominant source developed for domestic supplies in rural areas, the State Engineer Office's (SEO) Database of Wells was obtained to access information on domestic wells. This database includes the permitted water right for each well. However, this amount is generally not representative of actual water use. Because wells are typically only used periodically, the total annual volume of water used is considerably less than the well could produce if it were pumped continually. It is also likely that some of the permitted domestic water rights are inactive.

The spatial distribution of water rights for domestic wells in the planning area were aggregated, tabulated, and utilized to create a well information layer in the basin GIS, as shown in figure 2.4-1. Each domestic well was geospatially located with the GIS. The representative dot for each well in the GIS layer is linked to tabular data obtained from the SEO.

Population data, rather than water rights for ground water wells were utilized to estimate domestic water usage in the planning area. Rural domestic water use was estimated on the basis of the rural population served by wells in combination with assumed per capita usage rates. Year 2000 census information, sorted by county, was obtained from the U.S. Census Bureau. Estimates of population served by municipal systems discussed in Section 2.3, Municipal Use, were then subtracted from the total county population to estimate the number of domestic users. Table 2.4-1 summarizes the population served by community public water supplies and the estimated rural population for Big Horn, Fremont, Hot Springs, Park, and Washakie Counties using the method described above. For the approximately 19 domestic wells that are located within the planning area in Natrona County, domestic water use was estimated based on average household size, the number of wells, and an assumed per capita usage rate.

Total rural domestic water usage for the planning area has been estimated to range up to 7.8 MGD. Based on Table 2.4-1 and the assumption that there are 2.5 persons for each of the 19 wells or households in Natrona County, the total rural domestic population for the planning area is estimated to be 26,002. This population represents approximately 30% of the total population within the basin. It is presumed that this population is served by domestic ground water wells, and therefore, is independent of the population served by municipal water systems. Assuming this population uses between 150 and 300 gallons per capita per day (gpcpd), the total domestic ground water use ranges from 3.9 to 7.8 MGD.

Almost 83% of rural domestic water supplies are predominantly derived from wells located in Fremont and Park Counties. Fremont County contains approximately 59% of the estimated rural population, while Park County is inhabited by roughly 23.7%. The high density of wells in these counties is illustrated on Figure 2.4-1. Based on their locations, it appears that the Alluvial, Wind River, Willwood and several Paleozoic Aquifers provide the majority of ground water used for domestic purposes in rural areas, not only in Fremont and Park Counties, but throughout the planning area.

2.4.4 – Conclusions

Based on rural domestic and non-municipal public water system usage, total domestic water usage for the planning area has been estimated to range from 6.5 to 10.4 MGD. Assuming the rural domestic population of 26,002 uses between 150 and 300 gpcpd, estimated rural domestic ground water use ranges from 3.9 to 7.8 MGD. Almost 83% of rural domestic water supplies are predominantly derived from wells located in Fremont and Park Counties. For the 34,287 people who use the 115 non-municipal public water systems, domestic water usage is estimated at 2.57

MGD, assuming a usage rate of 75 gpcpd. Approximately 74% of the people who use these systems are located in Yellowstone National Park in Teton County.

Both ground and surface water supplies are utilized to meet daily domestic demands in the planning area. Of the estimated 6.5 to 10.4 MGD that are used, roughly 26% is supplied by surface water sources while 74% is supplied by ground water. Yellowstone National Park is the primary surface water user and obtains most of its water supplies from the Yellowstone River and Yellowstone Lake. Rural domestic water users consume approximately 58% of all ground water used for domestic purposes, while non-municipal public water systems in Yellowstone National Park and the rest of the planning area use roughly 23% and 19%, respectively.

TABLE 2.4-1
Rural Population Estimates by County
In the Wind/Bighorn Basin[1]

County Population	Population Served[2]
Total Big Horn County Population	11,461
Total Big Horn County Municipal Population	9,253[3]
Estimated Big Horn County Rural Population	**2,208**
Total Fremont County Population	35,804
Total Fremont County Municipal Population	20,461[4]
Estimated Fremont County Rural Population	**15,343**
Total Hot Springs County Population	4,882
Total Hot Springs County Municipal Population	4,276
Estimated Hot Springs County Rural Population	**606**
Total Park County Population	25,786
Total Park County Municipal Population	19,623[5]
Estimated Park County Rural Population	**6,163**
Total Washakie County Population	8,289
Total Washakie County Municipal Population	6,654[6]
Estimated Washakie County Rural Population	**1,635**
Estimated Rural Population of All Counties	**25,955**

Notes: [1] A more detailed description can be found in the Technical Memorandum "Domestic Water Use Profile".
[2] Inconsistencies in the total municipal population reflect differences in the populations served by municipalities as reported to the EPA and WWDC.
[3] Big Horn County municipal population estimate excludes the populations of those towns that are served by other water systems in the county.
[4] Fremont County municipal population estimate excludes the population of one subdivision that purchases surface water from the City of Lander.
[5] Park County municipal population estimate excludes the populations of those towns in Big Horn and Park Counties that are served by the Shoshone Municipal Pipeline.
[6] Washakie County municipal population estimate excludes the population of South Worland, which is served by the City of Worland.

2.5 – Industrial and Mining Water Use

2.5.1 – Introduction

Most industrial water users in the Wind/Bighorn Basin (WBHB) are comparatively small companies, with relatively low water needs. In most cases, these companies draw their water from municipal systems, or from their own wells. In many cases the water used from wells for industrial purposes is not suited for other uses due to poor water quality. For those industries utilizing water from municipal sources, that consumptive use is included in the WBHB as municipal use. Projections of industrial water needs at low, medium and high growth rates over the planning period are discussed in Chapter 4.

2.5.2 – Industry in the WBHB

The WBHB's economy, like Wyoming's as a whole, has long depended on a triad of industries: mining (especially coal, bentonite, oil and gas), tourism and agriculture. Mining's annual payroll in Wyoming nearly doubles that of retail trade, the nearest competing sector. In terms of numbers of jobs, it trails only retail trade and accommodation, and food services (U.S. Census Bureau, 1997 Economic Census). Other economic sectors, such as manufacturing, are significantly impacted by events in the minerals industries. Another energy-producing industry, hydroelectric power production, needs to be considered. Virtually all hydroelectric power is currently produced by the U.S. Bureau of Reclamation at its reservoirs, although there may be more potential in the power generation industry. Wyoming's electricity costs are well below the national average, and this might prove useful in attracting new manufacturing plants.

2.5.3 – Manufacturing

Large manufacturing companies are rare in the WBHB, as they are in the state as a whole. In the WBHB there are about two-dozen manufacturing companies that consistently maintain a workforce of twenty-five or more. Most of the larger companies' products are related to Wyoming's overall character – products derived from minerals, products for agriculture, and products for camping, hunting and fishing. Machinery, electronic goods, and fabricated metal products are also manufactured in the WBHB.

Table 2.5-1 Types of Manufacturing in the Wind/Bighorn Basin

Industry	Location
Sugar beet refineries	Worland, Powell
Bottling, water and beverages	Worland
Aluminum can manufacturing	Worland
Light manufacturing (Brunton Company)	Riverton
Bentonite Plants	Greybull, Lovell, Worland, Lucerne
Sulphur plant	Rural Fremont County

2.5.4 – Power Production

Hydroelectric power is produced by water-driven turbines at thirteen Bureau of Reclamation sites in Wyoming, six of which are in the WBHB. Collectively the six WBHB plants have a production capacity of 47,100 kW. Clearly the Wind/Bighorn system is capable of producing considerably more power. A 1993 study for the U.S. Department of Energy listed sites with potential for hydropower production on the Bighorn River at Kane and Thermopolis, as well as on the Clarks Fork, Popo Agie, and Shoshone Rivers. Other listed sites were on Shell, Sunlight, Sunshine, and Tensleep Creeks (Francfort, 1993).

The concern is whether or not there is a ready market for increased amounts of electric power, and whether or not the power can be transmitted to market. The possibility of the deregulation of the electric power industry exists, creating many uncertainties in the industry. Historically, the industry has been vertically integrated, with power generation, transmission, and distribution linked within corporations. Legislation mandating separation of these functions has been enacted in Oregon, Arizona, and Texas, and suspended in California after having been enacted. In Wyoming, restructure has been studied, but there are currently no active efforts to legislate deregulatory action. (Energy Information Administration, 2002. http://www.eia.doe.gov) Although the potential to produce more power in the WBHB exists, at this time the transmission capacity necessary to export that power is lacking. The future of the state's electric power industry is uncertain, since "transmission issues cloud investment in generation" (Wyoming Energy Commission, http://www.wyomingenergy.org). Development of additional generation capacity, for export outside the state, appears to hinge on further development of markets and transmission capacity. Power production for local consumption and/or peak demand is more promising.

Currently there are no commercial fossil fuel power generation facilities in the WBHB. Small gas-fired, gas-cooled, turbine generating stations are utilized in the oil and gas industry for internal use such as powering gas pumping stations. Historically there has been both coal mining and coal fired power production in the WBHB, however, reported coal production ceased in the WBHB in 1966 and 1994, respectively (Lyman, 2002). However, as discussed in the report "Power Generation Potential in the Wind River, Clarks Fork, and Bighorn Basins of Wyoming", there are sufficient coal and natural gas reserves in the WBHB to support at least modest power production.

Promising new developments in combined-cycle gas turbines, using gas-fired, gas-cooled turbines in combination with waste heat/gas-fired conventional steam turbines may make natural gas electric power production more competitive. William Liggett of the Energy Information Agency points out that "Technological improvements in gas turbines have changed the economics of power production. No longer is it necessary to build a 1,000- megawatt generating plant to exploit economies of scale. Combined-cycle gas turbines reach maximum efficiency at 400 megawatts, while aero-derivative gas turbines can be efficient at scales as small as 10 megawatts" (http://www.eia.doe.gov).

2.5.5 – Mining: Oil & Gas, Coal, Uranium, Bentonite, and Gypsum

Over the years the WBHB, as well as the state generally, benefited from repeated mining booms; there has been oil and gas, bentonite and industrial minerals, and coal production in the WBHB for many decades. Oil and gas remain important to the WBHB economy, with gas plants in all counties except Hot Springs, but it seems unlikely that the future will offer many more jobs in the industry. There appears to be more potential in the Wind River Basin Province than in the Bighorn Basin Province (Fox and Dolton, 1995).

The future for uranium mining appears to be in-situ development, in which wells, rather than open-pit mines, are used to extract the ores. Non-potable ground water is re-injected into ore seams as part of a reverse osmosis process, resulting in a net consumptive loss of only 5% or so. Uranium production via in-situ methods is active in the Powder River Basin, making Wyoming one of the largest uranium producing localities in the United States. One potential future in-situ uranium mine, Power Resources, Inc., is permitted but not in production in the Gas Hills Uranium District, Fremont County. Additional uranium reserves in the District, held by other interests, could support a second in-situ operation or enhance the longevity of the currently planned development.

Wyoming leads the nation in bentonite production, and it is mined at several locations in the WBHB. The outlook for bentonite production seems to be a continuance of the status quo. No large increases or decreases in productions seem likely. (Madsen and Magstaff, 2002). Bentonite processing plants are located in Big Horn County at Greybull and Lovell and Washakie County in Worland. The Black Hills Bentonite plant in Worland uses about 500,000 gallons of water per month, purchasing it from the City of Worland. Near Greybull, WyoBen's water is pumped from the Bighorn River, and used mainly for dust control on haul roads. Lovell's American Colloid plant uses bentonite to produce drilling mud, and uses very little water. The future of that operation is closely tied to that of oil and gas drilling (Bischoff, 2002.) There are gypsum plants in Park and Big Horn Counties, producing wallboard. Well water is used in the process, and recycling is practiced in all plants.

Despite the vicissitudes of minerals production, mining in the WBHB has generally offered better-paid jobs than most other industries. It remains fundamental to the WBHB's economic foundation. Absent the development in the WBHB of major new industries, such as light manufacturing or agriculturally related industry, the size and makeup of both the economy and population will continue to be strongly related to the economics of mineral production.

2.5.6 – Summary of Consumptive Industrial Use

Current Water Rights/Usage

The **Technical Memorandum, Chapter 2, Section 8, Appendix A** contains a listing of all industrial and mining water rights, surface and ground water, in the Wind River/Bighorn River

Basins, from Division III, State Engineer's Office, tabulation, 1999. In summary, the permitted water rights for mining and industrial uses in the Basin are:

Oil & Gas, including pipelines	73,792 acre feet per year
Mining, dust control and mine pit waters	2,741 acre feet per year
Manufacturing and miscellaneous industrial	15,708 acre feet per year
Total Permitted Water Use - Industrial and Mining	92,241 acre feet per year

Steam Power Plant Water Usage

Although there are currently no fossil fuels power plants in the WBHB, there is a potential reserve base for either coal or natural gas fired electric power production. It is estimated that a nominal 200 MW coal-fired steam turbine facility would require approximately 4,000 acre feet per year of water and a 500 MW gas-fired combination turbine facility would require approximately 5,000 acre feet per year of water.

2.6 – Environmental and Recreational Water Uses

2.6.1 – Introduction

Environmental and recreational uses are, for the most part, non-consumptive uses. Environmental and recreational uses are very important in the WBHB, with respect to socioeconomic impacts and general contribution to Wyoming's quality of life. Environmental and recreational water needs are closely related, and are often, in the current social and regulatory climate, controversial. Institutional factors play a large role in the management of water for these needs, particularly in the WBHB, where nearly eleven million acres are public lands. Recreational uses of water, such as fishing and boating, are usually non-consumptive, but dedication of water to environmental purposes can at times exclude other uses. The quality and quantity of good recreational opportunities, however, are highly dependent on water quality and quantity – the two uses are closely interrelated.

Recreation, including tourism, is one of Wyoming's three major industries. Hunters and anglers alone spent $700,588,360 in the state in the year 2000 (Equality State Almanac, 2000). Major recreational activities dependent on water are fishing, boating, waterfowl hunting, and swimming. Other recreational activities such as big-game and upland game bird hunting, snowmobiling, skiing, sight-seeing, photography, camping, and golfing are also more or less sensitive to water quantity and quality.

2.6.2 – Institutional Considerations

Institutional variables are very important in assessing current and future uses, both environmental and recreational. Management of land, water, wildlife and associated resources occurs within a multifaceted context of institutional constraints. However, perhaps the most basic institutional constraint is fragmented ownership and control of natural resources.

2.6.3 – Land Ownership and Management

An important factor in managing lands and waters for recreational and environmental purposes is the fractured nature of land ownership and control in the WBHB. 15.2 million acres land is publicly owned, with management divided among numerous governmental agencies at local, state and national levels. As well, demographic, economic, social and political factors within the Reservation can influence resource management in the whole of the WBHB. Refer to Chapter 1, Table 1.3-1 "Land Ownership in the WBHB" a tabulation of the diverse nature of land management in the WBHB.

2.6.4 – Threatened, Endangered, and Candidate Taxa:

The presence of threatened or endangered species of plants and animals, or of species that might be considered for such listing, can make water management and development more complex. A number of taxa in Wyoming are so listed. Section 2 (c)(2) of the Endangered Species Act requires state and local agencies to cooperate with federal agencies in issues involving such taxa. Particularly in cases in which federal land is involved, such cooperation means conducting wildlife and plant studies of the targeted area. Some of the listed animal and plant taxa are found in the WBHB. Animal Species include the grizzly bear, whooping crane, Kendall Warm Springs dace, bald eagle, black-footed ferret, lynx, Preble's meadow mouse, Pike minnow (squawfish), razorback sucker, Wyoming toad, and gray wolf. Listed plant species are Colorado butterfly plant, blowout penstemon, Ute ladies' tress, and desert yellowhead. There are also other taxa that have been proposed for addition to the Threatened list, and a long list of Candidates (258 species) for endangered or threatened status.

Efforts are ongoing to protect and restore populations of the Yellowstone Cutthroat Trout in the WBHB, particularly in the drainages of the Greybull, Wood, and South Fork of the Shoshone rivers. Shovelnose Sturgeon have been released in the Bighorn River in an effort to restore those populations.

In regard to threatened and endangered species, however, the U. S. Fish and Wildlife Service states that "While it is prudent to take candidate taxa into account during environmental planning, neither the substantive nor procedural provisions of the Act apply to a taxon that is designated as a candidate." Nonetheless, as a practical matter, the presence or possible presence of Threatened, Endangered, Proposed, or Candidate taxa in locales that could be affected by water projects, must be considered by developers. Wildlife and plant (and cultural) studies are routinely done early on in most projects, particularly if public lands are involved.

2.6.5 – Wild and Scenic Rivers

Wyoming's only Congressionally designated "Wild and Scenic River" is a twenty-mile stretch of the Clarks Fork River in Park County. Other WBHB streams have been suggested as deserving protective status, including the Porcupine drainage in Big Horn County, and Wiggins Fork in Fremont County. (U.S. National Park Service, 1982).

The Clarks Fork heads in Montana's Beartooth Mountains, flows into Yellowstone Park and Park County, and then north to Montana again. The river provides wilderness-type fishing and kayaking, especially in its spectacular canyon. Fishing pressure is higher outside the park, in the lower reaches of the river. The possibility of damming the river for purposes of storage, power generation, bringing new land under irrigation, and perhaps transferring Clarks Fork water into the Shoshone River Basin, has been investigated (WWDC, Clarks Fork Level II, 1986).

2.6.6 – Glaciers

The Wind River Mountains are home to the largest glacier field in the lower forty-eight states. The field covers about 17 square miles, and seven of the ten largest glaciers in the lower 48 are in this field. The melt waters from these glaciers contribute to the flow of the Wind/Bighorn River, and are thought to be particularly important in maintaining fisheries and irrigation water in late summer and early fall (July through October). For further discussion on the glaciers and their impact on the Wind River base flows, see Section 2.8, chapter 2, page 44, Wind River Range Glaciers.

2.6.7 – Yellowstone National Park

Yellowstone, the nation's and the world's oldest national park, is a World Heritage Site. Although management of Yellowstone National Park is the province of the U. S. National Park Service, Wyoming takes the position that the Park Service needs permitting from the state to use the water. Within the portion of Yellowstone in the WBHB drainage, the Park Service has received permits from the state to drill wells for the purpose of monitoring water levels and condition, and has a surface water right to one acre foot per year for domestic use at its East Entrance facilities. Fishing inside Yellowstone National Park is licensed by the park service and does not require a Wyoming (or any state) license. Recreational and environmental management within Yellowstone National Park is done by the Park Service.

Visitors to Yellowstone National Park provide the bulk of the WBHB's tourism. From 1990 through 2000, recreational visitors to Yellowstone National Park averaged nearly three million people per year, but the East Entrance, west of Cody, averaged fewer than 400,000 per year during the 1992-98 period (Yellowstone National Park, Visitation Statistics). The South Entrance, reached through Fremont and Teton Counties (as well as from the west and south) averaged more than 800,000 per year during the same period. These numbers suggest that perhaps 500,000 to 600,000 people bound for Yellowstone pass through the WBHB each year. The percentage of visitors who stop to recreate in the WBHB is probably best suggested by sale of short-term non-resident fishing licenses, 30,372 in 2000 (Wiley, 2001).

2.6.8 – Wind River Indian Reservation (WRIR)

The Wind River Indian Reservation, home of the Eastern Shoshone and Northern Arapaho Tribes, covers more than two million acres in Fremont and Hot Springs counties. Within the boundaries of the WRIR are extensive private lands, and the WRIR operates within a context of tribal, federal, state and local authority and activity. Natural resources on the WRIR are in general jointly owned by the two Tribes. Tribal water rights date from the 1868 Treaty between the United States and the Shoshone Tribe. Water is managed under the Wind River Water Code, jointly adopted in 1991 by the Tribes (Collins, August, 2000).

A Water Resources Control Board is the “primary enforcement and management agency responsible for controlling water resources on the Reservation.” (Wind River Water Code, 1991). Lengthy legal proceedings between the State of Wyoming and the Tribes awarded the right to 500,000 acre feet of water to the Tribes, of which 209,000 acre feet are reserved for future use. The Tribes sought to utilize their awards for such environmental/recreational purposes as wildlife usage or instream flows in litigation, but failed in court to make such changes.

Within the WRIR are more than 200 lakes and over 1000 miles of streams. Fishing on the WRIR requires a Tribal license. The Tribes reported selling 2,472 permits in 1998, and 3,577 in 1999. About 60% of these sales were to non-residents (University of Wyoming, Cooperative Extension Service, 1999). There is significant potential for further development of recreational opportunities, including water-based activities, in the WRIR.

2.6.9 – Reservoir-Allocated Conservation Pools and Recreation Permits

"Conservation storage" describes all of the storage capacity allocated for beneficial purposes, and is usually divided into active and inactive areas or pools. "Active storage" or “Active Conservation Pool” refers to the reservoir space that can actually be used to store water for beneficial purposes. Each reservoir has an allocation for an Active Conservation Pool, which holds reservoir inflow for such uses as irrigation, power, municipal and industrial, fish and wildlife, navigation, recreation, water quality, and other purposes. “Inactive storage" refers to water needed to increase the efficiency of hydroelectric power production, to areas beneath the lowest outlet structures, where water can't be released by gravity, and to areas expected to fill up with sediments.

Table 2.6-1 displays the size of the conservation pools in WBHB reservoirs. For a detailed description of the permitted water rights in the WBHB that have a recreational component, see **Chapter 2, Section 9, of the Technical Memorandum “Environmental and Recreational Use”.**

Table 2.6-1: WBHB Reservoir Conservation Pools (Acre-feet)

Reservoir	Active	Inactive	Total
Bighorn	336,103	477,576	813,679
Boysen	378,184	179,097	557,281
Buffalo Bill	604,817	41,748	646,565
Bull Lake	151,737	822	152,559
Pilot Butte	29,918	665	30,583
WBHB	1,500,759	699,908	2,200,667

2.6.10 - Instream and Maintenance Flows and Bypasses

In Wyoming, instream flow water rights cannot be issued to private interests, only the state can hold them. The Wyoming Instream Flow Statue (41-3-1001 to 1014) narrows the use of instream flow rights for fishery purposes only (Sue Lowry, Director of Policy, Wyoming State Engineer's Office, August 2002). However, maintenance of instream flows can also benefit water quality, riparian and flood plain management, ground water recharge, and aesthetic considerations.

The Wyoming Game and Fish Commission (WGFC) since 1986, has taken action to identify streams, for which the filing of applications for instream flow water rights were appropriate. The WGFC established general guidelines that are used to determine where to request applications for instream flow segments: the stream must be an important fishery, located on public lands or lands with guaranteed public access, or have existing instream flow agreements (Annear, T. C., and Dey, P. D., 2001). **Chapter 2, Section 9 of the Technical Memorandum "Environmental and Recreational Use"** provides detailed data on Instream Flow Applications in the WBHB. There is a total of 280,520 acre feet requirement permitted, and another 277,716 acre feet requirement pending. WGFC will likely request that more streams will be filed in the near future (Annear, T. C., WGFC, personal communication, July 2, 2001). Copies of instream flow Permits are included in the **Technical Memorandum, Chapter 2, Section 9, Appendix A.**

2.6.11 – Wetlands and Riparian Areas

Riparian areas and wetlands are ecologically important, helping to maintain streamflows, reduce erosion, and provide wildlife habitat. These beneficial effects contribute to higher quality recreational opportunities also, and have beneficial impacts for livestock as well. Wetlands are classified as lacustrine, palestrine, and riverine. Lacustrine wetlands lie in lowland channels, similar to but smaller than lakes. Palustrine systems are small, shallow water bodies, generally with lots of tree or shrub cover, and riverine wetlands lie along streams. A detailed listing of the type and acreage of wetlands are shown by county in Table 2.6-2. Figure 2.6-1 maps wetland areas in the WBHB.

Table 2.6-2 WBHB Wetlands (Types and Acreages by County)

County	Lacustrine	Palustrine	Riverine	County Total
Big Horn	8,054.52	22,582.79	5,286.18	35,923.49
Fremont	39,154.51	55,714.73	11,567.73	106,436.97
Hot Springs	114.00	4,791.81	1,259.32	6,165.13
Johnson	51.54	256.98	0.00	308.52
Natrona	0.00	1,182.00	14.46	1,196.46
Park	326,840.46	72,551.65	49,509.75	448,901.86
Sheridan	0.00	19.35	0.00	19.35
Teton	86,390.22	42,602.19	36,999.33	165,991.74
Washakie	627.22	4,845.70	11,961.54	17,434.46
Total	**461,232.47**	**204,547.20**	**116,598.31**	**782,377.98**

(Located in the Technical Memorandum "Environmental and Recreational Use" Chapter 2, Section9)

The U.S. Department of Agriculture has a number of programs administered by its Natural Resources Conservation Service (NRCS) that are relevant to wildlife habitat and riparian areas. Among these initiatives are the Wildlife Habitat Incentive Program (WHIP), the Environmental Quality Incentive Program (EQIP), the Conservation Resource Program (CRP), and the Wetlands Reserve Program (WRP). WHIP works with public and private organizations to improve riparian and wetland areas, as well as in upland improvement projects (U.S. Department of Agriculture, Natural Resource Conservation Service: www.nrcs.usda.gov). EQIP works with landowners on soil, water, and related concerns.

2.6.12 – Waterbodies with Water Quality Impairments

Waters are declared "impaired" when they fail to support their designated uses after full implementation of the National Pollution Discharge Elimination System permits and "best management practices." Under the Clean Water Act, every state must update its "303(d)" list of impaired waters every two years after reviewing "all readily available data and information." A listing of information on waterbodies in the WBHB that are considered quality impaired under section 303(d) of the Clean Water Act is available online at http://deq.state.wy.us.

2.6.13 – Summary of Consumptive Uses

<u>Evaporation</u>

In the WBHB's dry climate, evaporation losses are significant, particularly from the larger reservoirs. The Wind/Bighorn River traverses the lowest portions of the basins, where warmer weather increases evaporation rates. Evaporative losses are not specifically mentioned in the Yellowstone River Compact between Wyoming and Montana, but are accounted for in the gage readings used to calculate each state's allocation (Lowry, 2002.). Refer to Section 2.7 - Water Use From Storage, for evaporative losses from storage.

<u>Direct Wildlife Consumption</u>

There is no easy way to quantitatively estimate the amount of water required by wildlife in the WBHB. Differences in species, terrain, food sources, weather and climate are all relevant to the water needs of wildlife. Moose, for instance, are far more dependent on riparian areas than are pronghorns. Waterfowl and upland game birds have differing needs. The more moisture in the feed sources, the less water most wildlife consume directly. In times of drought, most herbivores require more drinking water.

Pat Tyrell, in a review of the topic in the Green River Basin plan, noted that estimates of wildlife use of surface water in that basin ranged from 100 to 400 acre-feet per year. Tyrell concludes that "while some uncertainty exists in the exact consumption value, its probable magnitude is not so high as to materially affect the water plan" (Tyrell, 2000). This conclusion seems reasonable, since beef cattle, on average, consume approximately 8 to 10 gallons of water per day, and sheep about one gallon (Wyoming Agricultural Statistics Service, 2001). The consumptive water needs of wildlife would be much lower than those of domestic livestock. If the WBHB were to double the estimated amount of water consumed by wildlife in the Green River Basin, it would be 200 to 800 acre feet – still not a large amount. It seems likely that Tyrell's estimate is conservative. If there were 250,000 animals in the WBHB each drinking a gallon a day the total consumption would only be .76 acre feet per day, or 280 acre feet per year. Distribution of water on ranges is probably a more significant problem than quantity. Forage is not as fully utilized by livestock or wildlife when it is too far from water.

2.6.14 – Recreational Demands

Water is important in both outdoor and indoor recreation. Although in terms of volume the water demand for "indoor" (in the present context meaning such facilities as swimming pools and water parks) is not high, such facilities are significant socially and can be economic assets. School, municipal, private, and commercial swimming facilities exist in most of the WBHB's larger towns. The water demand of such facilities is for the most part captured as part of municipal water demand.

Outdoor recreation is an integral part of the WBHB's culture. The larger reservoirs, in particular Buffalo Bill, Boysen, and Bighorn, are major water-based recreation destinations. Fishing, boating, and picnicking are popular pastimes at these reservoirs. The drainages of the Shoshone, the Clarks Fork, the upper Wind, and the Bighorn all attract anglers, as do many reaches of the rivers themselves. Rafting and boating is carried on in all the rivers, with kayaking and whitewater rafting available in canyon reaches of the rivers. Water is an important amenity in all the state parks in the WBHB. In addition to public waters, there are a few small private fishing reservoirs.

There are about 95 river miles along the Wind/Bighorn River from Boysen Dam to Bighorn Canyon. A 1986 Bureau of Land Management (BLM) report, prepared with the cooperation of the WGFC, estimated that most recreationists on this reach of the river were residents, with heavy use areas receiving around 1200 visitor days per year, medium use areas averaging perhaps 600 to 800 user days, and low use areas fewer than 500. The heavier use areas were mostly around the larger towns situated on the river – Thermopolis, Worland, Basin, Greybull and Lovell. Water quality is best through the southern reach of the river, near Thermopolis. In this vicinity the stream is fairly rapid, seldom freezes over, the water is usually clear, and there are good populations of fish and waterfowl. The BLM report noted that on the river there are limited opportunities for river recreation and flatboating (U.S. Department of the Interior, BLM, 1986).

2.6.15 – State Parks

There are five state parks in the WBHB: Medicine Lodge in Big Horn County, Hot Springs in Hot Springs County, Sinks Canyon and Boysen in Fremont County, and Buffalo Bill in Park County. The WBHB's state parks are estimated to attract more than a million visitor-days per year as calculated from Wyoming State Parks and Historic Sites Fee Program, Appendix C, "Visitation Statistics," 2001. State Parks and Historical Sites defines "Visitors" as "the total number of persons entering a park or site to carry on one or more recreation activities," while "a visitor day is 12 visitor hours that may be accumulated continuously or simultaneously by one or more visitors."

Water is an attraction at all of these parks. Boysen and Buffalo Bill are located at large reservoirs, Hot Springs (which hosts the most visitors) and Sinks Canyon State Parks are located at unique water resources, and Medicine Lodge Creek adds significantly to the attractiveness of its namesake park. In addition to the state parks, there is a state-designated historical site at Legend Rock in Hot Springs County.

2.6.16 – Fishing

Fishing is probably the WBHB's major water-based outdoor recreational activity, although pleasure boating and waterfowl hunting are popular also. The major source of data collected on fishing is the WGFC's license sales and creel censuses, but these data provide only a rough indication of fishing pressure. The available quantitative data on fishing are not readily adaptable to individual waters because angler surveys are usually conducted on major waters, in response to specific needs (Annear, June 2002).

In the year 2000, 20,942 resident and 30,372 non-resident licenses were sold in the five counties of the WBHB (Wiley, 2001). A comparison of fishing license sales in 1995 and 2000 indicates that during that period resident license sales dropped by about 8% in the WBHB as a whole, while non-resident sales increased by about 20%. There were about 25% more non-resident licenses than resident sold in 2000. This is a notable change from 1995, when the difference was less than 10%. Only about 5% of non-resident licenses sold are annual permits, however. Again, sales of Wyoming fishing licenses in 2001 declined by more than eight percent compared to sales in 2000 (American Sportfishing Assn). It seems clear that fewer than half of the WBHB's residents are recreational fishermen.

The majority of fishing licenses sold in the WBHB, both resident and non-resident, are sold in Fremont and Park Counties (Wiley, 2001). This suggests that the drainages of the upper Wind and the Shoshone see the heaviest stream fishing pressure. The Clarks Fork is another important fishery, and there are many popular streams and mountain lakes on the west side of the Bighorn Mountains. Boysen and Buffalo Bill Reservoirs are particularly popular fishing venues. Wind River Canyon itself is on the Wind River Indian Reservation (WRIR), and both state and reservation licenses are required. Fishing pressure in the canyon is probably decreased by this requirement, but the stretch remains a fairly popular destination. Several miles of the Bighorn River below (north) of Wind River Canyon, in the Thermopolis area, provide good fishing as well.

Among the reservoirs, Boysen and Buffalo Bill are particularly important fisheries. Other important reservoirs for fishing (and other water sports) are Deaver Reservoir, Lake Cameahwait, Newton Lakes, Ocean Lake, and Pilot Butte and Ralston Reservoirs. Many of the fishing streams are in the mountains, on the national forests (Bighorn and Shoshone), or in Yellowstone National Park. Fishing pressure varies with ease of access, and high mountain lakes and streams are quite fragile ecologically. Both the national forests include sizable wilderness areas. The Wyoming Game and Fish Commission (WGFC) manages wildlife and fisheries on the national forests, but not in the national park. About half of each national forest is within the Wind/Bighorn drainage.

The WGFC manages fisheries with the objectives of providing angling diversity, sustaining enough catchable fish, and establishing and maintaining areas which boast trophy fish, wild fish, and unique fish. Threats to fisheries include habitat losses due to erosion (both natural and man-made), inadequate instream flow, barriers to fish migration and spawning (such as dams and dewatered channels), fish losses due to diversions or non-point pollution, and competition to native species from non-native species or algae which produce oxygen deficits.

The WGFC has established a "walk-in" fishing program to enable public access to waters surrounded by private lands. Landowners cooperate with the WGFC to allow such access. There are 20 such areas below (north of) Boysen Reservoir and below WRIR boundaries. This program provides access points to fishing on the Bighorn, Greybull, and Shoshone Rivers, and Nowood and Paintrock Creeks. In the Wind River area the

WGFC has not been as successful in securing walk-in access, although it has secured a fishing easement near Dubois (Deromedi, 2002).

Anticipating continuing growth in demand for stream fishing venues, the WGFC notes that ensuring an adequate supply of good fishing spots "is dependent on maintaining adequate streamflows in existing good segments and restoring streamflows in streams that have the potential to support good recreational fisheries." (Annear, 2002). An available opportunity for public input in fisheries management and development lies in helping to identify potential fisheries, and suggesting ways to improve or maintain them. Opportunities to maintain adequate water flows to support all uses, wildlife and human, do exist. Cooperative water use agreements can often be worked out, and conservation of water may enable streamflows in some segments to be maintained or even increased.

2.6.17 – Waterfowl

Wyoming straddles two migratory waterfowl flyways, the Pacific (west of the Continental Divide) and the Central. All of the WBHB is east of the Continental Divide, within the Central flyway. Hunting of migratory waterfowl is largely controlled by guidelines issued by the U.S. Fish & Wildlife Service.

The WBHB is divided by the WGFC into two waterfowl management areas. The Wind River Basin (essentially Fremont County) is area 4C, while the Bighorn River Basin (the other four counties) is designated 4A. The vast majority of waterfowl hunting in Wyoming is for ducks and geese, although coot, snipe, rail and sandhill crane are also hunted, but in the WBHB ducks and geese account for nearly all the waterfowl harvest.

While data on specific locations are unavailable, the Game and Fish Commission estimated that in 2000, the WBHB duck hunter days totaled 13,395, with a harvest of 19,333 ducks. The WBHB is second only to the North Platte drainage in volume of duck hunting in Wyoming. Goose hunter-days in the WBHB were estimated to be 7,730, with a harvest of 5,331 birds. The heaviest duck and goose hunting occurs after the middle of November, extending into early February for geese.

Ducks Unlimited, which has over 4,000 members in Wyoming, reports that during the 1999-2000 hunting season 11,062 federal duck stamps were sold in the state. The WGFC reports that in the year 2000 a total of 36,208 bird licenses were sold in the state. From 1995 through 2000 an average of 24,647 geese and 54,187 ducks were harvested per year. License sales for both resident and non-resident bird licenses have increased sharply over the past five years, and the harvest trend is upward (Wyoming Game and Fish Department, 2001).

Maintenance and improvement of existing wetlands and riparian areas, and establishment of new ones will be helpful in maintaining and improving habitat for waterfowl. This is a good example of the interrelationship of recreational and environmental considerations. Agricultural cropping patterns are also a factor in waterfowl populations.

2.6.18 – Adequacy of Present Recreational Resources

It seems likely that most WBHB recreational resources are lightly used relative to national standards. The trend in resident fishing permit sales in the WBHB has been slightly down, which might be expected given the aging population and the out-migration of many younger Wyomingites. There seems at the same time to be a trend toward higher sales of non-resident licenses, although only about five percent of these are annual permits. However, the WGFC "anticipates continuing increases in demand for stream and river angling," and notes that satisfying this demand "is dependent on maintaining adequate streamflows in existing good segments and restoring streamflows in streams that have the potential to support good recreational fisheries." The Department notes that public help in identifying where these segments are or might be and hints on how such waters might be better managed "is an important opportunity for participants in the water planning process" (Annear, 2002).

Other strategies that can be useful in increasing the supply of fishing opportunities in the WBHB are designated “catch and release” areas, increased planting of catchable fish and/or fry, and the manipulation of size limits and catch limits.

A number of projects to diversify and add to water-based recreational opportunities have been suggested. Among them are improved signage to identify waterbodies, improved access for users, provision of more handicap access, and development and promotion of eco-tourism at water-based recreation areas. Whitewater recreation parks might be established as well. Boating and skiing, of course, are also water-based activities, as are snowmobiling, sled dogging, skiing, and the like. There is potential to increase the number of venues and of participants in such activities (Hansen, 2002). Most of these activities, of course, are non-consumptive. However, funding mechanisms and project sponsors are not clear. Other projects can be designed to provide recreational opportunities as multiple-use components.

2.7 – Water Use From Storage

2.7.1 – Major Reservoir Information

The WBHB contains several large reservoirs used for various purposes including storage for irrigation, municipal, industrial, recreation, fish propagation, and flood control. Various federal, tribal, and private interests own the reservoirs described in this report. For purposes of the WBHB Water Plan, reservoirs having storage capacity of 500 acre feet or greater are the focus of this analysis. Table 2.7-1 identifies the reservoirs that are considered in the surface water assessment presented as part of the WBHB Plan.

2.7.2 – Reservoir Descriptions

A detailed description of each reservoir can be found in **Chapter 2, Section 9 of the Technical Memorandum “Environmental and Recreational Use”**. Table 2.7-1 shows a brief description of each reservoir with greater than 500 acre-feet of storage capacity.

2.7.3 – Evaporation

Evaporation from reservoirs is a consumptive use. These reservoirs include: Boysen, completed in 1952 (water storage, however, was initiated in October, 1951), Bighorn Lake, completed in 1966, and the entire series of reservoirs developed in the Cottonwood Drain (e.g. Lake Cameahwait and Middle Cottonwood Reservoir). Figure 2.7-1 shows the locations of the reservoirs in the WBHB.

To compute evaporation losses of each reservoir with a storage capacity of greater than 500 acre-feet, the Wyoming Climate Atlas was utilized. Table 2.7-2 of this text provides a map of mean annual lake evaporation adapted from Lewis, 1978. In order to distribute annual evaporative losses on a monthly basis, monthly evaporation data were obtained from the US Bureau of Reclamation's web site for the Buffalo Bill and Boysen Reservoirs. This data was combined with the estimated monthly evaporation data for the City of Lander provided in Martner, 1986 to develop an average monthly distribution.

Evaporation losses for each reservoir were estimated by plotting their location on the map of annual evaporation, determining an annual loss rate through means of linear interpolation, and establishing the monthly evaporative loss based on the derived distribution described above. The above process provided a reasonable estimate of the gross evaporative loss.

To determine net evaporative losses, reservoir locations were plotted on a map of average annual precipitation, Lowham, 1988. Annual precipitation depth for each reservoir was determined by linear extrapolation. A monthly precipitation distribution was developed by obtaining average monthly precipitation depths over a 30-year period, for 12 weather stations scattered across the project area. Monthly precipitation depth is determined by using the derived distribution to determine the estimated annual precipitation depths for each reservoir.

Data describing the gross evaporation and precipitation as well as any available data on average End-of-Month (EOM) reservoir storage are found in the **Technical Memorandum, Chapter 2, Section 10, Appendix A**. Table 2.7-2 presents an estimate of the maximum net evaporation loss for each reservoir considered in the Wind/Bighorn River surface water model. Calculations for net evaporative loss are conservative as the surface area considered is equal to the high water line. The **Technical Memorandum, Chapter 2, Section 10, Appendix B** provides stage-storage curves for each reservoir by drainage basin.

Table 2.7-1 – Reservoirs with Greater than 500 ac-ft of Storage Capacity

Reservoir Name	Source	Use	Priority Date	Permitted (ac-ft)
Albert Wardell Reservoir	Wardell Draw	Irr-stk	12/24/1954	294.8
Albert Wardell Reservoir Enlg.	Wardell Draw	Irr-stk	11/21/1961	265.0
Adelaide Reservoir	Adelaide Creek	Irr.	8/8/1910	4,763.5
Anchor Reservoir	S.F. Owl Creek	Irr.	12/18/1933	17,412.0
Beck Lake	S.F. Shoshone River	Irr-dom	7/24/1908	623.0
Beck Lake Enlg.	S.F. Shoshone River	Irr-dom	8/26/1969	15.0
Bighorn Lake	Bighorn River	Irr-rec	Montana Right	1,328,360.0
Boysen Reservoir	Bighorn River	Dom-irr-mun-pwr-ind	10/22/1945	757,851.0
Buffalo Bill Reservoir	Bighorn River	Dom-irr-mun-pwr-ind	3/5/1904	644,540.0
Bull Lake Reservoir	Bull Lake Creek	Dom-irr-mfg-pwr	12/26/1906	151,951.0
Cameahwait Reservoir	Cottonwood Drain Draw	Fish-wildlife-irr-stk	1/29/1973	6,683.1
Christina Reservoir	Little Popo Agie River	Mine-mill-irr-stk-dom	9/1888	3,860.0
Deaver Reservoir	Short Draw	Fish-irr-mun-rec	6/18/1991	719.5
Debatable Reservoir	Willow Creek	Irr.	9/16/1910	582.3
Enterprise Reservoir	Roaring Fork	Irr-dom-stk	8/30/1933	1,697.5
Fairview Reservoir	Manny Draw	Irr-dom-stk	12/7/1934	1,411.0
Foster No.1 Reservoir	Sage Creek	Irr.	11/2/1935	573.1
Greybull Valley Reservoir	Greybull River	Irr-rec	11/14/1989	33,169.0
Jack Pot Reservoir	Alkali Creek	Irr-RR	1/4/1911	772.0
Lake Creek Reservoir	Lake Creek	Irr.	10/1/1935	1,373.0
Leavitt Reservoir	Beaver Creek	Irr.	4/9/1954	643.5
Louis Lake Reservoir	Louis Creek	Pwr	1/6/1926	8,013.8
Luce Reservoir	Paint Creek	Irr.	8/7/1905	2,128.8
Middle Cottonwood Res.	Cottonwood Drain Draw	Irr-stk-fish-wildlife	1/29/1973	612.2
Newton Reservoir	Trail Creek	Irr.	2/7/1898	4,225.2
Perkins & Kinney Reservoir	South Sage Creek	Irr.	10/4/1893	746.3
Pilot Butte Reservoir	Big Wind River	Irr -pwr	8/8/1906	34,600.0
Prairie Reservoir	Dry Muddy Creek	Irr.	10/16/1911	578.0
Sage Creek Reservoir	Sage Creek	Irr.	12/28/1901	2,785.0
Shell Creek Reservoir	Shell Creek	Irr.	10/20/1911	1,949.0
Shoshone Reservoir	Shoshone Creek	Irr.	7/15/1937	9,740.4
Teapot Reservoir	Dry Creek	Irr.	9/9/1916	1,577.5
Ten Sleep Reservoir	Ten Sleep Creek	Irr-dom-fire-rec-stk	1/31/1938	3,508.9
Thomas Reservoir	North Rawhide Creek	Irr.	9/25/1900	863.5
Thompson No 1 Reservoir	Owl Creek	Irr	12/4/1907	920.2

* Wyoming State Engineer's Office reservoir permits were used to develop information presented in Table 2.7-1
* Irr = Irrigation, Dom = Domestic, Stk = Stock, Rec = Recreation, RR = Rail Road, Pwr = Power, Ind = Industrial, Mun = Municipal, Mfg = Manufacturing

Table 2.7-2 Annual Maximum Net Evaporative Loss

Reservoir Name	Surface Area (acres)	Evap. (in)	Precip. (in)	Net Evap. (ac-ft)
Albert Wardell Reservoir	66.2	42.6	8.0	190.7
Adelaide Reservoir	14.5	45.0	17.0	33.8
Anchor Reservoir	437.0	40.0	15.2	903.1
Beck Lake	110.0	40.5	10.0	279.6
Bighorn Lake	17,279.0	42.0	10.0	46,077.3
Boysen Reservoir	19,660.0	40.8	9.0	52,099.0
Buffalo Bill Reservoir	8,315.0	40.0	14.0	18,015.8
Bull Lake Reservoir	3,186.0	35.0	10.0	6,637.5
Cameahwait Reservoir	414.4	40.8	8.5	1,115.4
Christina Reservoir	350.0	36.1	19.0	498.8
Deaver Reservoir	80.0	41.7	6.0	238.0
Debatable Reservoir	86.0	39.0	13.0	186.4
Enterprise Reservoir	134.1	37.7	16.8	233.6
Fairview Reservoir	140.7	42.6	8.5	399.8
Foster No.1 Reservoir	140.7	40.0	22.3	207.5
Greybull Valley Reservoir	691.1	41.5	9.5	1,842.9
Jack Pot Reservoir	98.1	45.0	10.0	286.2
Lake Creek Reservoir	59.1	40.0	16.0	118.1
Leavitt Reservoir	48.8	43.9	10.0	137.9
Louis Lake Reservoir	282.2	37.7	16.8	491.5
Luce Reservoir	62.0	39.5	18.4	109.0
Middle Cottonwood Res.	116.6	40.5	8.6	310.0
Newton Reservoir	150.8	40.0	12.0	351.9
Perkins & Kinney Reservoir	44.5	40.1	18.0	82.0
Pilot Butte Reservoir	950.0	37.2	9.2	2,216.7
Prairie Reservoir	81.5	38.5	9.5	197.0
Sage Creek Reservoir	226.0	40.9	12.0	544.3
Shell Creek Reservoir	113.5	45.0	17.0	264.8
Shoshone Reservoir	502.8	36.9	20.0	708.1
Teapot Reservoir	185.0	35.0	9.8	388.5
Ten Sleep Reservoir	280.6	45.0	15.8	682.8
Thomas Reservoir	45.0	40.0	21.7	68.6
Thompson No.1 Reservoir	49.5	41.2	11.3	123.3
Sunshine Reservoir	1,158.5	40.0	15.4	2,374.9
Wiley Reservoir	67.5	40.8	13.3	154.7
Worthen Meadows Res.	92.0	37.7	19.2	141.8

2.8 – Wind River Range Glaciers

2.8.1 – Introduction

The Wind River Range of Wyoming is the headwaters of the three major drainage systems in the United States, the Wind-Bighorn-Yellowstone-Missouri-Mississippi, Snake-Columbia, and Green-Colorado drainages. The range is also home to a total of 63 glaciers, covering 17 square miles, greater than the total of all other glaciers in the American Rockies at 12 square miles. Seven of the ten largest glaciers in the continental United States are located in the Wind River Range. Of the total area of glaciers in the Wind River Range, by area, 77% are located in the Wind River drainages, with the remainder draining to the Green and Snake Rivers (Marston, et. al., 1991). Based upon a literature search of available documents relating to the glaciers in the Wind River Range, the glaciers have been retreating during recent times. Glaciers have been compared to natural reservoirs, which store water in the form of ice during cool periods both on an annual and long-term climatological scale, and release water during warmer periods. The melt water from the glaciers contributes to the flow in the Wind River, and is thought to be important during late summer and early fall to supplement flows in the Wind River needed for irrigation and fisheries, and for the fulfillment of interstate water compacts. This report summarizes the results of Wind River glacier literature review, and addresses three potential scenarios for future impacts to the Wind River due to glacial changes.

2.8.2 – Glacial Recession and Paleoclimatic Research

The earliest references to the Wind River glaciers are found dating back to 1851, with formal studies as early as 1878. Most of the studies indicate that the glaciers have been steadily retreating since the 1850's, with the exception of Wentworth and Delo, (1931), who reported that Dinwoody Glacier had readvanced by 1930 to the furthest terminus of the late Neoglacial period. Renewed retreat occurred during the 1930's, slowing in the 1940's with little or no retreat during the late 1940's, then continuing to retreat from the 1950's to the present.

Very little research was performed on the glaciers from 1960 until 1988. From 1988 to the present there has been renewed interest in the glaciers as sources of paleoclimatic and environmental data. Researchers estimate that the glaciers may disappear within 20 years if retreat continues to occur at the rates observed during this past century. This belief has contributed to a sense of urgency among the scientists who wish to obtain ice cores for research purposes before the glaciers melt completely. (Schuster, Naftz, et. al., 2000).

Ice cores from Upper Fremont Glacier were analyzed by the USGS using data from electrical conductivity measurements (ECM), oxygen isotope ratios, concentrations of elements including chlorine, sulfur, mercury, and radioactive tritium, and Carbon 14 dating of a grasshopper leg belonging to an extinct species found in ice core near the base of the glacier. The data was then compared with known events such as volcanic eruptions, periods of nuclear testing, and other natural and anthropogenic events which could have left a chemical signature in the ice. A combination of these time indicators was used to refine the chronological time line of the ice core. The data for Upper Fremont Glacier indicates that the glacier was formed during a cooling period known as the Little Ice Age, which occurred from approximately 1740 to 1845 A.D. The end of the Little Ice Age appears to have been quite abrupt, occurring within a span of less than 10 years. Prior to the Little Ice Age, tree ring records show evidence of a warming period, which extended from approximately 1650 to 1740 (Naftz, et. al., 1996, 2002 and Schuster, et. al., 2000).

2.8.3 – Potential Watershed Impacts of Glaciers

The total annual runoff from glaciers in the Wind River Range is estimated to be approximately 56,756 acre feet (70 x 10^6 m^3) for the annual melting period of July through October. Assuming equitable distribution of flows based upon aerial location, 77% of glacial runoff would enter Wind River drainages, or 43,783 acre feet (54 x 10^6 m^3) on an annual basis. This flow represents approximately 8% of the total flow in the Wind River during the same period (Marston, Pochop, et. al., 1989). The two primary creeks by which glacial meltwater is conveyed to the Wind River are Bull Lake Creek and Dinwoody Creek. Dinwoody Creek, which is fed by both Gannett and Dinwoody Glaciers, drains more glacial area than any other single headwater creek in the continental United States (Wentworth and Delo, 1931). The following table summarizes the results of limited streamflow gaging efforts on Dinwoody Creek in July, 1988 by Pochop, Marston, et. al., and extrapolation of that data by comparison with flow measurements made in the Cascade Mountains. Dinwoody Creek is estimated to convey 25% of the total ice-melt contribution to the Wind River.

Table 2.8-1
ESTIMATED CONTRIBUTION OF DINWOODY AND GANNETT GLACIERS TO DINWOODY CREEK FLOWS

MONTH	ESTIMATED ICE MELT (ACRE-FT)	DINWOODY CREEK FLOW (ACRE-FT)	% OF FLOW FROM ICE MELT
JUNE	691	27790	3
JULY	4080	30642	13
AUGUST	3268	19990	16
SEPTEMBER	2117	7929	27
OCTOBER	812	2527	32

The above estimates (Marston, Pochop, et. al., 1989) show the importance of glacial meltwater to total flows during the late season flows (27% and 32% of Dinwoody Creek during September and October, respectively). Similar estimates have not been made on other glacial fed creeks in the Wind River Range. Three scenarios are discussed regarding the potential impacts glacial change may have on flows in the Wind River.

Scenario 1: No Significant Climate Change

Under scenario 1, the assumption would be that the climate will remain fairly stable within observed average ranges, with brief periods of glacial accumulation followed by periods of drought and glacial melting on a decadal scale. One example of this type of behavior would be the brief glacial advance from 1920 to 1935 at Dinwoody Glacier, replenishing water reserves, followed by a melting period. Alternatively, snowfall contributing to glacial accumulation could roughly equal glacial ablation, resulting in continued release of melt without an overall net loss in glacial volume. The effects of glacial recession or advance would remain relatively constant, and the overall streamflows would not vary significantly. The overall impact would be minimal to irrigators and other stream uses.

Scenario 2: Drought Conditions Persist

The assumption made by Marston, et. al., and Naftz, et. al. regarding the life span of the glaciers was that the current warm / dry climate trends will continue without ceasing, and cause the disappearance of the glaciers within 20 years. If this occurs, flow to the Wind River could be reduced by approximately 8%, creating or exacerbating shortages for irrigators and instream flow demands. Under this scenario, the effects are predicted to be most noticeable during late summer and early fall, when runoff from snowmelt and rains is minimal and water use is high. If these climate predictions are correct, the loss of glacial input to Wind River flows will not be the only reduction in flow, as snow pack and annual precipitation will be expected to fall below observed averages, further reducing flows.

Scenario 3: Return of Cool / Wet Period

Review of the dates of cooling periods and warming trends presented as a result of ice core and tree ring data from the Wind River Range indicates that warming and cooling cycles are natural phenomena. Geologists estimate that there have been seven major continental glacial episodes in Earth's history, punctuated by many smaller events such as the Little Ice Age. Five different periods of glacial advance and retreat have been documented in the Wind River Range. Glacial ice core and tree ring data indicates a warming trend of approximately 90 years from 1650 to 1740, a 105 year cooling period known as the Little Ice Age from 1740 to 1845, another warming trend for 75 years extending from 1845 to 1920 followed by a brief cooling trend from 1920 to 1935, with 67 years of warming from 1935 to the present. If an average of these cycle lengths is taken as 70 years, it would not be unreasonable to predict that a new cooling episode may occur in the near future. Paleoclimatological data suggests that the shift between warm and cool periods may be quite abrupt, and the scale of such an event may be relatively large, such as the Little Ice Age, or small such as the brief advance of Dinwoody Glacier in the 1920's and 1930's. For an extended planning period of 50 years, the question would be the timing of such an event. If the cooling period were to occur within the next

15 to 20 years, before the glaciers melt completely, the glaciers would be replenished for future melt contributions to flows in the Wind River. If the current warming cycle continues for a longer period of time, the available flows would be diminished, much like Scenario 2 above, until conditions change. Jan Curtis, the Wyoming State Climatologist, indicates that if the current pattern of drought-wet years continues, increasing annual precipitation and resulting increases in glacial mass should occur over the next twenty years.

> "Glaciers have decreased probably more because of lack of precipitation than due to global (regional) warming. Since 1931, decadal average annual temperature trend shows no appreciable change over the Wind River, thus the argument for glacier melting (decrease in mass) is questionable. Unless (If) we continue to have less annual precipitation (especially winter snows), the glaciers will decrease in size. Projecting when they would disappear is highly speculative. If the pattern of drought-wet years resumes, then we should see increasing annual precipitation and therefore increasing glacier mass over the next twenty years. Since 1200 A.D., regional droughts have been relatively short and mild compared with the pre-Columbian era. I don't see that we are returning to this scenario. However, the increased population and land / water use will certainly impact the total water availability in the future irregardless of climate" (Personal correspondence, Jan Curtis, WRDS Coordinator, Wyoming State Climatologist, July 12, 2002).

2.8.4 – Summary

The meltwater from glaciers in the Wind River Range contributes to flow in the Wind River. The glaciers have been observed to be receding in recent decades, and are estimated by some to be completely gone in 20 years if current weather trends continue. If this were to occur, flows in the Wind River could be diminished by as much as 8%, impacting irrigators, instream flow demands, and interstate compacts. A review of ice core records, tree ring data, and historical temperature and precipitation data indicates that the climate has a cyclic nature, with alternating cool/wet and warm/dry periods. The impact of climate on the glaciers and subsequently the Wind River water users will depend on the timing of the next cool/wet period. In the event that the current dry period continues for an extended period of time, decreased quantities of base flow in the Wind River will exacerbate shortages caused by low precipitation and snowpack. However, if cool/wet weather patterns return, increasing annual precipitation would result in renewed advance of the glaciers, providing storage for future dry periods.

2.9 – Water Conservation

2.9.1 – Overview

Water conservation is the intelligent use, or wise management of water. Water is a finite resource, essential economically, ecologically, and sociologically. Good management considers all these aspects of water use. The original goal of Wyoming's Water Law was to foster agricultural development and other recognized "beneficial uses." The definition of beneficial uses includes: "Water rights can be issued to anyone who plans to make beneficial use of the water. Recognized beneficial uses include: irrigation, municipal, industrial, power generation, recreational, stock, domestic, pollution control, instream flows, and miscellaneous. Water right holders are limited to withdrawals necessary for the purpose. For example, irrigators are allowed to divert up to 1 cfs (cubic foot per second) for each 70 acres under irrigation (Wyoming State Engineer's Office (SEO), 1972).

The SEO, Department of Agriculture, WGFC, WDEQ/LQD, State Forestry, State Parks, and WWDC play important roles in water management at the state level. At the local level, conservation districts, water districts, municipalities, and irrigation organizations are important players. Conservation Districts in the WBHB are headquartered in Cody, Dubois, Thermopolis, Riverton, Meeteetse, Lander, Lovell, Greybull, and Worland. The Wind River Indian Reservation manages water systems on the Reservation.

Given that over 61% of the WBHB is Federal land, the Bureau of Land Management, Bureau of Reclamation, Fish and Wildlife Service, Park Service, and U.S. Department of Agriculture agencies, such as the Forest Service and Natural Resource Conservation Service, manage resources or are programmatically active in virtually all areas of the WBHB. These agencies make assistance, technical and/or financial, available to landowners or associations wishing to develop, improve the use of, or conserve water. This plethora of official and quasi-official agencies, combined with numerous private or public groups representing tourism, agriculture, hunting and fishing, municipalities, industrial, and business, ensures a broad representation of interests in the development of water management policies and decisions.

2.9.2 – Agriculture

In terms of consumptive use, agricultural irrigation using surface water is by far the largest water use in the WBHB (as in Wyoming and the West as a whole). Much of the water used for irrigation returns to the water table and to streams eventually, of course, but irrigation withdrawals remain a far larger consumer of water than municipal, domestic, or industrial uses. Major crops include alfalfa, grass hay, sugar beets, beans, corn, malt barley, and spring grains.

According to BOR Water Conservation Plans, there are approximately 380 miles of major irrigation district canals and ditches using water from Bureau of Reclamation reservoirs. These are primarily dirt conveyances, with potential water losses as high as 40%. Although it has been estimated that up to 75% of irrigation water may return to the system through overland and underground flow, return flows vary according to weather, terrain and soil conditions (Wyoming State Engineer's Office, 2000).

Most of the WBHB's agricultural water comes from the Wind/Bighorn drainage, but the Shoshone and Clarks Fork watersheds are also important. Park County leads the WBHB in the value of agricultural sales, and the larger part of that value is produced in the

Shoshone drainage. The Greybull/Wood River drainage around Meeteetse, the upper reaches of which are also in Park County, is part of the Bighorn drainage.

Irrigation is essential for most crop production in the WBHB. Major crops are alfalfa, small grains, and sugar beets. Alfalfa production dominates in terms of acreage and value, and also requires the most water. Sugar beets are important in some areas, and also demand considerable water. Spring grains (oats, barley) require less water. (Wyoming Water Resources Center, 1992). Irrigation methods vary in efficiency, with sprinkler irrigation generally considered most efficient, followed by gated pipe and lined ditches. Automated diversion and sprinkling can be helpful in maximizing the efficiency and effectiveness of water application. Center pivot systems cost around $75,000 for a quarter mile system. Pivot systems 9-12 feet high are good for such crops as corn, and can achieve 80-85% efficiency. Micro pivots (about 6' high – too low for corn) cost around $40,000 to $50,000. Gated pipe is the next most efficient system, while flood irrigation runs 40-60% efficiency. While not many such systems are in use in the WBHB, micro-irrigation, drip systems with pressure-flow regulation, are promising in some situations.

Another management option is the burial of gypsum blocks in fields. Gypsum blocks absorb and release water. Measurement of the water in the blocks indicates the amount of moisture in the soil, helping the farmer determine when it is necessary to irrigate. The use of gypsum blocks may save, on average, about one irrigation cycle per season.

Many farmers and ranchers actively seek to diversify income sources, deriving income for the same ground from multiple uses. Some raise corn and after cropping rent the fields for livestock feeding on stalks. After cropping, some plant radishes or turnips to kill nematodes and provide winter graze. A key tactic is re-irrigation after cropping, which encourages late growth for forage. Diversification opportunities include seed production, setting up small feedlots, providing space for commercial beehives, offering space for recreation activities, and, in some areas, selling bentonite.

Other conservation methods include contouring fields to improve water distribution and good maintenance of headgates and ditches. Canals and ditches may need to be lined, since many of the soil types found in the WBHB do not seal well. On rangeland, maintaining, enhancing, or creating riparian areas is beneficial ecologically and practically. Intermittent streams, as well as perennial ones, can be enhanced in terms of both quality and quantity of water, browse, wildlife habitat, and erosion control. Cost sharing programs for conservation purposes are available from several governmental agencies (Galloway, 2001).

2.9.3 – Public Water Systems

Public water systems (PWS) are charged with supplying the populace with safe and adequate supplies of potable water. There are currently 58 active municipal and non-municipal community public water systems in the WBHB. Thirty-six of these are serviced by ground water. These systems serve, collectively, about 59,000 people. Total daily water usage by these systems is about 10.6 million gallons per day, or about 180 gallons per day per person. The source of about 69% of the water used in these systems is surface water.

The EPA lists 174 permitted water systems within the WBHB, serving everything from rest stops and campgrounds to larger municipalities. A community water system, by EPA definition, is "any water system that serves 15 connections or 25 people per day for a minimum of 60 days per year."

Water conservation measures are scarce in Wyoming: of the 188 systems listed in the WWDC's 2002 report on public water systems, only 29 report having tiered rates as a water conservation measure, 24 have ordinances prohibiting the wasting of water and two report providing subsidies for efficiency. There are 25 entities that have some other form of water conservation measures in place. The average reported percentage of water loss due to leakage is 8.5% (http://wwdc.state.wy.us).

In the WBHB, according to the 2002 report of the WWDC, thirteen water systems have some form of conservation measure. Wasting ordinances are the most common measure (although used in a minority of systems), while tiered rates are used in three systems. Greybull and Lander report a 10% reduction of water usage due to conservation measures, while Byron reports a 25% reduction. Other systems did not report any reductions.

The primary factor discouraging overuse of water is probably cost to the user. As long as water is accurately metered and appropriately billed, it will generally be used in a reasonably conservative manner. The same logic applies to commercial and industrial water users, especially those which rely on public water systems.

In Wyoming the average cost of treated water is about $1.90 per thousand gallons. One WBHB industry was using over 66,419 gallons per day (gpd) for cooling compressors. The company discovered it could operate on 23,081 gpd by installing a recirculating cooling system. This provided an annual savings of 11 million gallons per year of treated water, lowering water costs as well as the bill for wastewater, which is based on the amount of metered water used (Donnell & Allred, Inc., August 2002).

2.9.4 – Environmental and Recreational Considerations

Non-consumptive uses of water have become increasingly important, for a variety of reasons. Growing societal sensitivity about ecological considerations is an important factor. Additionally, the economic value of recreational opportunities and facilities is well known, tourism is a fundamental component of Wyoming's economy. It can be enhanced by the development of more and higher-quality water-related recreational opportunities. Such opportunities include the desire of people to enjoy clean, relatively pristine water. Consideration of the ideational and recreational value of water is now a fundamental element in water planning and conservation.

Many visitors to the WBHB come to experience relatively unspoiled natural vistas and high-quality outdoor recreational opportunities. Most of these opportunities, such as fishing, pleasure boating (including white-water rafting and kayaking), swimming, photography, nature viewing, hunting, backpacking and skiing are fundamentally non-consumptive in terms of water usage. Providing infrastructure for these kinds of amenities makes the WBHB a more attractive place to live, and thus may aid economic development efforts.

A list of suggestions for recreational facilities to be considered in water development includes whitewater recreation parks, fishing access at all state highway stream crossings, identification signage at all stream and canal highway and road crossings, handicapped access to fishing and hunting at existing and future impoundments and lakes, canoe and rafting access and portages at existing and future low-head dams, diversions, etc., and development and promotion of eco-tourism components at water projects (Hansen, August, 2001).

Agricultural water uses also have recreational, environmental, and ecological effects. These effects must not be overlooked, although some may seem more ecologically benign than others. In regard to wastewater, for instance, the Greater Yellowstone Coalition notes that: Even though it is a major concern, water "waste" is an imprecise term. Comparing the ecosystem consequences of water delivery systems is more complex than adding and subtracting volumes of water. For example, while pipelines and sprinkler systems may be more efficient in transporting water and delivering it precisely, they are less effective than flood irrigation systems for recharging ground water and enhancing private land for wildlife. Overgrown, unlined irrigation ditches provide habitat and movement corridors, and flooded fields offer nesting habitat to species such as sandhill cranes (http://www.greateryellowstone.org, 2002). This statement encapsulates the complexity of water management in the WBHB. Water "loss" is a "natural" occurrence, but human actions, such as constructing dams and irrigation systems, add to "natural" evaporation from lakes, ponds, streams and wetlands.

Riparian areas produce forage and habitat for both domestic livestock and wildlife, and are ecologically important in many other ways, including erosion control. Reservoirs maintain conservation pools, generate power, control flooding, ensure streamflows, enable solids to settle out, improve downstream water quality, and provide recreational opportunities. Waterfowl and upland game bird hunting, as well as the well being of wildlife of all sorts, are helped by good water conservation.

2.9.5 – Summary

All these considerations are important elements in the WBHB's economy, its quality of life, and in water management regimes that may be developed. In the WBHB, as in Wyoming as a whole, focal points for water managers are many. Irrigation, livestock water, industrial, municipal, recreational, ecological, and fish and wildlife uses must all be considered. Whether labeled water conservation, wise use, or multiple use, what is required is careful definition, consideration and balancing of all beneficial uses.

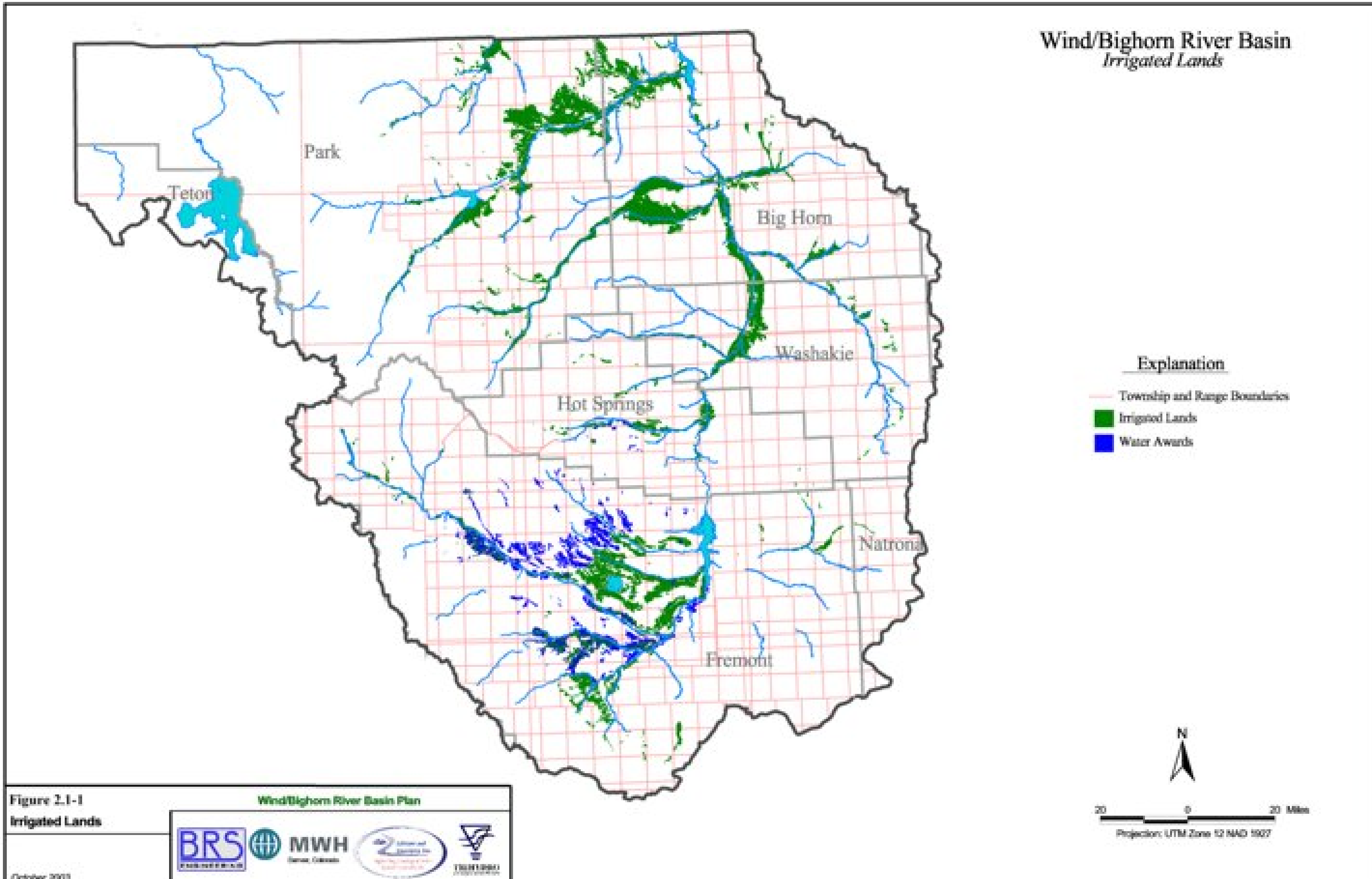
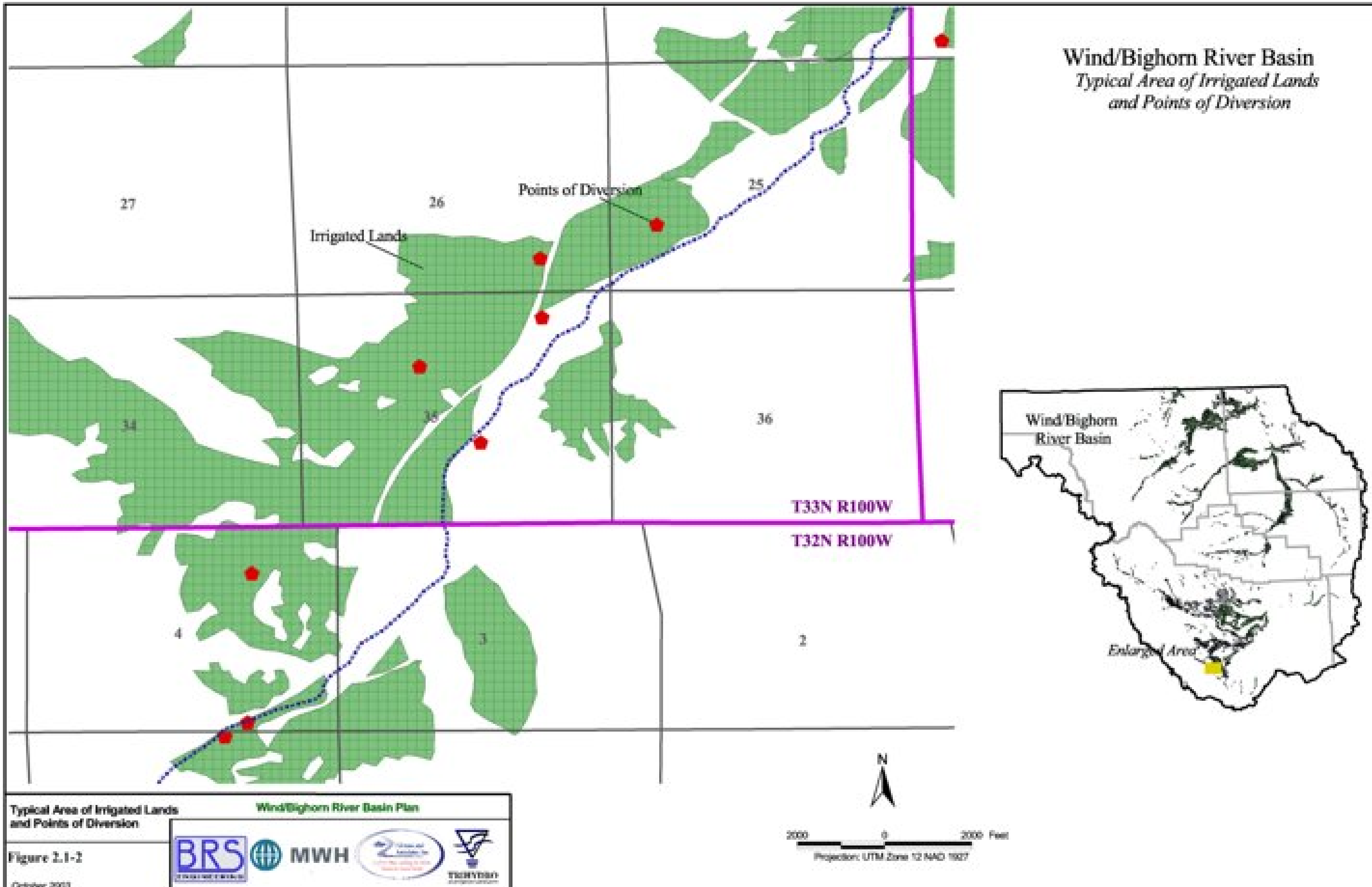


Figure 2.1-1
Irrigated Lands


Wind/Bighorn River Basin
Typical Area of Irrigated Lands and Points of Diversion
Points of Diversion
Irrigated Lands
27
26
25
34
35
36
T33N R100W
T32N R100W
4
3
2
Wind/Bighorn River Basin
Enlarged Area
N
2000 0 2000 Feet
Projection: UTM Zone 12 NAD 1927
Typical Area of Irrigated Lands and Points of Diversion
Wind/Bighorn River Basin Plan
Figure 2.1-2
October 2003
MWH

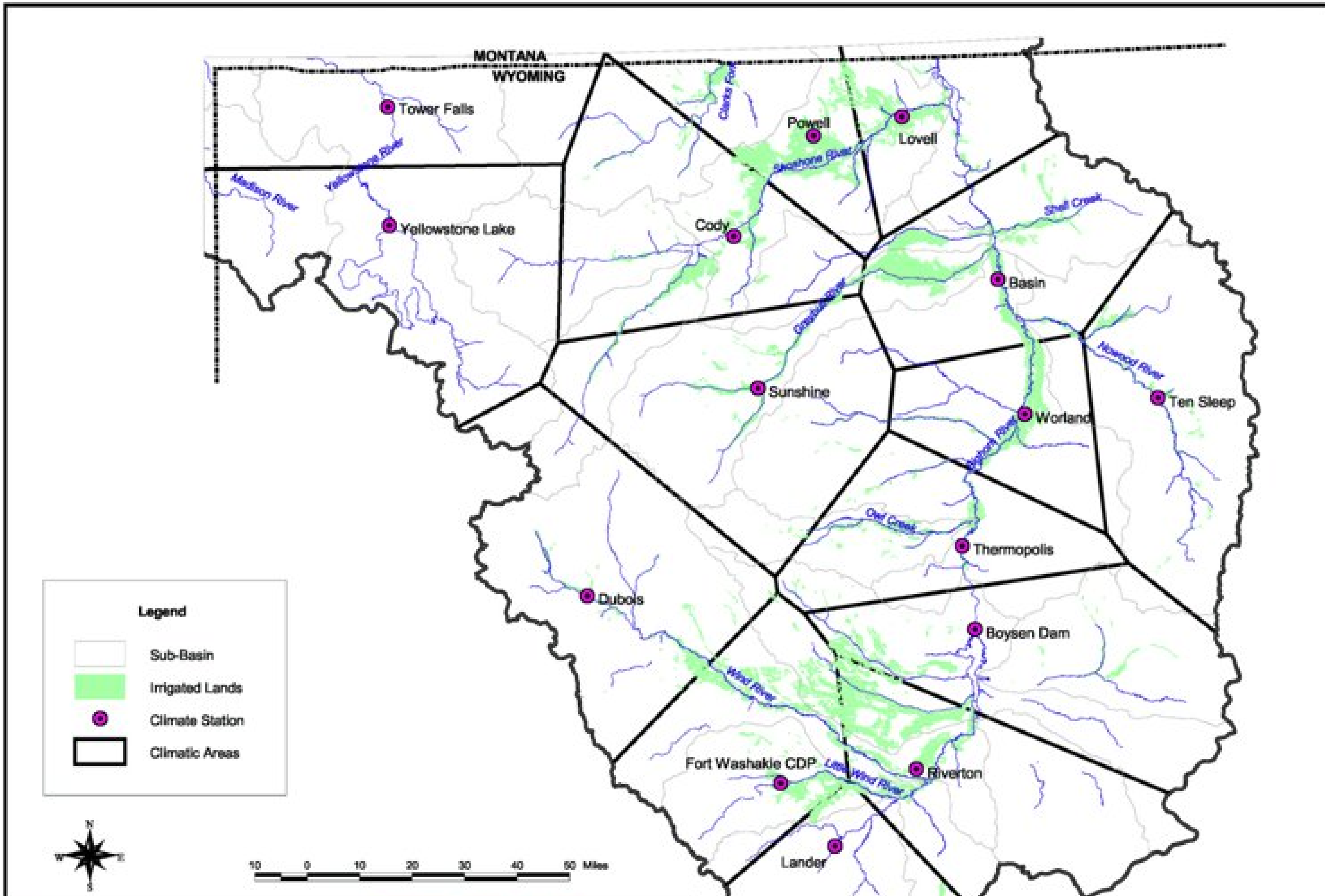


Figure 2.2-1
Climate Stations and Climatic Areas

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Wind/Bighorn River Basin Plan

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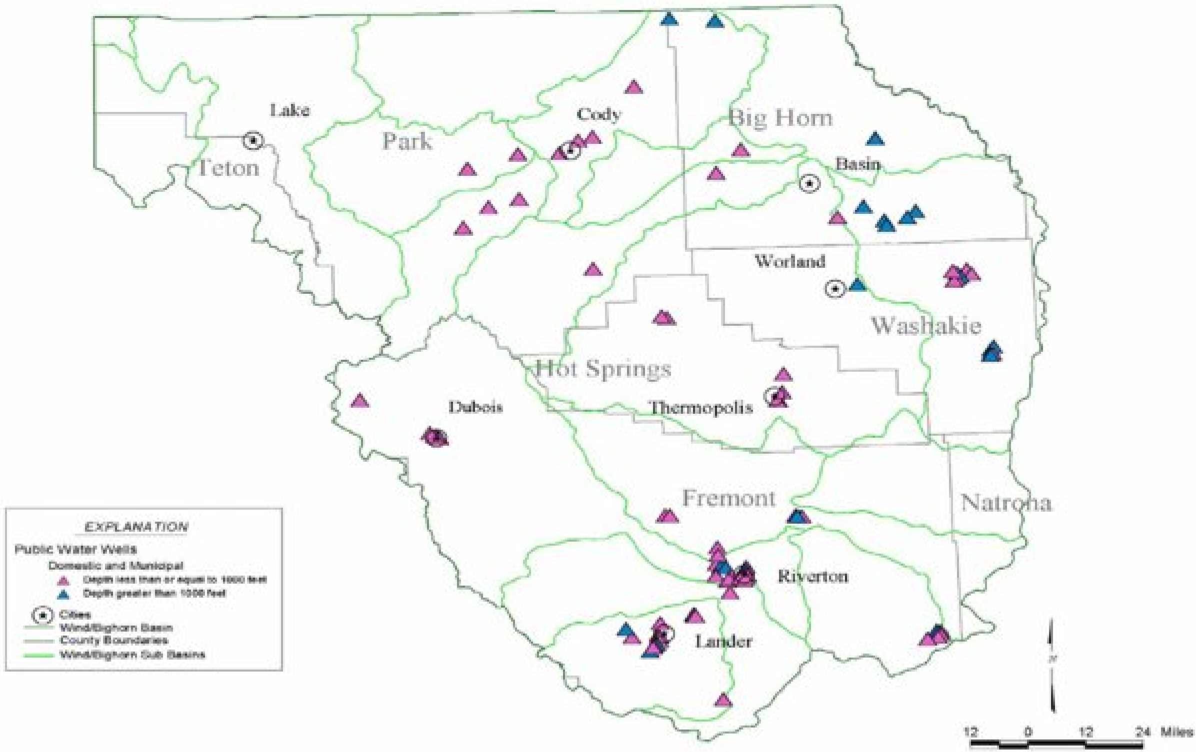

Figure 2.3-1
Public Water Supplies

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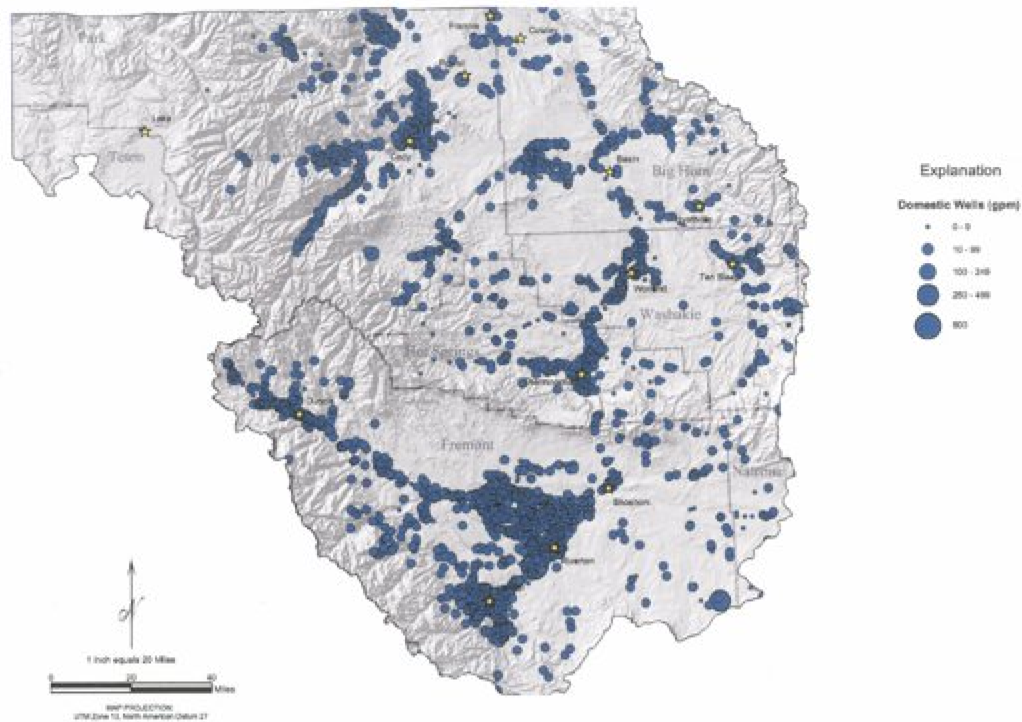

Figure 2.4-1
Domestic Ground Water Wells
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Wind/Bighorn River Basin Plan

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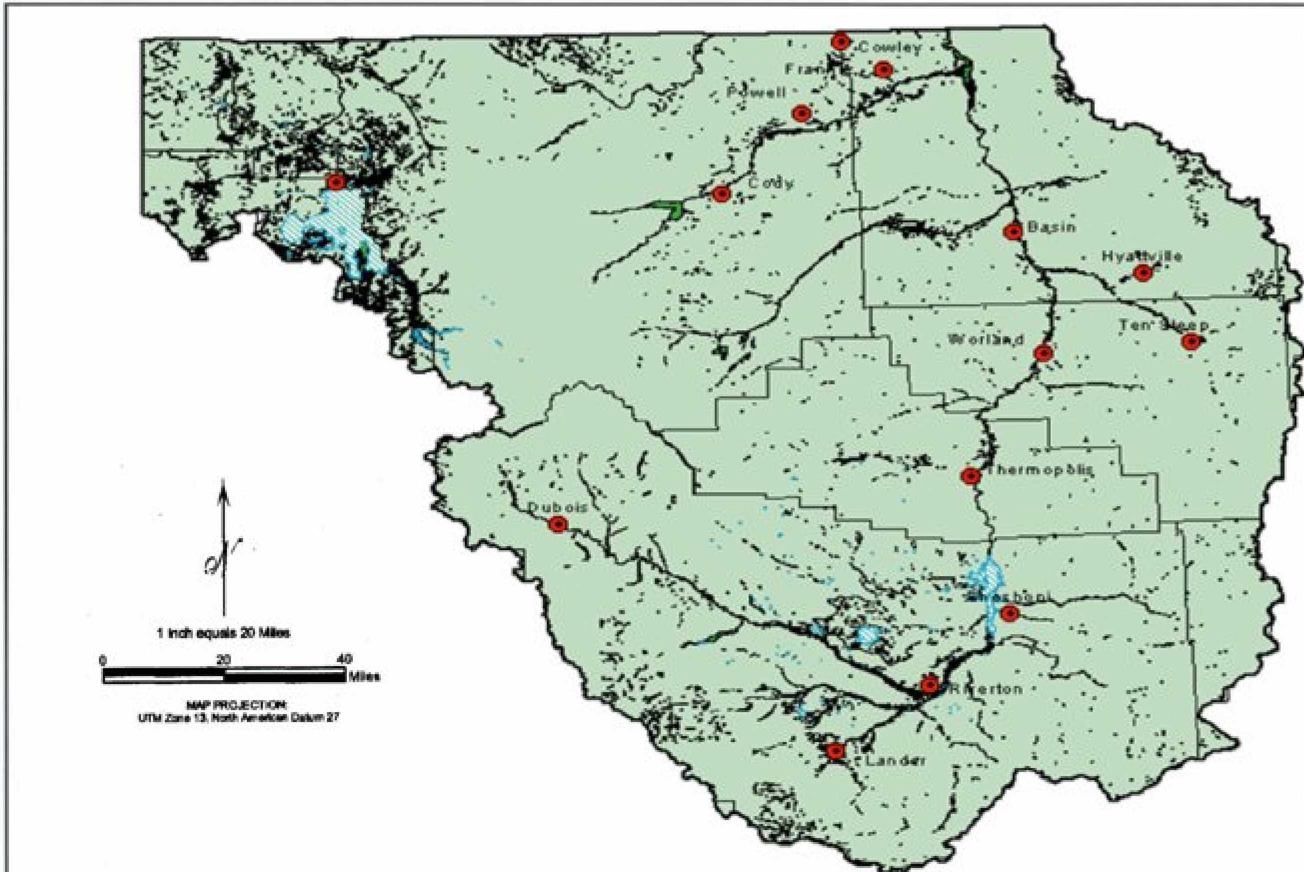

Figure 2.6-1
Wetlands

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Wind/Bighorn River Basin Plan

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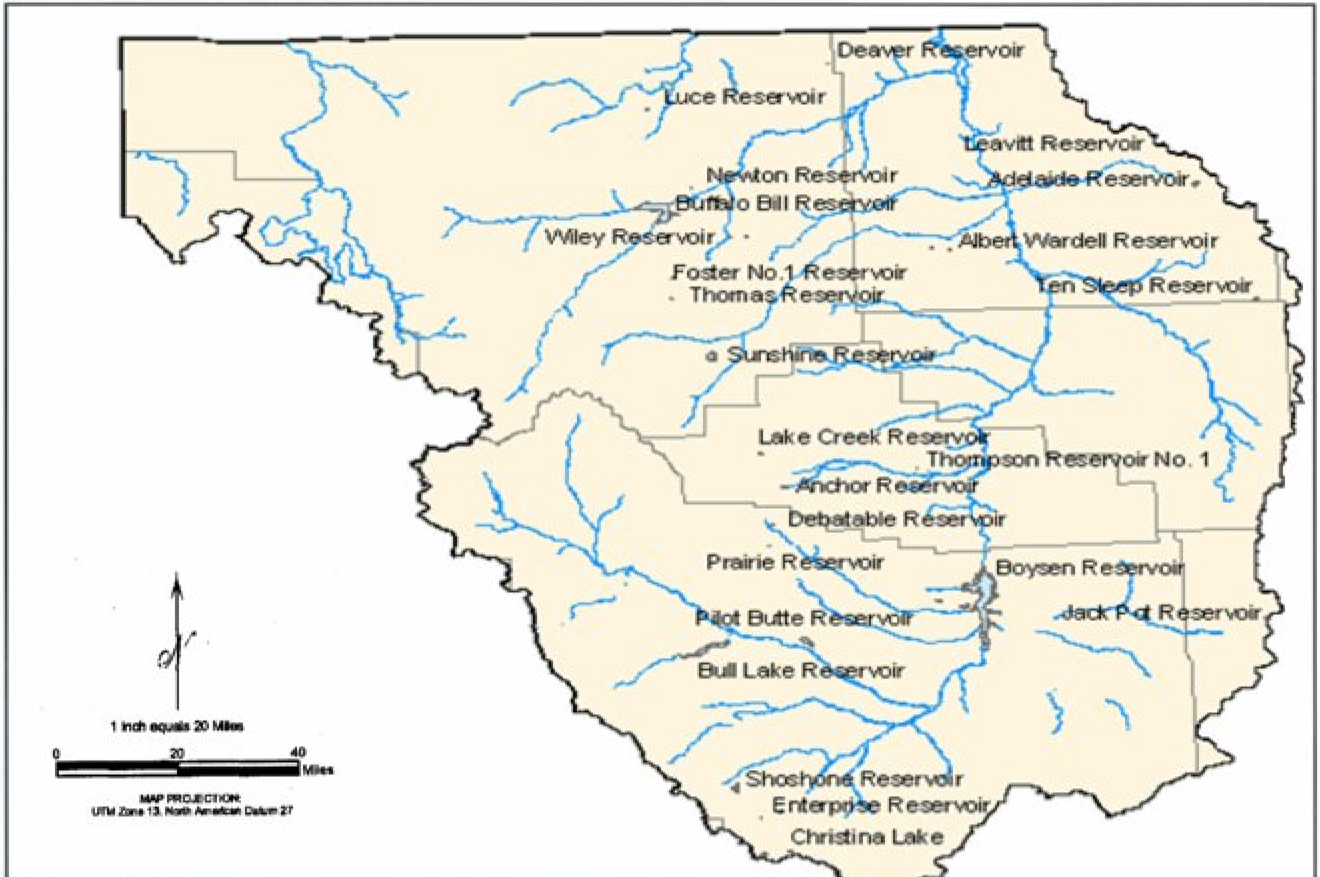

Figure 2.7-1

Reservoirs

October 2003

Wind/Bighorn River Basin Plan

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CHAPTER 3
SURFACE AND GROUNDWATER AVAILABILITY

3.1 – Surface Water Hydrology

3.1.1 – Introduction

An important part of the river basin planning process is to estimate water availability within the river basins for future development and use, this includes both surface water and ground water. The availability of surface water was determined through the construction and use of a spreadsheet simulation model that calculates water availability based on the physical amount of streamflow less historical diversions, compact requirements and minimum flows. The availability of ground water was primarily performed based on a review of existing information throughout the study area.

The Guidelines for Development of Basin Plans (WWDC, 2001) recommends that for the purposes of the river basin planning process, a hydrologic analysis be conducted for three 12-month periods using average dry-year conditions, average average-year conditions and average wet-year conditions. Therefore, each hydrologic region in the model has three associated spreadsheet models representing those three hydrologic conditions. The gaged flows used in the spreadsheet model are developed by averaging recorded monthly streamflows for groups of years falling into those three hydrologic categories during a consistent period of record.

A study area map containing major sub-basins and locations of key gages and index gages (as described later in the text) is presented in Figure 3.1-1. The study area includes the Missouri River Basins located in northwestern Wyoming, including the portions of the Madison River Basin, Gallatin River Basin, Yellowstone River Basin and Wind/Bighorn River Basin located within the State of Wyoming. Table 3.1-1 shows the USGS Hydrologic Unit classifications, which are included in the planning area and the model in which each sub-basin is included. All of the river basins are tributary to the Yellowstone River in southern Montana, which is subsequently tributary to the Missouri River in western North Dakota.

For purposes of the discussion herein, the Study Area was divided into five basins: the Madison/Gallatin River Basin, the Yellowstone River Basin, the Wind River Basin and the Bighorn River Basin. The Madison River and Gallatin River are not hydrologically connected, however, they were grouped together because the models are very small. The Wind and Bighorn Rivers are actually the same river, changing names at the “Wedding of the Water” near Thermopolis. The river is called the Wind River south of the Owl Creek Mountains while it is called the Bighorn River north of the Owl Creek Mountains. The river was separated because of the clear basin distinctions that occur through the Owl Creek Mountains. There are no hydrologic connections, other than the river itself, across the mountain chain.

Table 3.1-1 USGS Hydrologic Units and Associated Models Included in Study Area

Hydrologic Unit Code	USGS Hydrologic Unit Name	Area (acres)	Study Basin	Study Sub-Basin	Model
10020007	Madison	1,638,991	Madison/Gallatin	Madison/Gallatin	Madison/Gallatin
10020008	Gallatin	1,162,356	Madison/Gallatin	Madison/Gallatin	Madison/Gallatin
10070001	Yellowstone Headwaters	1,654,127	Yellowstone	Yellowstone	Yellowstone
10070002	Upper Yellowstone	1,897,992	Yellowstone	Yellowstone	Yellowstone
10070006	Clarks Fork Yellowstone	1,784,937	Clarks Fork	Clarks Fork	Clarks Fork
10080001	Upper Wind	1,628,472	Wind	Upper Wind	Upper Wind
10080002	Little Wind	708,641	Wind	Little Wind	Little Wind
10080003	Popo Agie	511,611	Wind	Not Included(1)	Not Included(1)
10080004	Muskrat	466,187	Wind	Lower Wind	Lower Wind
10080005	Lower Wind	1,084,233	Wind	Lower Wind	Lower Wind
10080006	Badwater	538,167	Wind	Badwater	Lower Wind
10080007	Upper Bighorn	2,217,263	Bighorn	Upper Bighorn	Upper Bighorn/Owl Creek
10080008	Nowood	1,282,397	Bighorn	Nowood	Nowood
10080009	Greybull	733,218	Bighorn	Greybull	Greybull
10080010	Bighorn Lake	1,150,802	Bighorn	Bighorn Lake	Lower Bighorn
10080011	Dry	281,821	Bighorn	Bighorn Lake/Greybull	Lower Bighorn
10080012	North Fork Shoshone	545,062	Bighorn	Shoshone	Shoshone
10080013	South Fork Shoshone	417,701	Bighorn	Shoshone	Shoshone
10080014	Shoshone	954,605	Bighorn	Shoshone	Shoshone

Notes:
(1)The Popo Agie River Basin is modeled in the Popo Agie River Watershed study. This model contains an inflow node for the Popo Agie River that incorporates these results.

3.1.2 – Historical Streamflow Records

The basin spreadsheet models utilize historical data to simulate river operations on a monthly basis during average dry, average and wet years. Therefore, data collection and reduction to useable formats within the model was the first task in the modeling effort.

Streamflow data were available for hundreds of locations throughout the study area for various periods of record. Streamflow gages are primarily operated and maintained by the U.S. Geological Survey (USGS), while the State Engineers Office (SEO) has historically operated miscellaneous gages in the Wind/Bighorn River Basin (WBHB) for brief periods to assist in water delivery and accounting. USGS data available from both the Wyoming Water Resources Data System (WRDS) and the USGS National Water Information System (NWIS) on the Internet (USGS, 2002). USGS data used in this model was researched using WRDS, then downloaded from the Internet to facilitate incorporation into existing data reduction spreadsheets.

Separate spreadsheets for each hydrologic unit were developed to store streamflow data. Typically, the base reporting level for the USGS is average daily streamflow in cubic feet per second (cfs). Therefore, in order to have available the most detailed records in the database, the average daily streamflow was downloaded from the Internet and stored in the spreadsheet. Then, the spreadsheet was used to reduce daily data into total monthly flow and total annual flow in acre-feet for each month and year that data were available.

3.1.3 – Study Period Selection

Because historical data is not available for all gages since the inception of data collection, and to make the model less expansive and easier to use, a representative study period was selected from the data set. The study period is intended to be representative of the overall long-term gage records and hydrologic conditions. To be consistent within the study period, overall patterns of basin inflows, diversions and storage must remain constant through the study period. Therefore, study periods were selected to minimize the impacts of major reservoirs or diversion projects within the period of record. This required examination of reservoir and diversion construction records. Streamflow statistics within each study period were checked against long-term statistics at gages with long-term records to ensure that the data were representative of the long-term period.

The following events were considered in selection of a model study period. Note that this list of events focuses primarily on significant events during the past 50 years that could have had significant impacts on streamflow.

- Construction of Boysen Reservoir was completed in 1952. Boysen Reservoir is located on the Wind River at the upstream end of the Wind River Canyon north of Shoshoni. The reservoir has a capacity of approximately 760,000 acre-feet.
- Pumping plants for the Hanover-Bluff Unit were completed from 1956 through 1958. The pumping plants have a combined capacity of 240 cfs.
- Anchor Dam, located in the Owl Creek Basin, was completed in 1960, and was used to temporarily store water in the mid-1960's. However, due to seepage problems in the floor of the reservoir, it typically does not provide any carryover storage, and is limited to only a portion of its original 17,000 acre-foot capacity.
- Construction of Yellowtail Dam, located on the Bighorn River at the Wyoming-Montana state line, was completed in 1967. Although the reservoir does not directly impact flows in Wyoming, the reservoir is important for downstream river management.
- In 1972, construction was completed on Lower Sunshine Reservoir, which is an off-channel reservoir in the Greybull River Basin. The reservoir has a conservation capacity of approximately 66,000 acre-feet.
- In 1973, construction was completed on Lake Cameahwait Reservoir and Middle Cottonwood Creek Reservoir. These reservoirs are located in the Riverton Unit and primarily control return flows from Riverton Unit irrigation. These facilities likely have only small impacts on overall river flow.
- Modifications on Buffalo Bill Dam, which is located at the confluence of the North and South Forks of the Shoshone River, were completed in 1993. The modifications included an increase in conservation capacity of approximately 190,000 acre-feet of conservation storage. Total reservoir capacity is approximately 640,000 acre-feet.
- In 2000, construction was completed on Greybull Valley Dam, an off-channel facility tributary to the Greybull River. Total reservoir capacity is approximately 30,000 acre-feet.

- Several other minor enlargements (generally less than 5,000 acre-feet) were completed on a variety of small reservoirs throughout the study period. However, because the impact of these reservoirs has little effect on carryover storage, their overall impacts are minimal.

As shown, there is no time period that would completely eliminate impacts of new projects within the period-of-record. However, several events occurred between the 1950's and early 1970's, which would have had a substantial impact on river flows. In addition to the major projects shown above, use of more modern irrigation practices such as gated pipe and sprinklers also increased significantly during the early 1970's. Therefore, for purposes of this study, a study period of 1973-2001 was chosen. This period is especially beneficial in that for most of the basins, both the driest and wettest years on record are contained in the study period. A brief summary of the selected study period as compared with overall streamflow records for each major sub-basin is presented in the following paragraphs.

A statistical summary of the period-of-record and the study period for the Clarks Fork of the Yellowstone River near Belfry is presented in Table 3.1-2. As shown, the average flow during the study period is approximately 2.0% less than the long-term average. In addition, the hydrologic year averages for the study period are all slightly less than the long-term average, which results in the model being slightly conservative towards water supply in general.

Table 3.1-2 Statistical Summary for Clarks Fork Yellowstone River near Belfry (06207500)

Statistic	Period-of-Record 1922 – 2001	Study Period 1973-2001	Difference
Mean	678,048	664,349	-2.0%
Standard Deviation	156,308	170,919	9.3%
Average – Dry Years	482,266	430,150	-10.8%
Average – Average Years	659,734	658,300	-0.2%
Average – Wet Years	928,773	915,688	-1.4%
Maximum	1,075,109	1,075,109	0.0%
Minimum	395,919	395,919	0.0%

A statistical summary of the period-of-record and the study period for the Little Wind River near Riverton is presented in Table 3.1-3. As shown, the average flow during the study period is approximately 2.2 percent less than the long-term average. For the hydrologic year classification, the dry and average years are slightly drier than the long-term average, while the wet years are slightly wetter than the long-term average, which will generally make the model slightly conservative regarding water supply. However, if excess water were used to fill a reservoir for carryover storage, the model may show that there is slightly more water available to fill the reservoir during wet years than what has been available during the long-term average.

Table 3.1-3 Statistical Summary for Little Wind River Near Riverton (06235500)

Statistic	Period-of-Record 1942 – 2001	Study Period 1973-2001	Difference
Mean	417,778	408,775	-2.2%
Standard Deviation	151,116	169,197	12.0%
Average – Dry Years	212,305	199,337	-6.1%
Average – Average Years	415,338	396,907	-4.4%
Average – Wet Years	630,568	651,841	3.4%
Maximum	739,201	739,201	0.0%
Minimum	126,379	126,379	0.0%

A statistical summary of the period-of-record and the study period for the Shell Creek near Shell is presented in Table 3.1-4. As shown, the average flow during the study period is approximately 0.2 percent less than the long-term average. For the hydrologic year classification, the dry years are significantly drier than the long-term average, the wet years are slightly drier and the average years slightly wetter than the long-term averages. With the drier years, the dry years will generally make the model slightly conservative regarding water supply.

Table 3.1-4 Statistical Summary for Shell Creek Near Shell (06278500)

Statistic	**Period-of-Record 1941 – 2001**	**Study Period 1973-2001**	**Difference**
Mean	70,879	70,758	-0.2%
Standard Deviation	14,258	13,904	-2.5%
Average – Dry Years	64,545	50,416	-21.9%
Average – Average Years	71,812	72,046	0.3%
Average – Wet Years	89,192	87,452	-2.0%
Maximum	98,394	98,394	0.0%
Minimum	37,374	37,374	0.0%

3.1.4 – Data Filling and Extension

Many of the gages used in the model have an incomplete record or have periods within the record where data is missing. Therefore, in order for the gage data to be used in the model, the period-of-record for the gage requires either extension or filling. For purposes of this analysis, the same methodologies were used for both filling of gage records and extension of gage records. In addition, the gage records were only filled or extended for those periods in the selected study period (1973-2001).

Many methods can be used for filling gage records. The most common and easiest to use method is regression of measured streamflow at the dependent gage (the gage where data filling is required) to measured streamflow at the independent gage (the gage where data exists for the missing period). Once this mathematical relationship is established, measured data from the independent gage can be used to estimate the streamflow for the dependent gage. Typical regression relationships can be based on linear, polynomial, power or logarithmic relationships. For this study most of the strongest relationships were found to be either linear or polynomial in nature. The measure of the degree to which the two gages correlate is typically called the correlation coefficient (or r^2 value). A correlation coefficient of 1.0 indicates perfect correlation.

Therefore, those relationships with correlation coefficients closer to 1.0 have good correlation. Typically, in streamflow data filling and extension, correlation coefficients greater than approximately 0.7 are desired. When correlation coefficients are less than this value, then relationships are considered weak, and attempts to find gages with better relationships are made. Correlations were developed between monthly streamflows.

For a majority of the gages, monthly regressions with nearby streamflow gages yielded acceptable correlations to fill the records. However, for the gages where correlations were weak, attempts were made to find other relationships to fill the streamflow values. First, regressions with precipitation data were attempted. This regression is typically more valid where snowmelt is not a significant component of streamflow, which limits its use in the study area. Another methodology that can be used is correlation between annual streamflows, then distribution of annual streamflow to monthly streamflow using historical distributions. If the annual streamflow regression correlation was weaker than the original monthly streamflow correlation, then the monthly regression was used. Finally, the streamflow record can be filled using regional equations based upon basin characteristics. However, this methodology is only used in rare occasions when the correlation coefficient is extremely weak. This methodology was not used for any of the streamflow gaging stations. Overall, approximately 88 percent of the gages filled had correlation coefficients greater than 0.7, while all but one station had correlation coefficients greater than 0.5.

3.1.5 – Ungaged Headwater Site Data Estimation

In order for the model to accurately simulate streamflow and diversions for the entire WBHB, an estimation of streamflow above all diversions is required. However, in many parts of the WBHB, there are no streamflow gaging stations above the most upstream diversion on the stream. Therefore, streamflow upstream of the diversion must be estimated. Two methods are available to make these estimations:

- Estimate streamflow based on regional equations, which are a function of basin characteristics such as location, elevation and orientation;
- Estimate streamflow by adding diversions and subtracting inflows from the closest downstream gage.

For most locations, the regional equation methodology was used to estimate streamflow for ungaged headwater sites. However, in areas where this methodology yielded implausible results, such as the streamflow being less than the actual measured diversion, or the streamflow being greater than the next downstream gage adjusted for inflows and diversions, then the estimated headwater flows were adjusted based on the available data. More detailed explanations are found in the detailed model description chapters.

For the study area, two sources of regional regression equations are available for estimating natural flows. The USGS (Rankl, 1994) has published monthly regression equations for the Wind River Basin based upon several physical basin characteristics, including drainage area, mean basin elevation, basin slope, maximum basin relief and mean annual precipitation.

Discharges are given for the 10, 50, 70 and 90 percent exceedance levels (Q_{10}, Q_{50}, Q_{70} and Q_{90}). For purposes of this report, Q_{10} was used for wet years, Q_{50} was used for average years and Q_{90} was used for dry years. Monthly regional regression equations for the entire State of Wyoming were developed by Miselis (1999). Equations were developed for the Wind, Bighorn and Absoraka ranges within the study area and are a function of drainage area and precipitation. The USGS study was used for the Wind River Basin (because the study was more specific to the WBHB) while the Miselis data were used for the other two areas. Physical data were estimated using various Geological Information Survey (GIS) coverages and techniques.

3.1.6 – Hydrologic Year Classification

Once the study period was selected, the monthly data were further reduced into average data for dry, average and wet hydrologic year classifications. To determine which years within the period-of-record fall into which hydrologic year classifications, index gages were selected within each of the hydrologic units. These gages were selected based upon their period-of-record and their lack of influence by diversions and return flows. Then, the hydrologic classification for the index gage was applied to the remaining gages within its influence area. The hydrologic classifications for the WBHB plan are consistent with the hydrologic classifications for the other river basin plans and with the guidelines. A summary of the classification methodology is shown in Table 3.1-5, while a summary of the hydrologic year classification for each index gage is shown in Table 3.1-6. Locations of the index gages are presented in Figure 3.1-1.

Table 3.1-5 Hydrologic Classification Methodology

	Dry	Average	Wet
Percent of Years	Driest 20 percent	Middle 60 percent	Wettest 20 percent
Number of Years in 29-year Study Period	6	17	6

Table 3.1-6 Summary of Hydrologic Classifications for Study Area

Basin	USGS Gage No	Gage ID	1970							1980										1990										2000	
			3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
Mad. /Gal.	06037500	Madison Near West Yellowstone																													
	06191500	Yellowstone At Corwin Springs																													
	06205500	Clarks Fk Ab Squaw Ck																													
Wind	06222700	Crow C Nr Tipperary Wyo																													
	06224000	Bull Lake Creek Above Bull Lake																													
	06228350	SF Little Wind Ab Washakie Res																													
Bighorn	06260000	South Fork Owl Ck Near Anchor																													
	06270000	Nowood River Near Tensleep																													
	06275000	Wood River At Sunshine																													
	06278500	Shell Creek Near Shell																													
	06280300	SF Shoshone River Near Valley																													

Notes:

(1) Hydrologic Year Classification
- Wet Year (Wettest 20 percent of years)
- Average (Middle 60 percent of years)
- Dry Year (Driest 20 percent of years)

Both the Madison River near West Yellowstone gage and the Gallatin River gage contain adequate data to classify hydrologic years. However, since the primary gages that need to be classified in the model are Madison River tributaries, the Madison River near West Yellowstone gage (06037500) was selected for the analysis.

There are three gages within the Yellowstone model that would be adequate for hydrological classification: the Yellowstone River at the Yellowstone Lake Outlet (06186500), Gardner River near Mammoth (06190500) and the Yellowstone River at Corwin Springs (06191500). The first two gages, respectively, have short periods where data would need to be filled. In addition, the annual flow variation at the Yellowstone Lake Outlet gage is small and may not provide a good measure of hydrologic variability throughout the entire WBHB. Therefore, the Corwin Springs gage was selected as the index gage for the entire WBHB.

Although the Clarks Fork near Belfry gage contains continuous data through the period-of-record, the gage is located downstream of agricultural diversions. These diversions have an influence on the relative flow at the gage making it unsuitable for use as an index gage in the hydrologic year classification. Two other gages within the WBHB are located upstream of diversions making them more suitable for use as the index gage: the Clarks Fork Yellowstone River above Squaw Creek and Sunlight Creek near Painter. Neither of these gages have any data in the study period. However, since the correlation coefficients used to fill the data were very strong, the filled data should be representative of actual flows at the gage, allowing either to be used as an index gage. Because the Clarks Fork above Squaw Creek gage is on the mainstem and contains a larger portion of flow in the WBHB, it was selected as an index gage.

Several gages within the Wind River Basin contain adequate data to serve as index gages for development of hydrologic year classifications. As with previous index gage selection, gages that are not significantly influenced by diversions, storage or return flows are the most desirable gages. For the Wind River Basin, to account for differences in hydrology between sub-basins and location of gages, separate gages were selected for sites along the Wind River range in the Wind River sub-basin and Little Wind River sub-basin, and those located along the Owl Creek range. For purposes of this analysis, the following gages were selected as index gages: Bull Lake Creek above Bull Lake (06224000), South Fork Little Wind River above Washakie Reservoir (06228350) and Crow Creek near Tipperary (06222700).

Only a few gages within the Bighorn Basin contain adequate data to serve as index gages for development of hydrologic year classifications. As with previous index gage selection, gages that are not significantly influenced by diversions, storage or return flows are the most desirable gages. In the Bighorn Basin, separate gages were selected for sites along the Owl Creek Range in the Upper Bighorn Basin and Nowood River Basins, the Bighorn range in the Nowood River Basin, and Bighorn Lake River Basin, and the Absaroka range in the Greybull and Shoshone River Basins. For purposes of this analysis, the following gages were selected as index gages: the South Fork of Owl Creek near Anchor (06260000), Nowood River near Tensleep (06270000), Wood River at Sunshine (06275000), Shell Creek near Shell (06278500) and the South Fork Shoshone River near Valley (06280300).

3.2 – Spreadsheet Model Development and Calibration

3.2.1 – Introduction

The Guidelines for Development of Basin Plans (WWDC, 2001) and WWDC required that the river basin planning models be consistent with the other models that have already been developed. The original spreadsheet model was developed by Anderson Consulting Engineers for the Bear River Basin, which was the initial pilot study for the river basin planning process. That model was utilized as a base model for the Green River Basin Plan by Boyle Engineering, which was subsequently used by HKM as a base model for the Powder-Tongue and Northeast River Basin Plans. Improvements in the model were made upon each successive iteration of the model, including improvements in data entry, calculation methodologies and the Graphical User Interface (GUI). It should be recognized that the models are quite general in nature and although they provide a reasonable indication of water availability on any given stream, caution should be exercised in drawing conclusions from the results about individual diversions or water uses.

USGS Hydrologic Unit classifications and their associated models were previously shown in Table 3.1-1. As shown, the study area has been divided into 12 models. The models generally follow the same areas as the study sub-basins, with the following exceptions:

- The Madison and Gallatin sub-basins have been combined into one model;
- The Little Wind sub-basin includes the outflow gage from the Popo Agie sub-Basin. The Popo Agie sub-basin has been modeled as part of the Popo Agie River Watershed Study and is not modeled as part of this work or discussed further in this document;
- The Lower Wind model includes the Lower Wind and Badwater sub-basins;
- The Lower Bighorn model includes Bighorn Lake and Dry Creek sub-basins.

The models are intended to simulate existing river operations for dry, average and wet year hydrologic periods. In general, existing operations are reflected in the historical operations within the study period. In a few instances where existing conditions are different than either a portion or all of the historical conditions, special provisions in the data input and modeling calibration were required and are documented within the calibration section of **Technical Memorandum, Chapter 3, Tab 15 "Spreadsheet Model Development and Calibration"**.

The primary data required for the spreadsheet models are streamflow, actual (or estimated actual) diversions, full supply diversions, irrigation returns and reservoir operations. For each of these, the data within the study period was reduced into dry, average and wet year data. The reduction of streamflow data, including the calculation of natural flow data for those tributaries that do not contain diversions, is described in the **"Surface Water Hydrology" Technical Memorandum**. Development and reduction of actual diversion data is discussed in the **Technical Memorandum "Irrigation Diversion Operation and Description", Task 2A Technical Memorandum "Agricultural Water Use and Diversion Requirements**", while the estimation of actual diversion for those diversions without actual measurements is discussed later in this report.

The model is run on a monthly timestep for the given calendar year of the hydrologic condition (dry, average, and wet). Starting reservoir levels are the same as the historical end-of-month contents on the last day for that hydrologic condition (i.e., the dry year model starting contents in January is the historical dry year end-of-month contents in December).

The basic model calculation procedure is shown in Figure 3.2-1. Natural flows for each main channel and tributary are either taken from gage data (preferred but not normally available) or estimated using the regional regression techniques as describe in the **Task 3A/3B Technical Memorandum "Surface Water Hydrology"**. Then, the incremental gains and losses are calculated for each reach. This is performed by locating the first downstream gaged node and constructing a "basin" containing all of the known upstream inflows, diversions and reservoir operations. The basins often contain many tributaries to the gaged node. Once the ungaged gains and losses are calculated, they are distributed to each reach within the basin by pro-rating the gains and losses based upon the reach's contribution to the gage flow. Ungaged gains are applied at the top of the reach to allow for diversion, while the ungaged losses are applied to the bottom of the basin to allow diversion of computed inflows.

Once the ungaged gains and losses are calculated, a mass balance (or water budget) is computed at each node. At nodes other than storage nodes, the amount of flow available to the next downstream node is calculated as the difference between known inflows, such as tributary inflows, return flows, basin gains and imports, and outflows, such as diversions, basin losses and exports. At storage nodes, the losses due to evaporation and the gains/losses due to change in storage are included in the calculations. Diversions are limited to the lesser of the full supply diversion and the physical streamflow. The mass balance is performed from upstream to downstream for each node in the reach, and for each reach in the model.

Model output includes the following:

- Comparisons of the full supply diversion to the model simulated diversion at each of the diversion nodes;
- Calculation of streamflow at each node in the model;
- Available flow for each reach.

The limitations of the model should be noted:

- The model does not explicitly account for water rights, appropriations or compact allocations and is not operated on these legal principals. For instance, the model cannot forego a diversion to an upstream junior water right to satisfy a downstream senior water right. However, due to the construction and calibration procedure, if this situation happened historically, it would be reflected in the model construction (the junior would show a shortage).
- The model does not "operate" storage reservoirs to meet downstream demands, nor can the model differentiate between different owners of storage accounts. The model

only uses historical reservoir releases and satisfies the diversions in order of their physical location on the stream. However, as with water rights, the historical operations and diversion of stored water is normally reflected in the historical records.

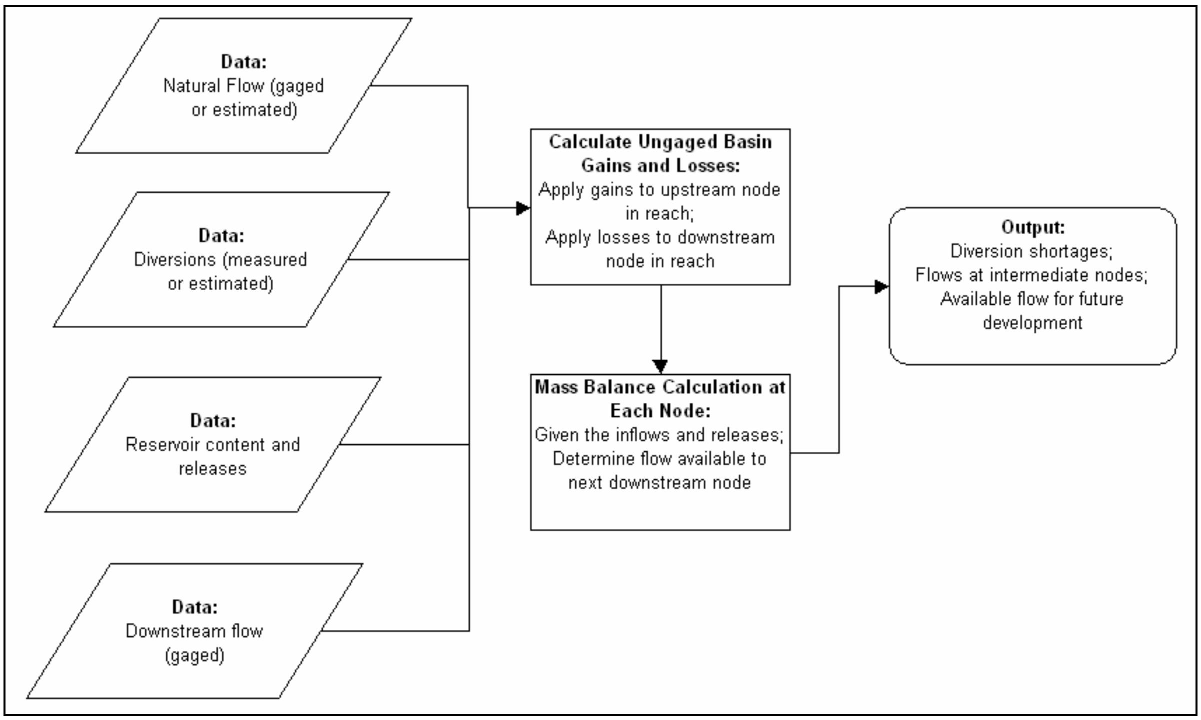

Figure 3.2-1 Generalized Model Flowchart

- Because the model does not contain time-series hydrology, it does not perform a detailed analysis of carryover storage. This is important when a dry year is followed by a dry year. As the model is constructed, it shows the starting reservoir level as the September end-of-month contents during an normal year, which does not necessarily simulate a drought (although this specific scenario could be at least partially analyzed in the model by varying starting storage contents). However, the importance of filling and emptying large reservoirs over a number of years is not explicitly analyzed in the model.

3.2.2 – Model Development

As with the previous river basin plans, the models for the Wind/Bighorn River Basin plans were developed using Microsoft® Excel 97. All computations within the workbooks are performed using formulas written in the cells of the workbooks. The workbooks also contain macros that are used only for navigation between the various worksheets in the workbooks. The model calculations are completely automated so that when data is changed in any cell, the entire model is updated. The one exception is when data is shared between models. The procedures for sharing data between models are discussed in more detail later in this document.

As requested by the WWDC, the models were developed for the novice Excel user. Basic proficiency in spreadsheet usage is required to view results and to make minor changes to input data and variables. However, to input additional nodes or reaches in the model, a more advanced level of proficiency is required. Interactive buttons have been placed throughout the spreadsheets to allow for easier navigation between the spreadsheets. All "tabs" and "row-column headers" within the model have been activated as it was found that for most users, this information is useful to view. Also, due to the size and calculation time of the models, "manual calculation" has been selected as the calculation procedure. In this mode, model calculations are not performed until the users hits the "F9" key on the keyboard. Extreme caution should be exercised by those wishing to make changes to the model construction.

3.2.3 – Model Schematics

The physical structure of each model is represented in the river basin schematics and the reach schematics. Separate schematics have been developed for each model. The development of these schematics is discussed in the following paragraphs.

The river basin schematics are detailed link-node representations of the river basins. The schematics include nodes representing streamflow gages, natural flow nodes, diversion nodes, lumped diversion nodes, points of confluence and specific points of return flows if not already represented by a node. The nodes are connected by a series of links that represent the actual flow of water (normally in a stream) between the nodes. It should be noted that for visual clarity, the schematics are connected by straight links and are not to scale. Normally, the general flow direction through the schematic mirrors the actual flow direction, with north pointing towards the top of the schematic.

The reach schematics are simplified versions of the river basin schematics that are developed on a "reach" basis. Reaches are a group of nodes that represent an entire tributary or a portion of the main river. As discussed in later sections, the model calculations and water availability are generally performed and reported on a reach basis. The reach schematics are also used for navigational purposes within the model GUI. Reach schmatics for each model are presented in Figures 3.2-2 through 3.2-13.

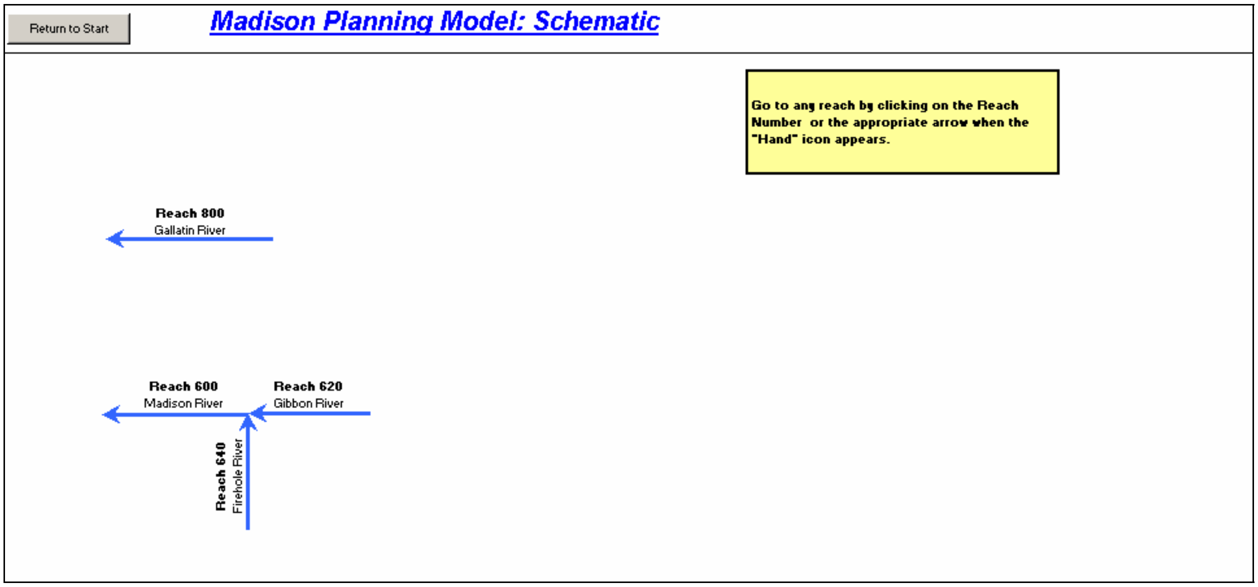

Figure 3.2-2. Reach Schematic - Madison/Gallatin Model

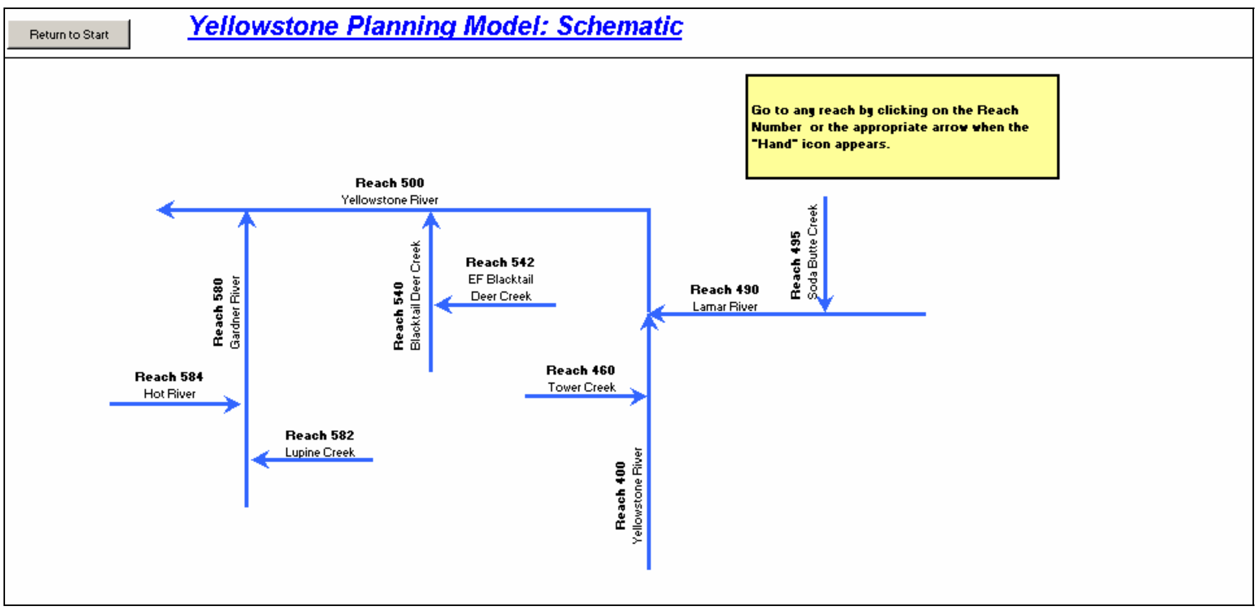

Figure 3.2-3. Reach Schematic - Yellowstone Model

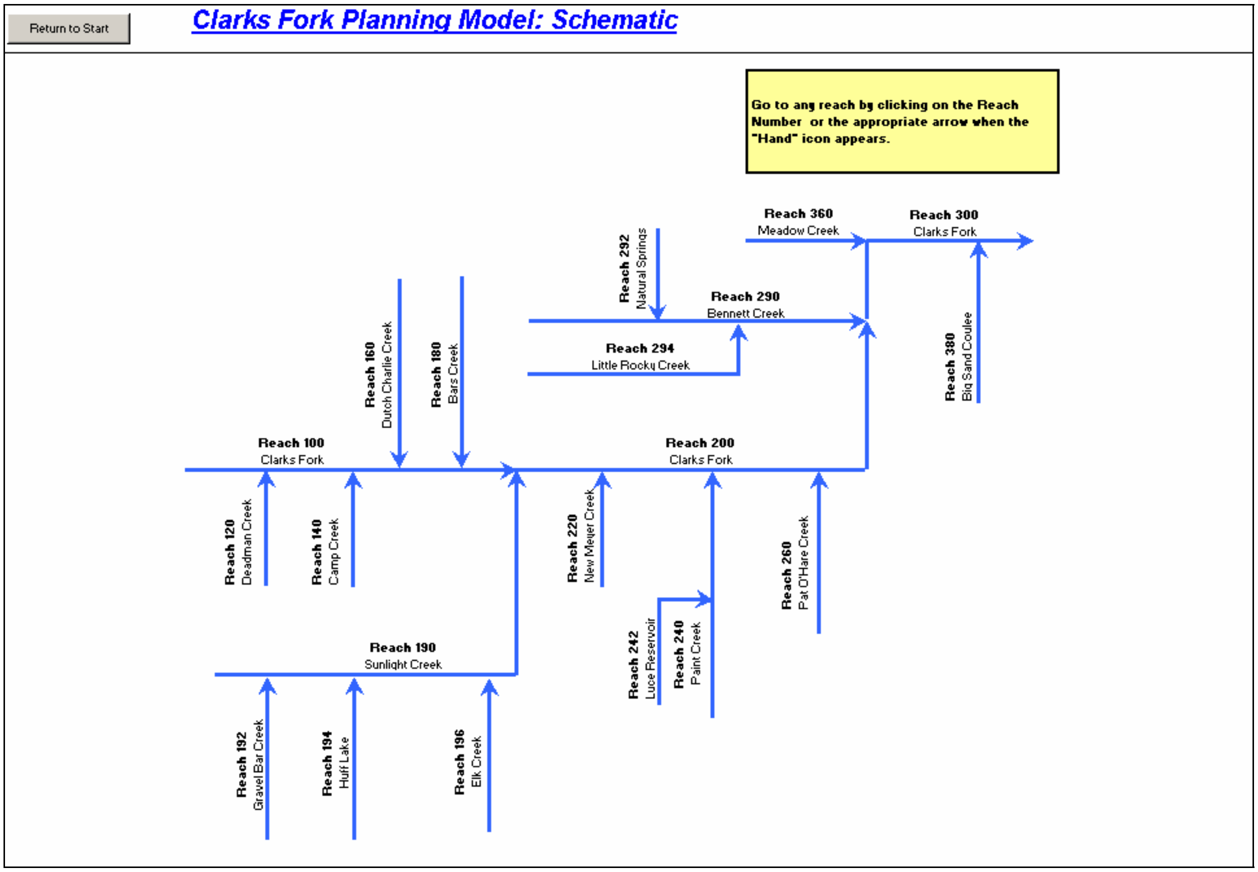

Figure 3.2-4. Reach Schematic – Clarks Fork Model

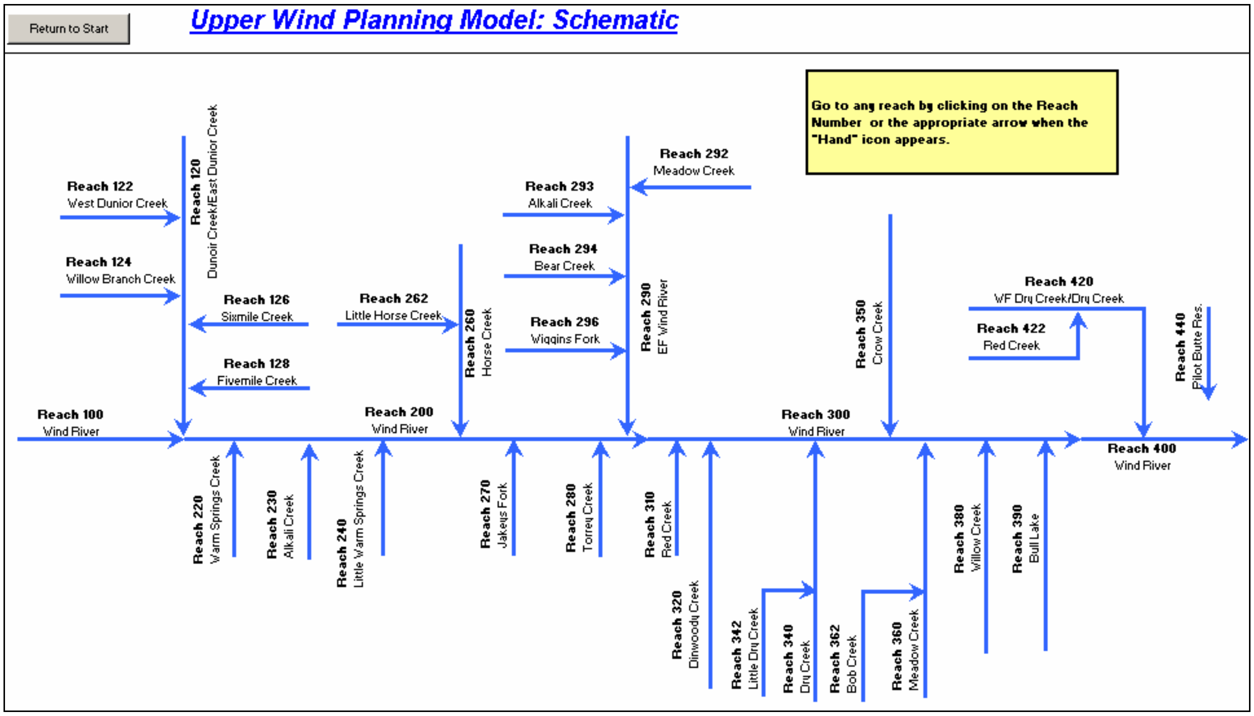

Figure 3.2-5. Reach Schematic – Upper Wind Model

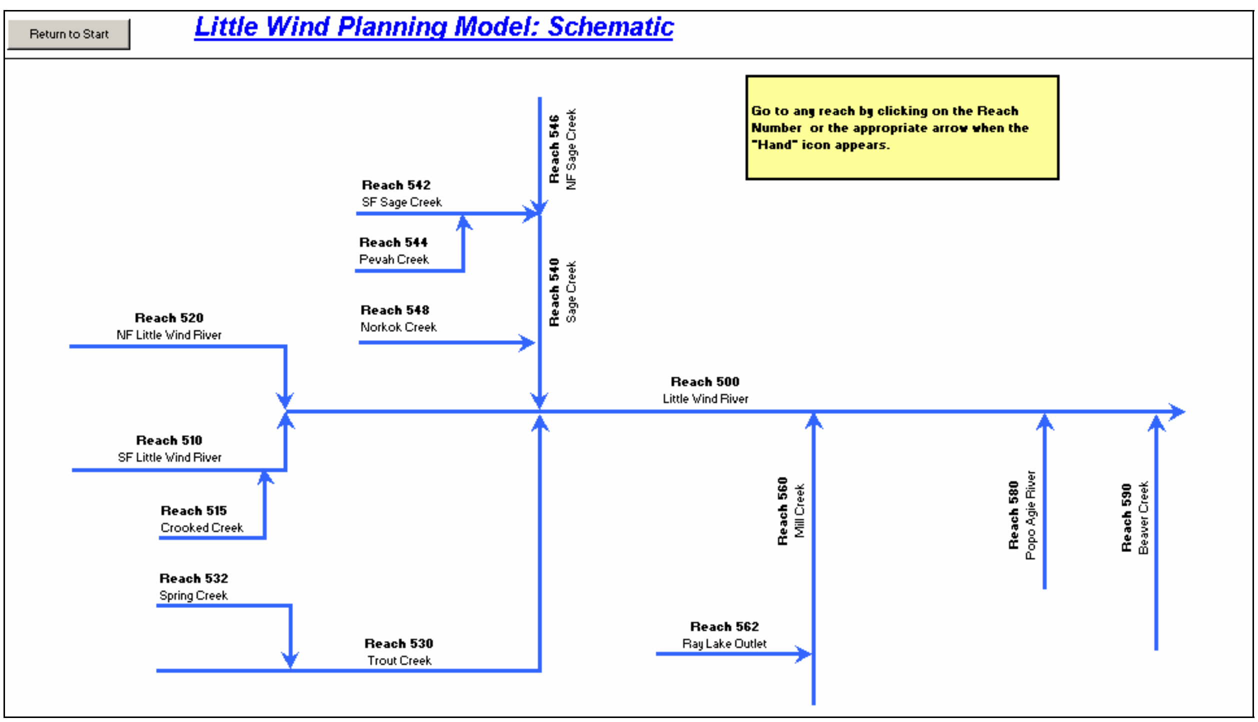

Figure 3.2-6. Reach Schematic – Little Wind Model

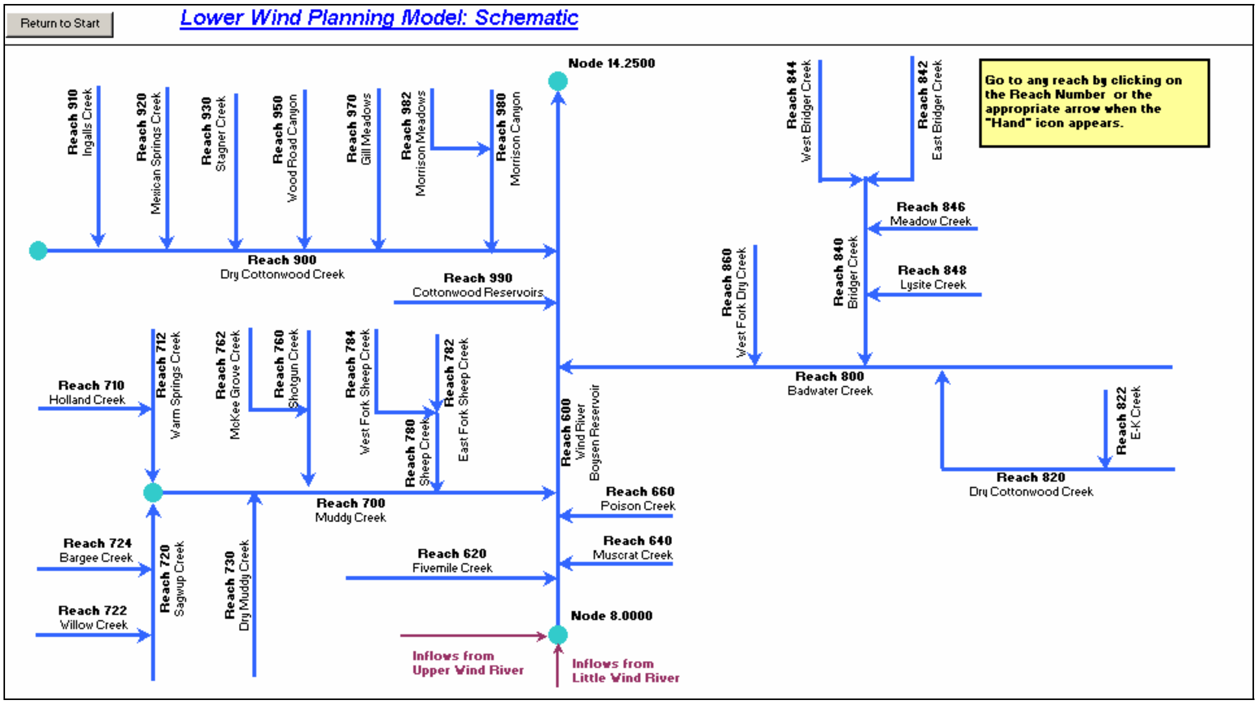

Figure 3.2-7. Reach Schematic – Lower Wind Model

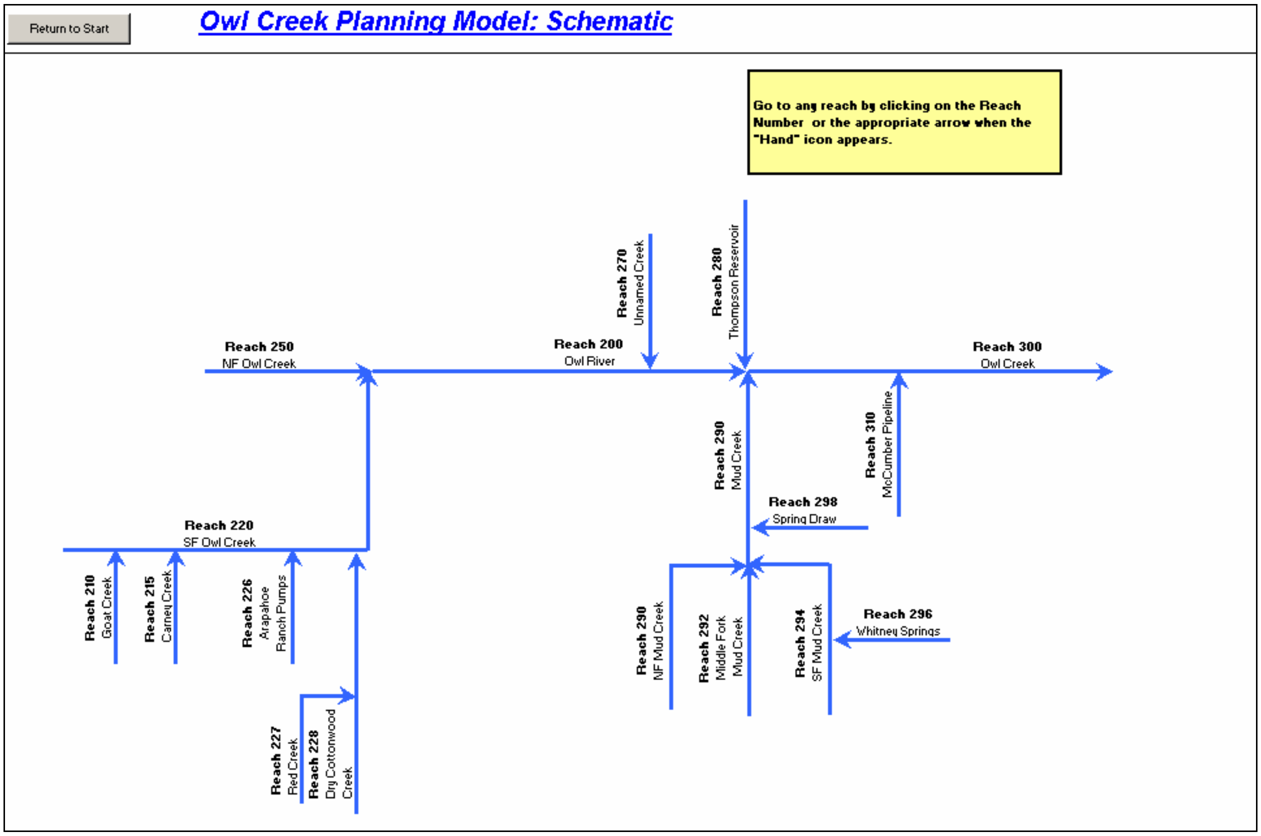

Figure 3.2-8. Reach Schematic – Owl Creek Model

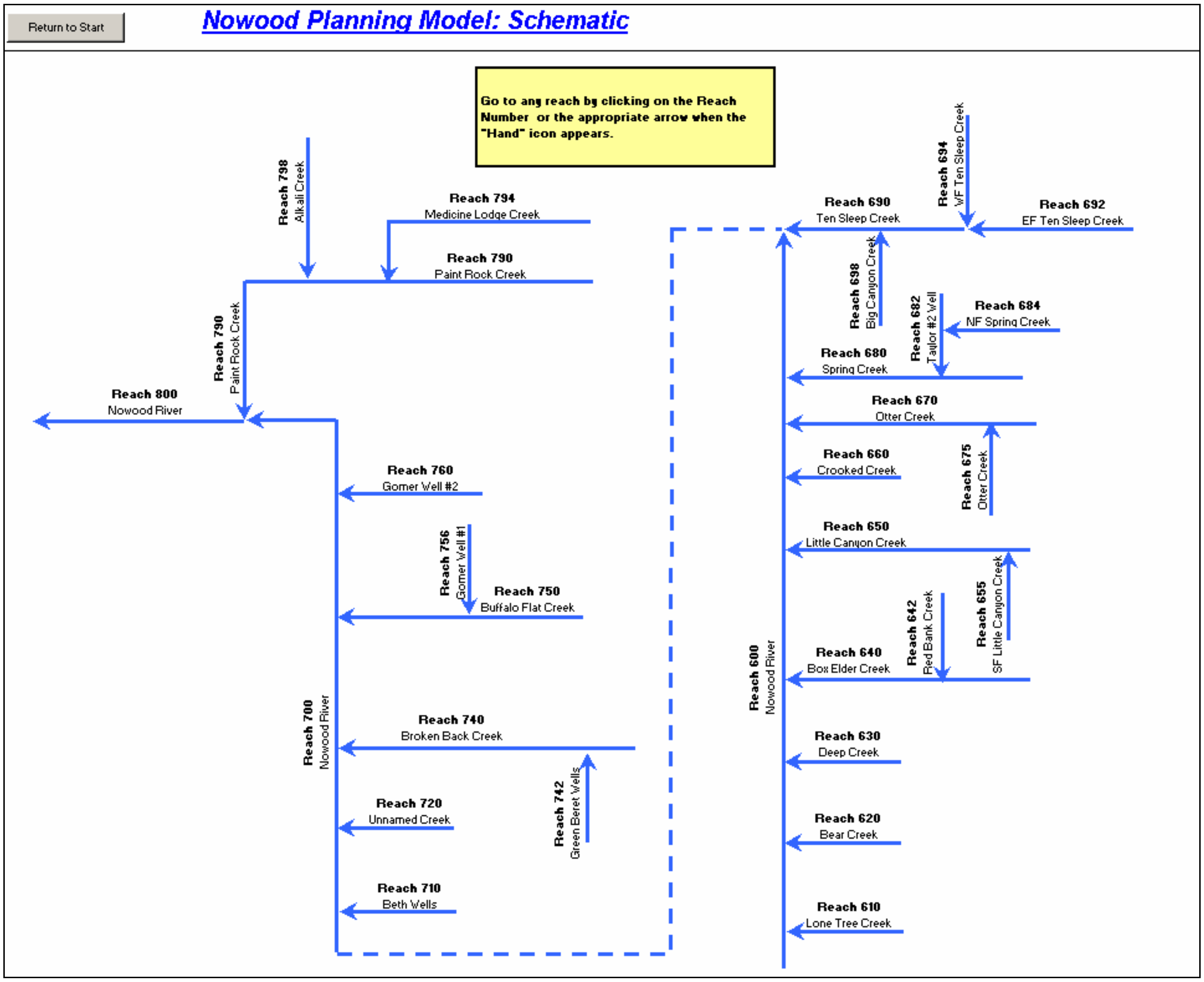

Figure 3.2-9. Reach Schematic – Nowood Model

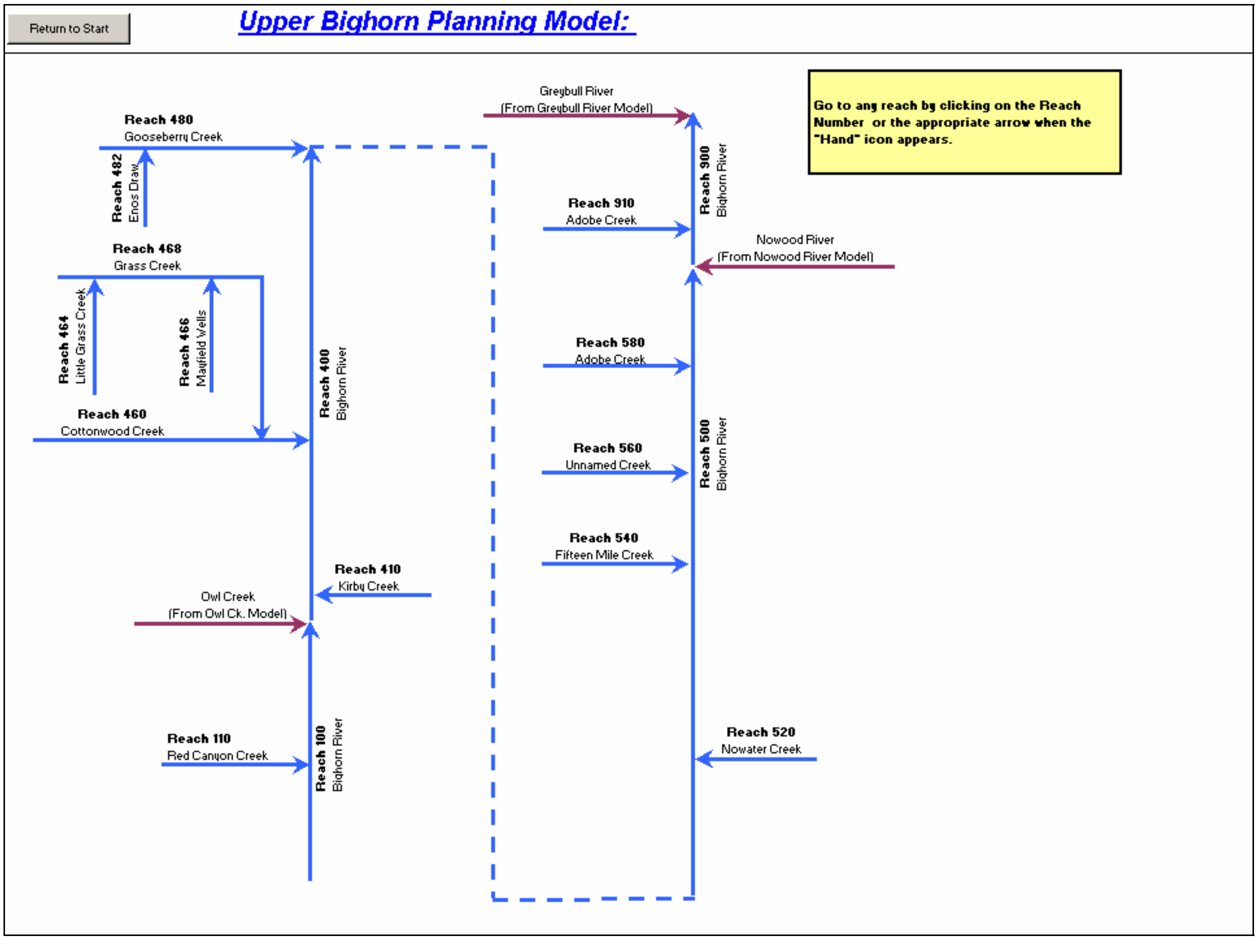

Figure 3.2-10. Reach Schematic – Upper Bighorn Model

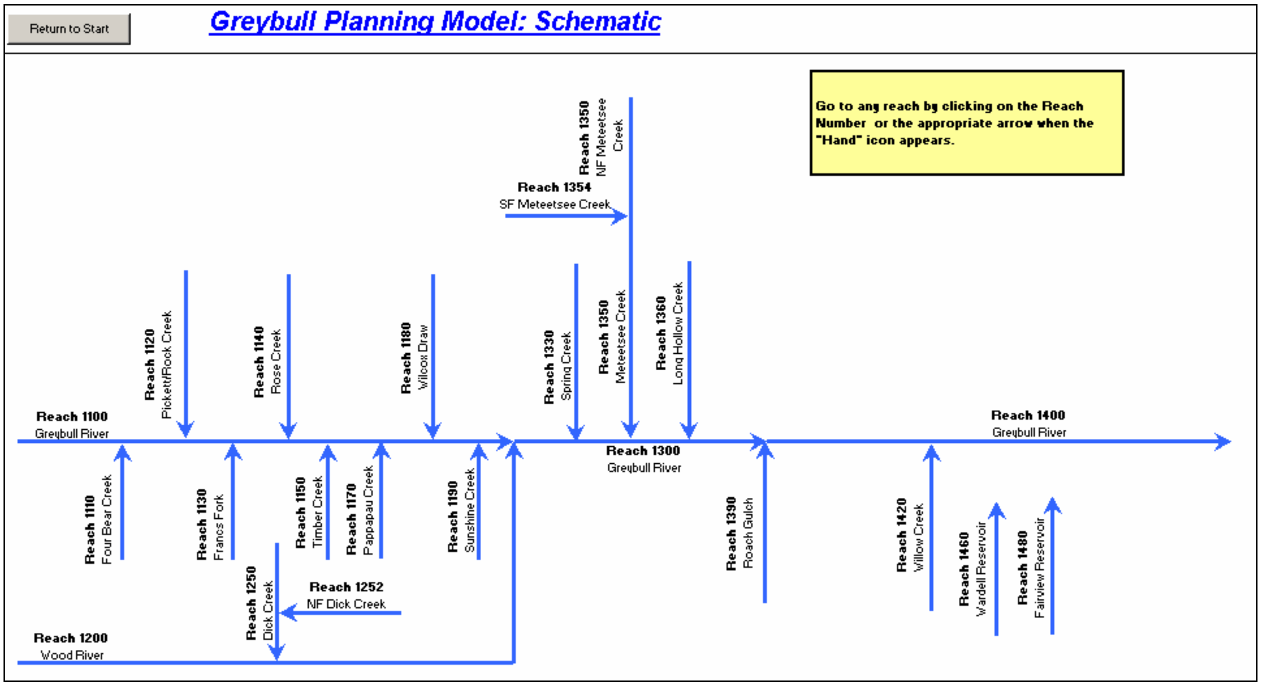

Figure 3.2-11. Reach Schematic - Greybull Model

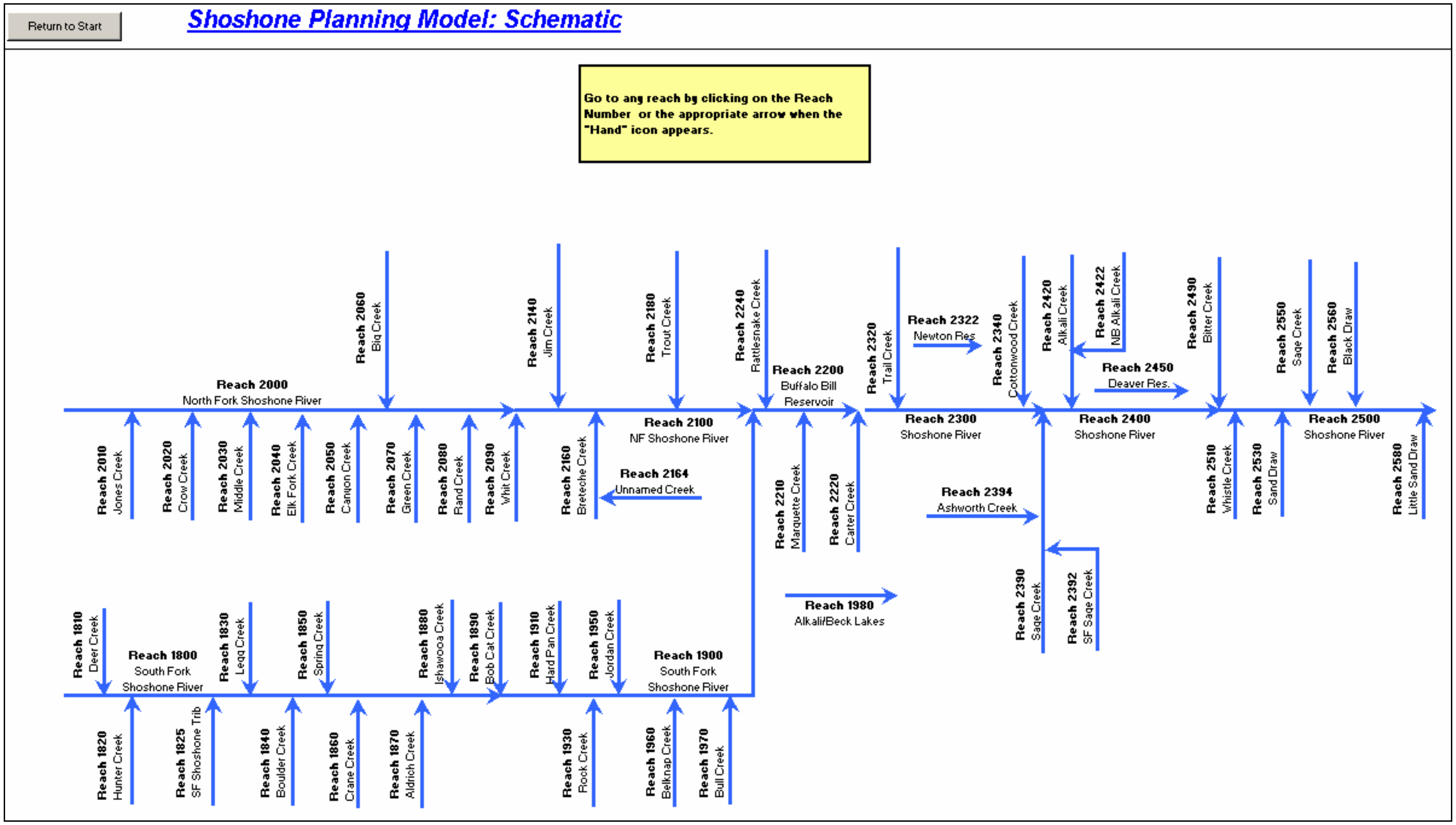

Figure 3.2-12. Reach Schematic - Shoshone Model

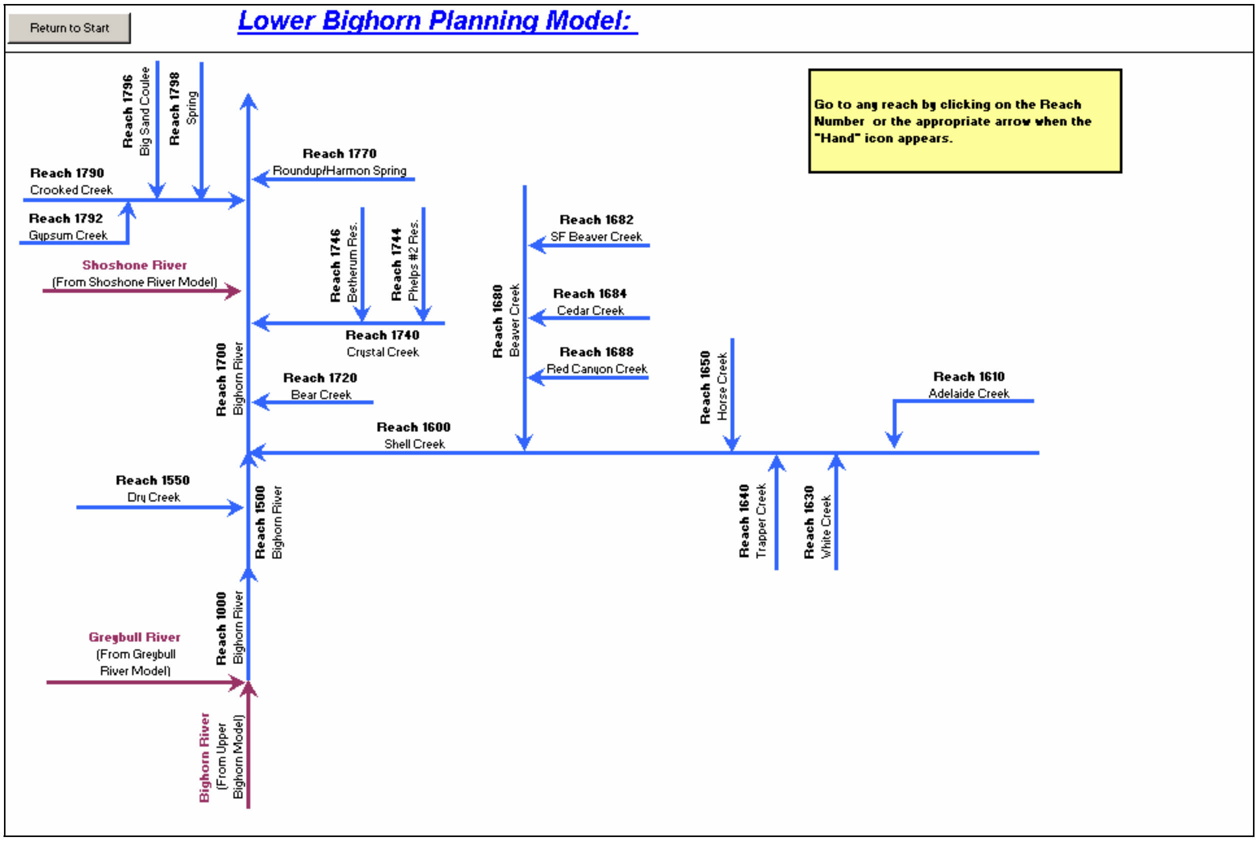

Figure 3.2-13. Reach Schematic – Lower Bighorn Model

3.2.4 – Differences from Previous River Basin Planning Models

As previously indicated, in general, the WBHB planning models are consistent with those developed for previous basins. However, some improvements to the previous models were incorporated to fit the needs of the Wind/Bighorn River Basin plan. The primary difference is that previous models ran the calibration and simulation modes simultaneously. However, in the Wind/Bighorn River Basin Plan, historical diversions were significantly different than full supply diversions. Therefore, calibration was not possible because the model was attempting to divert a full supply diversion, but calibrating to historical streamflows. Therefore, the following additions were made to the model.

The model can be run in three different modes: Calibration (or historical), Full Supply diversions, and Futures diversions. The run mode is selected using buttons on the navigation worksheet.

- Calibration (Historical) – models actual historical diversions. This mode is primarily used for model calibration.
- Full Supply for Existing Irrigated Lands – models full supply, based on computed diversion requirements, for irrigated lands with water rights mapped as part of the planning process.

- Full Supply for Existing Irrigated Lands and Futures Projects - models full supply, based on computed diversion requirements, for irrigated lands with water rights mapped as part of the planning process and Tribal futures projects.

Because the model can be run in full supply or futures diversion modes, a slightly different calculation methodology was used in the Wind/Bighorn models than in previous models. In previous models, reach losses at the ends of the reaches are calculated based on the downstream gage, so that the simulated gage always matches the calculated gage flow (the ungaged loss calculated in the gain/loss calculations was not used). However, in the Wind/Bighorn models, the streamflows are fully simulated, meaning that the reach loss calculated in the gain/loss calculations is used in the reach calculations. The model is then calibrated using gaged flow versus simulated flow.

3.3 – Available Surface Water Determination

3.3.1 – Introduction

The models are intended as a tool for identifying regional demand shortages and the opportunity for additional water development given major hydrologic and institutional constraints. Per the definition of the calibration mode, the model does not show any shortages at diversions when run in this mode, and thus, no results from this run are presented as part of the results. The results presented herein are for the "Fully Supply for Existing Irrigated Lands" and the "Full Supply for Existing Irrigated Lands and Futures Projects" modes.

3.3.2 – Diversion Shortages

An important result of the WBHB planning models is the calculation of diversion shortages. The model construction allows calculation of shortages at each node in the model. However, it must be realized that the model does not explicitly account for water rights, storage ownership rights or other delivery constraints within the delivery system. Any of the diversions within the WBHB can experience shortages from time-to-time. For instance, in 2001 and 2002, which were drier years than the dry-year used in the modeling hydrology, nearly all diversions within the basins experienced shortages of one degree or another. Therefore, it is best to review this information for the WBHB as a whole and within the context of the model limitations.

Table 3.3-1 presents a summary of the shortages within each sub-basin model for the full supply condition, shortages are more severe in the Wind River Basin than in the other basins, with the exception of the Owl Creek Basin, especially in dry years. Shortages occur on the mainstem of the Wind River and Little Wind River, and in most tributaries. The Owl Creek Basin experiences shortages during all hydrologic conditions at nearly every diversion point. In the remaining portion of the Bighorn Basin, shortages are primarily on smaller tributaries. There are very few shortages on the mainstems of the Bighorn, Shoshone, Nowood and Shell Creek. There are significant shortages on the mainstem Greybull River, especially without the influence of the recently completed Greybull Valley Reservoir, which was included in the model construction, but not included in the model runs. It is expected that the reservoir will alleviate most shortages in normal and wet years, with some remaining shortages in dry years. It should also be noted that there was a significant difference in Full Supply diversion requirements compared to historical diversion requirements in the Greybull model, primarily due to differences in the quantity of irrigated lands.

Table 3.3-1 Summary of Modeled Diversion Shortages – Full Supply

Basin	Full Supply Diversion (ac-ft)	Reach Shortages (ac-ft)			Reach Shortages (percent)		
		Dry	Normal	Wet	Dry	Normal	Wet
Clarks Fork	106,293	30,402	18,786	11,645	29%	18%	11%
Yellowstone	0	0	0	0	0%	0%	0%
Sub-Total	106,293	30,402	18,786	11,645	29%	18%	11%
Upper Wind	933,909	192,930	54,067	43,948	21%	6%	5%
Little Wind	344,734	97,916	38,741	29,206	28%	11%	8%
Lower Wind	80,635	20,537	15,839	11,634	25%	20%	14%
Sub-Total	1,359,278	311,383	108,647	84,788	23%	8%	6%
Upper Bighorn	329,300	12,220	7,499	5,450	4%	2%	2%
Owl Creek	116,769	39,790	24,919	19,590	34%	21%	17%
Nowood	117,327	7,482	5,273	3,362	6%	4%	3%
Lower Bighorn	170,209	26,747	11,169	6,943	16%	7%	4%
Greybull	505,395	172,142	47,001	29,905	34%	9%	6%
Shoshone	829,711	29,097	18,348	9,801	4%	2%	1%
Sub-Total	2,068,711	287,478	114,209	75,051	14%	6%	4%
Total	3,534,282	629,263	241,642	171,484	18%	7%	5%

Notes:

(1) Shortages are for historical Full Supply Conditions without Futures projects.

(2) The modeled shortages do not include releases from Greybull Valley Reservoir.

Table 3.3-2 presents a summary of modeled diversion shortages for the full supply Condition with futures projects. The futures projects were modeled with a full supply diversion requirement of approximately 198,000 acre-feet for those projects within the Wind and Little Wind Basins. The futures projects would increase shortages within the Wind River Basin, not including the Popo Agie, by approximately 205,000 acre-feet in dry years, 70,000 in average years and 39,000 in wet years. The dry year value actually exceeds the diversion requirement because return flows for the North Crowheart Project accrue to the river at locations where they cannot be rediverted by downstream entities which is the current practice.

Downstream of Boysen Reservoir, the model does not show any impacts. This is because Boysen Reservoir acts as a “buffer” between the Wind and Bighorn Basins. More storage within the reservoir can be used to meet downstream demands. The model shows, however, as time progresses, there may be more difficulty in filling Boysen Reservoir if all Futures Projects are on-line. A graph depicting storage for the two scenarios during the average year is shown in Figure 3.3-1. The model starts the reservoir contents the same as historical October beginning-of-month contents. For both the historical and full supply simulation, the September end-of-month contents are greater than or approximately equal to the October end-of-months contents, which indicates that the assumption of starting reservoir contents is likely valid. However, the full supply with futures projects simulated end-of-month contents are less than the October end-of-month contents. Therefore, the assumption of end-of-month contents may not be valid. If this value is continually adjusted downwards to match September end-of-month contents, it is likely that they would not converge. A more detailed carry-over storage analysis is required to analyze the full affects of futures projects on storage in Boysen Reservoir.

Again, the model limitations should be recognized. The model does not contain a water rights accounting system. In addition, the model does not "operate" storage to meet downstream demands. It simply releases the historical volumes. For instance, in the Futures scenario, additional releases could be made from Bull Lake to meet some Wind River shortages, or additional water could be stored in Boysen Reservoir during peak runoff, which would impact flows downstream of the reservoir during those months.

Table 3.3-2 Summary of Modeled Diversion Shortages – Full Supply with Futures Projects

Basin	Full Supply Diversion (ac-ft)	Reach Shortages (ac-ft)			Reach Shortages (percent)		
		Dry	Normal	Wet	Dry	Normal	Wet
Clarks Fork	106,293	30,402	18,786	11,645	29%	18%	11%
Yellowstone	0	0	0	0	0%	0%	0%
Sub-Total	106,293	30,402	18,786	11,645	29%	18%	11%
Upper Wind	1,113,585	399,102	125,825	83,921	36%	11%	8%
Little Wind	348,159	97,916	38,667	29,206	28%	11%	8%
Lower Wind	95,151	20,537	15,839	11,634	22%	17%	12%
Sub-Total	1,556,895	517,555	180,331	124,761	33%	12%	8%
Upper Bighorn	329,300	12,220	7,499	5,450	4%	2%	2%
Owl Creek	116,769	39,790	24,919	19,590	34%	21%	17%
Nowood	117,327	7,482	5,273	3,362	6%	4%	3%
Lower Bighorn	170,209	26,747	11,169	6,943	16%	7%	4%
Greybull	505,395	172,142	47,001	29,905	34%	9%	6%
Shoshone	829,711	29,097	18,348	9,801	4%	2%	1%
Sub-Total	2,068,711	287,478	114,209	75,051	14%	6%	4%
Total	3,731,899	835,435	313,326	211,457	22%	8%	6%

Notes:

(1) The modeled shortages do not include releases from Greybull Valley Reservoir .

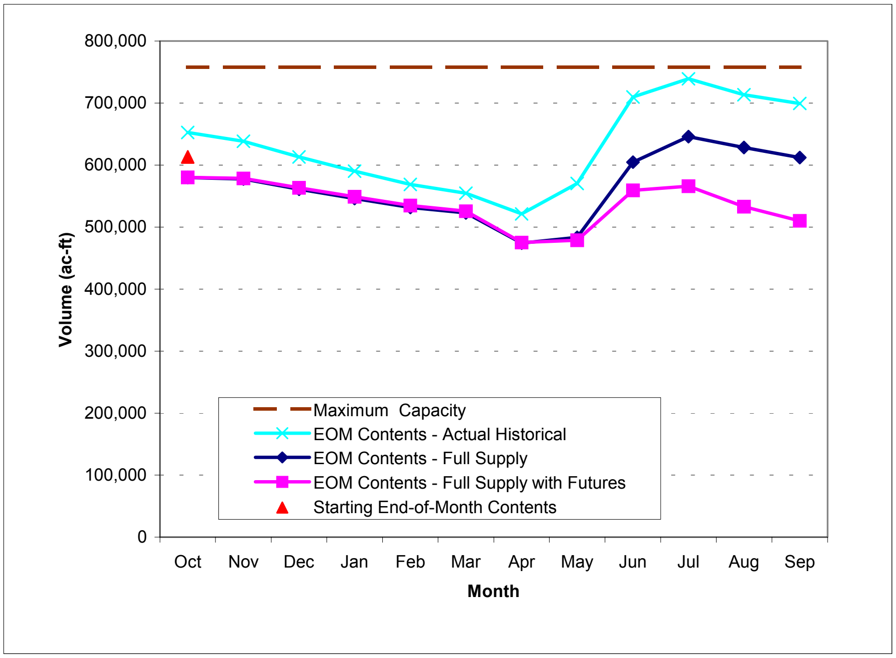

Figure 3.3-1 Simulated End-of-Month Contents for Boysen Reservoir – Average Year

3.3.3 – Streamflow

Streamflow is a fundamental output of any river basin simulation model. The Wind/Bighorn River sub-basin models use streamflow as a calibration measure. This implies that simulated streamflow matches or is very close to measured historical streamflow. Therefore, in Calibration mode, simulated streamflows generally match historical streamflow. As previously discussed, the Wind/Bighorn River sub-basin models are configured to allow the simulation of streamflows given variations in model input parameters, such as diversion requirements. Therefore, for the Full Supply and the Full Supply with Futures Projects scenarios, the impacts to streamflows can be shown. Streamflow impacts at any node within the model can be obtained simply by running the model in the desired modes and comparing the "node inflow" on the reach worksheets at the desired nodes.

3.3.4 – Available Flow

The available surface water for each basin is defined as the amount of water available for water development after meeting downstream demands. These demands include:

- Existing irrigation, municipal or industrial demands
- Compact Requirements
- Instream Flow Requirements

Available flows under the Full Supply scenario for the Wind River Basin, Bighorn River Basin and Clarks Fork, Yellowstone and Madison/Gallatin River Basins are shown in Table 3.3-3, Table 3.3-4 and Table 3.3-5. Available flows under the Full Supply with Futures Projects scenario for the Wind River Basin are shown in Table 3.3-6. As previously mentioned, the model does not show any affects on streamflow due to the Futures Projects (see model constraints). The development of available flows is discussed in the following sub-sections.

Table 3.3-3 Wind River Basin Available Flow - Full Supply Scenario

Basin	Location	Available Flow (ac-ft)		
		Dry	Normal	Wet
Upper Wind	Reach 100: Wind River Headwaters to DuNoir Creek	0	32,973	61,735
	Reach 200: Wind River from DuNoir Creek to East Fork	0	52,255	82,993
	Reach 300: Wind River from East Fork to Bull Lake Creek	74,745	249,772	470,811
	Reach 290: East Fork Wind River	2,586	25,922	52,810
	Reach 320: Dinwoody Creek	5,550	40,388	64,188
	Reach 390: Bull Lake Creek	14,327	107,703	161,938
Little Wind	Reach 400: Wind River from Bull Lake Creek to Little Wind	98,817	312,982	528,328
	Reach 500: Little Wind River	26,825	88,499	137,008
	Reach 510: South Fork Little Wind	7,454	15,620	39,709
	Reach 520: North Fork Little Wind	11,641	62,887	94,835
	Reach 530: Trout Creek	2,833	5,717	8,317
	Reach 580: Popo Agie River	26,825	88,499	137,008
Lower Wind	Reach 600: Wind River from Little Wind Confluence to Boysen Reservoir	332,085	748,665	987,068
	Reach 700: Muddy Creek	2,676	3,441	4,131
	Reach 800: Badwater Creek	22,101	22,007	18,305

Notes:

(1) Available Flow in Upper Wind River Basin affected by Instream Flow requirements in Reach 200. The East Fork Wind River is downstream of this Instream Flow segment. However, due to model construction, its impacts are imposed on the East Fork.

Table 3.3-4 Bighorn River Basin Available Flow – Full Supply Scenario

Basin	Location	Available Flow (ac-ft)		
		Dry	Normal	Wet
Upper Bighorn	Reach 100: Bighorn River to Owl Creek	758,909	1,103,618	1,451,214
	Reach 400: Bighorn River from Owl Creek to Gooseberry Creek	775,972	1,117,130	1,496,273
	Reach 460: Cottonwood Creek	7,275	14,338	30,873
	Reach 480: Gooseberry Creek	7,926	14,601	22,515
	Reach 500: Bighorn River from Gooseberry Creek to Nowood River	840,185	1,266,937	1,659,049
	Reach 900: Bighorn River from Nowood River to USGS Gage	871,488	1,303,478	1,694,604
Owl Creek	Reach 200: Owl Creek from N. & S. Fork Conf. To Mud Creek Conf.	5,477	17,269	26,746
	Reach 220: South Fork Owl Creek	1,468	9,521	16,013
	Reach 250: N. Fork Owl Creek	1,737	6,678	11,483
	Reach 300: Owl Creek from Mud Creek Conf. To Bighorn River	8,907	27,540	48,091
Nowood	Reach 600: Nowood River above Ten Sleep Creek	6,500	15,214	25,902
	Reach 690: Ten Sleep Creek	3,114	12,235	24,183
	Reach 700: Nowood River from Ten Sleep Ck. To Paint Rock Ck.	146,433	169,466	251,569
	Reach 790: Paint Rock Creek	82,113	91,162	112,187
	Reach 800: Nowood River from Paint Rock Ck. To Bighorn Riv.	248,827	295,779	424,924
Lower Bighorn	Reach 1000: Bighorn River at Greybull River	915,630	1,438,245	1,797,531
	Reach 1500: Bighorn River at Shell Creek	917,826	1,463,859	1,829,238
	Reach 1600: Shell Creek	19,218	46,793	57,027
	Reach 1700: Bighorn River at Yellowtail	919,801	1,567,955	1,911,814
	Reach 1740: Crystal Creek	1,025	2,812	6,807
Greybull	Reach 1100: Greybull River Headwaters	29,634	85,629	74,207
	Reach 1200: Wood River	66,134	84,738	104,651
	Reach 1300: Greybull River below Wood River	39,696	94,879	86,534
	Reach 1350: Meeteetse Creek	1,531	3,552	5,828
	Reach 1400: Greybull River Below Roach Gulch	48,053	108,263	96,906
Shoshone	Reach 1800: South Fork Shoshone River Headwaters	6,274	11,667	18,472
	Reach 1900: South Fork Shoshone River below Bob Cat Creek	97,126	260,356	425,296
	Reach 2000: North Fork Shoshone River Headwaters	27,097	55,797	97,618
	Reach 2100: North Fork Shoshone River below Wapati	156,891	348,970	560,480
	Reach 2200: Buffalo Bill Reservoir	196,528	403,274	636,417
	Reach 2300: Shoshone River below Buffalo Bill Reservoir	196,528	403,274	636,417
	Reach 2390: Sage Creek	0	0	103
	Reach 2400: Shoshone River below Sage Creek	302,875	521,599	749,870
	Reach 2500: Shoshone River below Bitter Creek	471,534	748,196	1,082,116

Table 3.3-5 Clarks Fork, Yellowstone and Madison/Gallatin Basin Available Flow - Full Supply Scenario

Basin	Location	Available Flow (ac-ft)		
		Dry	Normal	Wet
Clarks Fork	Reach 100: Clarks Fork River above Sunlight Creek Confluence	240,422	370,501	528,966
	Reach 190: Sunlight Creek	48,383	70,615	86,899
	Reach 200: Clarks Fork River from Sunlight Creek to Bennett Creek	240,422	370,501	567,608
	Reach 300: Clarks Fork River below Bennett Creek Confluence	294,923	444,004	681,550
Yellowstone	Reach 400: Yellowstone River above Lamar River Confluence	813,647	1,146,594	1,328,581
	Reach 500: Yellowstone River below Lamar River Confluence	1,531,126	2,140,310	2,469,129
	Reach 580: Gardner River	65,111	113,663	144,366
Madison/Gallatin	Reach 600: Madison River	340,745	375,009	437,417
	Reach 620: Gibbon River	89,203	109,391	135,155
	Reach 640: Firehole River	251,542	265,618	302,261
	Reach 800: Gallatin River	501,921	634,324	716,471

Table 3.3-6 Wind River Basin Available Flow - Full Supply with Futures Projects Scenario

Basin	Location	Available Flow (ac-ft)		
		Dry	Normal	Wet
Upper Wind	Reach 100: Wind River Headwaters to DuNoir Creek	0	28,187	43,626
	Reach 200: Wind River from DuNoir Creek to East Fork	0	47,469	62,968
	Reach 300: Wind River from East Fork to Bull Lake Creek	70,387	150,190	354,645
	Reach 290: East Fork Wind River	2,586	21,858	36,403
	Reach 320: Dinwoody Creek	5,550	37,336	57,003
	Reach 390: Bull Lake Creek	14,327	70,862	111,811
Little Wind	Reach 400: Wind River from Bull Lake Creek to Little Wind	91,783	214,625	406,565
	Reach 500: Little Wind River	26,825	88,499	137,008
	Reach 510: South Fork Little Wind	7,454	15,620	39,709
	Reach 520: North Fork Little Wind	11,641	62,887	94,835
	Reach 530: Trout Creek	2,833	5,717	8,317
	Reach 580: Popo Agie River	26,825	88,499	137,008
Lower Wind	Reach 600: Wind River from Little Wind Confluence to Boysen Reservoir	292,772	684,113	878,067
	Reach 700: Muddy Creek	2,676	3,441	4,131
	Reach 800: Badwater Creek	22,101	22,007	18,305

Notes:

(1) Available Flow in Upper Wind River Basin affected by Instream Flow requirements in Reach 200. The East Fork Wind River is downstream of this Instream Flow segment. However, due to model construction, its impacts are imposed on the East Fork.

Available Flow in Excess of Existing Demands

The Wind/Bighorn sub-basin models are divided into reaches that represent an individual reach of stream. The available flow is calculated as the minimum of the available flow within the individual reach and the available flow of all downstream reaches.

In previous river basin planning models, the available flow within each reach was calculated as the minimum of the outflow from the reach (HKM, 2002). However, it was found that in the Wind/Bighorn sub-basin models, some of the reach outflows were greater than the minimum flow within the reach. Thus, the defining flow availability is the minimum flow within the reach, taking into account compact requirements for the WBHB and instream flow requirements within the reach. Therefore, for the Wind/Bighorn available flows, the available flow within each reach was taken as the minimum flow at all nodes within the reach. The minimum flow for the individual reach was then calculated as the minimum flow within the reach plus the minimum flow of all downstream reaches.

It should be noted that performing these calculations on an annual basis could result in different results than performing the calculations on a monthly basis. The monthly basis is considered more accurate because of the shorter calculation time period. The annual value of available flow is the sum of the 12 months' available flow.

Compact Constraints

The Yellowstone River Compact, which was ratified in 1950 by the states of Wyoming, Montana and North Dakota, governs the allocation of the tributaries to the Yellowstone River between the states. The following is a brief summary of the rules for dividing water according to the Compact (WWDC, 2002):

> *To all tributaries the following rules apply:*
>
> 1) *existing rights as of January 1, 1950 maintain their status quo;*
>
> 2) *no water may be diverted from the Yellowstone River Basin without consent from all states;*
>
> 3) *existing and future domestic and stock water uses including stock water reservoirs up to a capacity of 20 acre-feet are exempted from provisions of the Compact.*
>
> *The unappropriated or unused total divertible flow of each tributary after needs for supplemental supply for existing rights are met, is allocated to Wyoming and Montana on a percentage basis.*

The information used in this study to determine the volume of availability under the Yellowstone River Compact is based upon conversations and information from the U.S. Geological Survey and with the Wyoming State Engineer's Office (SEO) (YRCC, 2002). For the Clarks Fork of the Yellowstone River, the Compact allocates 60 percent of the unallocated flows to Wyoming and 40 percent to Montana. For the Bighorn River, the Compact allocates 80 percent of the unallocated flow to Wyoming and 20 percent to Montana. A summary of the annual unallocated flow calculations using the methodologies prescribed by the Compact Commission are shown in Table 3.3-7.

Table 3.3-7 Calculation of Wyoming Portion of Unallocated Flow

	Clarks Fork			Bighorn River		
	Dry Year	Normal Year	Wet Year	Dry Year	Normal Year	Wet Year
Gaged Flow (ac-ft)	491,713	733,406	1,137,418	1,911,049	2,778,269	3,591,471
Adjusted Flow (ac-ft)	498,664	740,007	1,144,083	1,686,523	2,559,384	3,382,968
Wyoming Portion of Unallocated Flow (ac-ft)	299,199	444,004	686,450	1,349,218	2,047,507	2,706,375
Wyoming Portion of Unallocated Flow (ac-ft) minus Futures Projects	N/A	N/A	N/A	1,099,218	1,797,507	2,456,375

Notes:
(1) Based on 1973 – 2001 data.

Instream Flow Conditions

The Wyoming Water Development Commission (WWDC) applies for instream flow permits for fishery uses within the stream reach. Within the Wind/Bighorn Basin Plan study area, there are three streams with permitted instream flows, one stream with two separate reaches, and two streams with pending instream flow applications. The permitted and pending instream flow reaches and flow rates are shown in Table 3.3-8 (Brinkman, 2002). The instream flows are more fully discussed in the Technical Memorandum Recreational and Environmental Uses and Demand (BRS, 2002).

Table 3.3-8 Permitted and Pending Instream Flow Rates

		Permitted/Pending Instream Flow (cfs)											
Instream Flow Segment	Model Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Clarks Fork	200	200	200	200	200	200	200	200	200	200	200	200	200
Tensleep	690	22	22	22	22	22	22	22	22	22	22	22	22
Big Wind	200	102	102	102	110	110	102	102	102	102	102	102	102
Shell 1 (1)	1600	19	19	19	45 (1)	70	70	40	40	40	19	19	19
Shell 2	1600	23	23	23	23	23	23	40	40	40	23	23	23
Medicine Lodge Creek (2)	794	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	15	15	8.9
Shoshone River (2)	2300	350	350	350	350	350	350	350	350	350	350	350	350

Notes:
(1) The flow requirement in April for Shell No. 1 is 19 cfs April 1-15 and 70 cfs April 16-30. The calculations assume the average of these two values for the April value.
(2) The Medicine Lodge Creek and Shoshone River instream flow applications are pending.

Instream flows exert a demand on the river the same as any other consumptive use water right. Flow must be passed through the instream flow segment according to the water right priority date. Once that flow is through the segment, the water can be diverted for consumptive use. Therefore, available flows for reaches upstream of the permitted instream flow rights are affected assuming that water rights for use of the available flows would be junior to the instream flow rights.

All available flow calculations assume that both the permitted and pending instream flow water rights are in place. Therefore, any upstream flows that are not in excess of the instream flow right are shown to be unavailable for future uses. Each of the instream flow segments is within a modeled reach as shown in the table. For purposes of the calculations, it was assumed that the entire reach is subject to the instream flow requirement even if the instream flow segment occupies only a small portion of the reach. The reaches most affected by the instream flow water rights are the Upper Wind River, Shell Creek, Medicine Lodge and Tensleep Creek, especially in the winter months. Flows in Medicine Lodge Creek are a concern primarily during the summer when flows in the instream flow reach typically drop very low.

3.4 – Available Ground Water Determination

3.4.1 – Introduction

This section provides a qualitative summary of the ground water resources of the Wind, Bighorn, Yellowstone, Clarks Fork, Gallatin, and Madison River Basins of north-central Wyoming. Additional information is provided in the Technical Memorandum, "Available Ground Water Determination", Chapter 3, Tab 17, for the Wind/Bighorn River Basin Plan. In completion of this study, no original investigations were performed. The study represents an inventory, compilation, and review of published literature on the geology and ground water resources of the planning area.

Study Objectives

The first objective was to inventory and document existing published data on ground water studies and ground water planning documents for the planning area. A listing of related ground water studies is provided in Appendix A, of the technical memorandum, Chapter 3, Tab 17. Most of the existing ground water studies and ground water planning documents have considered the planning area with respect to either individual counties or as separate geographic areas such as the Wind River Basin, the Bighorn Basin, and the Yellowstone Plateau. Additional information on specific geographic areas within the planning area is available through the U.S. Geological Survey (USGS), the U.S. Bureau of Land Management (BLM), and other federal agencies.

A second objective was to inventory and catalog the SEO ground water permit database for various categories of ground water uses in the planning area, and incorporate the extracted information into four GIS data layers. This was accomplished through a cooperative effort of personnel of the SEO and WWDC. GIS data layers prepared from information on file with the SEO as of December 31, 2001, are presented in Appendix B, of the technical memorandum, Chapter 3, Tab 17, and include:

- Permitted active agricultural, municipal, industrial, and recreational wells with production rates of 50 gallons per minute (gpm) or greater at depths less than 150 feet
- Permitted active agricultural, municipal, industrial, recreational, and environmental wells with production rates of 50 gpm or greater at depths greater than 150 feet
- Permitted active domestic wells at depths of 150 feet or less
- Permitted active domestic wells at depths of greater than 150 feet

A third objective of this investigation was to semi-quantitatively assess the impacts of well interference in more intensively developed ground water production areas near Hyattville and Riverton. The Wind River Aquifer near Riverton has been extensively developed primarily for municipal and domestic use. In the vicinity of Ten Sleep and Hyattville, the Tensleep, Madison, and Flathead Aquifers have been developed principally for agricultural use, but are also used for municipal and industrial purposes. These particular areas were investigated at the request of WWDC personnel to assess whether or not a control area designation may be warranted at this time.

Other objectives include:

- Summarize existing information on aquifers with regards to location, storage, yield and development potential within the planning area.
- Summarize the potential effects that ground water development might have on the ground water and surface water systems in the basins.

3.4.2 – Geological Setting

Encompassing approximately one quarter of the state, the planning area contains a wide variety of geologic formations and structural elements within the Wind River Basin, the Bighorn Basin, and the Yellowstone Plateau. Geologic formations vary in thickness and in age from Precambrian crystalline rocks to recent alluvial and terrace deposits of silts, clays, sands, and gravels. The Wind River Basin contains roughly 18,000 feet of Cenozoic through Paleozoic sedimentary strata (Richter, 1981). Similarly, the Bighorn Basin contains approximately 33,000 feet of Cenozoic through Paleozoic sediments (Libra and others, 1981). In contrast, the Yellowstone Plateau and mountain ranges to the east contain at least 15,000 feet of Cenozoic volcanics and volcanic sediments that overlie Mesozoic and Paleozoic sedimentary rocks (Cox, 1976). General surficial and bedrock geology of the planning area is shown on Figures 3.4-1 and 3.4-2.

The Wind River and Bighorn Basins are both large asymmetrical structural depressions that contain up to 18,000 and 33,000 feet, respectively, of Cenozoic, Mesozoic, and Paleozoic sediments that rest unconformable on Precambrian crystalline basement rocks (Libra and others, 1981; Richter, 1981). With the exception of the western Bighorn Basin that is covered with Absaroka Volcanics, these structural Basins are bordered by compressional uplifts of Precambrian granite cores mantled by moderately to steeply dipping sedimentary formations (Libra and others, 1981). While it has been speculated that these or similar structures extend far into Yellowstone National Park, the Yellowstone Plateau coincides with a large volcanic caldera (Cox, 1976; Libra and others, 1981). The configuration of these geologic formations and structural elements greatly influence the occurrence and availability of ground water in the planning area.

Within the Bighorn and Wind River Basins, significant quantities of oil, gas, and uranium have been commercially developed from sedimentary rocks. Coal and bentonite have both been commercially developed within the Bighorn Basin. Most oil and gas in the region has been developed from Mesozoic and Paleozoic rocks in structurally sympathetic anticlines (Richter, 1981; Libra and others, 1981). The Wyoming Oil and Gas Conservation Commission (2000) reported approximately 20 million barrels of oil and 156 million cubic feet of natural gas were produced from 4,937 wells in Big Horn, Fremont, Hot Springs, Park, and Washakie Counties in 2000. Uranium has been produced from the Wind River Formation in the Wind River Basin.

3.4.3 – Hydrostratigraphy

An aquifer is generally defined as a geologic formation or group of formations that are sufficiently saturated and permeable enough to yield a significant quantity of water to wells or springs. Of the more than 40 geologic formations that are present in the planning area, at least 12 aquifers and two aquifer systems have been recognized (Richter, 1981; Libra and others, 1981). The two aquifers primarily developed for high capacity municipal supply are the Wind River and Madison Aquifers.

For this report, the formations have been grouped into 13 principal aquifers that have historically been the major ground water sources for development. The grouping was based on that presented in the 1981 reports on the "Occurrence And Characteristics of Ground Water in the Wind River Basin, Wyoming," and on the "Occurrence And Characteristics of Ground Water in the Bighorn Basin, Wyoming," by the Wyoming Water Resources Research Institute (WWRI) (Richter, 1981; Libra and others, 1981). Figure 3.4-3 graphically summarizes the hydrogeologic role of the geologic formations in the area.

The WWRI aquifer division used herein was based on the hydrogeologic character of the geologic formations of Richter (1981). While more detailed than the description of Libra and others (1981), the division allows for a more accurate, regional presentation of the principal sources of ground water in the planning area. The 13 major aquifers are (youngest to oldest):

- Quaternary Aquifer
- Wind River Aquifer
- Willwood Aquifer
- Fort Union/Lance Aquifer
- Mesaverde Aquifer
- Frontier Aquifer
- Muddy Aquifer
- Cloverly Aquifer
- Sundance/Nugget Aquifer
- Phosphoria Aquifer
- Tensleep Aquifer
- Madison Aquifer
- Flathead Aquifer

As previously mentioned, the two aquifers primarily developed for high capacity municipal supply are the Wind River and Madison Aquifers. The Wind River Aquifer is composed of sufficiently saturated and permeable sandstone and conglomerate of the Wind River Formation, and it is the major source of drinking water for domestic and water supply purposes in the vicinity of Riverton and Shoshoni in the Wind River Basin. Although these lenticular sandstone and conglomerate beds are difficult to correlate, aquifer tests of the Riverton Municipal Well Field and the Fremont Minerals deep well in Riverton have revealed the entire sandstone, siltstone, and shale sequence of the Wind River Formation is sufficiently hydraulically connected (Gores and Associates, 1998). Nevertheless, the presence of these shales and siltstones has resulted in a series of semi-confined and confined sandstone subaquifers. Approximately 1,700 wells had been drilled into the Wind River Aquifer as of

1981. These wells reportedly yield water from both unconfined and confined sandstone beds (Richter, 1981).

The Madison Aquifer is composed of sufficiently saturated and permeable portions of the Madison Limestone, Darby Formation, and Bighorn Dolomite, and it is a primary source of drinking water for several municipalities in the Bighorn Basin. The Madison Limestone and Bighorn Dolomite are thick-bedded carbonate rocks that include considerable chert. Cooley (1986) noted that in most outcrops Madison and Bighorn strata are transected by many large vertical fractures, which can make drilling difficult and cause the loss of drilling fluid circulation. Along the crests of anticlinal folds in which through-going vertical joints provide conduits for vertical flow, the Madison Aquifer is locally hydraulically connected to the overlying Tensleep Aquifer (Cooley, 1986). Yield from the Madison Aquifer is contingent upon the number of permeable interconnected fractures or solution tubes encountered in individual wells.

3.4.4 – Ground Water Quality

Water quality conditions in the aquifers of the planning area were extensively reviewed by the USGS during the preparation of county water resources reports during the 1990s, and by the Wyoming Water Resources Research Institute in the early 1980s. This research indicated the best quality ground water is usually derived from areas closest to the geologic outcrop areas of each aquifer. Generally, the water quality of ground water derived from each aquifer is variable and dependent upon a variety of factors including, but not necessarily limited to the following: distance from the recharge area, aquifer transmissivity and storage, ground water flow rates, aquifer rock type, dissolution of soluble salts within the aquifer matrix, and leakage of poor quality water from adjacent units (Richter, 1981).

Water Quality Standards and Suitability for Use

The State of Wyoming has identified the following standards for different classes of ground water (WDEQ, 1993):

- Class I ground water is defined as ground water suitable for domestic use.
- Class II ground water is defined as ground water suitable for agricultural use where soil conditions and other factors are adequate.
- Class III ground water is defined as ground water suitable for stock use.
- Class Special (A) ground water is defined as ground water suitable for fish and aquatic life.
- Class IV ground water is defined as ground water suitable for industry.
- Class V ground water is defined as ground water found closely associated with commercial deposits of hydrocarbons, or ground water which is considered a geothermal resource.
- Class VI ground water is defined as ground water that may be unusable or unsuitable for use.

While used for municipal and domestic supply in the Basin, ground water has historically been used primarily for agricultural and industrial purposes (Richter, 1981; Libra and others, 1981). Ground water used for agricultural purposes has principally been used for cropland irrigation, but stock watering has also been a major component. While the production of uranium and iron ore has beneficially used ground water resources, the most significant industrial production of ground water has been for petroleum recovery. With the adoption of the Surface Water Treatment Rule, ground water not directly affected by surface water has become an attractive target for primary or supplementary supply sources in the planning area, particularly for Greybull, Manderson, Basin, Worland, and Riverton. Other municipalities, including Lander and Thermopolis, are currently exploring this option as well. A relatively small percentage of ground water is also used for environmental and recreational purposes. Ground water used for these purposes is used to supply water to fish hatcheries, campgrounds, a golf course, state and national parks, and private hot springs resorts. Although its quality can vary widely over the planning area, ground water remains a very valuable source of water for many people, livestock, and industries. The key to its satisfactory development is directly related to the primary purpose for which the ground water will be used in accordance with the above list of bulleted ground water classes.

Aquifer Sensitivity/Vulnerability

The University of Wyoming's Spatial Data and Visualization Center (SDVC) developed a system to assess the sensitivity and vulnerability of ground water to surface water contamination in Wyoming (Hamerlinck and Arneson, 1998a). Potential sources of contamination in the planning area include railroad and highway transportation routes, oil and gas pipelines that traverse the Basin, oil and gas wells and well fields, hazardous waste spills, agricultural chemicals applied to farmlands, mining related chemicals and wastes, and underground injection wells. Development of the system was made possible through EPA Section 319 Program funding. Additional financial support was provided by the Wyoming Non-Point Source Task Force, USEPA Region VIII, and the Wyoming Department of Environmental Quality, Water Quality Division. The Wyoming Department of Agriculture also provided support and guidance in the initial planning phase to develop the assessment system (Hamerlinck and Arneson, 1998a).

With the exception of the Yellowstone National Park area, the SDVC developed aquifer sensitivity maps to define the potential for surface contamination to impact ground water in the uppermost aquifer throughout Wyoming. **Plate D.1, Appendix D, technical memorandum, Chapter 3, Tab 17** is a map of aquifer sensitivity to contamination within the planning area. Lands rated as being most sensitive to contamination generally are located on alluvial deposits adjacent to rivers, streams, and lakes; on slope wash, colluvium, residium, and eolian deposits; and on fractured bedrock areas.

Plate D.2, Appendix D, technical memorandum, Chapter 3, Tab 17, is a map of aquifer vulnerability to pesticide contamination for the uppermost or shallowest aquifers in the area. Ground water is vulnerable in areas with high water tables, sandy soils, and areas of presumed pesticide application. Areas with the highest vulnerability are also generally located in the floodplains of major streams or are associated with slope wash, colluvium, residium, and eolian deposits.

3.4.5 – Ground Water Development

Within the limits of the planning area, ground water is the primary source of water for many uses. While the Madison and Wind River Aquifers represent the most utilized sources of municipal supply, all 13 aquifers are important water sources for different reasons throughout the planning area.

Existing Development

The 12,381 active ground water permits inventoried by the SEO as of December 31, 2001, demonstrate the overall significance of ground water resources in the planning area. From these wells, two GIS database layers were prepared to show the locations of non-domestic wells that have water rights of greater than 50 gpm. Two maps showing the locations of all permitted domestic wells were also prepared. The following bulleted list summarizes the number of wells for each usage category that were used in the preparation of the GIS data layers:

- 138 permitted active agricultural wells with production rates of 50 gpm or greater
- 84 permitted active municipal wells with production rates of 50 gpm or greater
- 165 permitted active industrial wells with production rates of 50 gpm or greater
- 10 permitted active recreational wells with production rates of 50 gpm or greater
- 6 permitted active environmental wells with production rates of 50 gpm or greater
- 7,575 permitted active domestic wells

The locations of these wells are presented with respect to surficial and bedrock geology, and usage type in **Plates B.1 through B.4, Appendix B, Technical Memorandum, Chapter 3, Tab 17**. Review of the plates provides a general understanding of the overall significance of individual aquifers based on the type of use, well depth, geologic formation outcrop areas, and geographic location.

Within the planning area, the SEO has permitted approximately 222.6 million gallons per day (MGD) of ground water for various uses. While this amount does not indicate average daily usage, it does reveal the magnitude of existing ground water development in the area. The following paragraphs further discuss existing ground water development according to the type of use.

Agricultural wells in the Basin are used to deliver approximately 88.5 MGD or 39.7% of the total. Most of these wells are used to irrigate croplands or hayfields along either the margins of the Basin or along alluvial channels.

The second largest use of ground water in the Basin, industry uses approximately 63.3 MGD or 28.4% of the total. Petroleum and mineral development companies are the major developers of ground water in this area. In fact, the Wyoming Oil and Gas Conservation Commission (2000) reported approximately 108 MGD of ground water were produced from 4,937 wells in Big Horn, Fremont, Hot Springs, Park, and Washakie Counties in 2000. It is uncertain how much of this quantity was actually consumed, however, and it is presumed that most of this water was used to enhance oil or gas recovery.

Based on information provided to the WWDC, municipalities in the Basin use 3.9 MGD of ground water on average and a maximum of 8.8 MGD. This ground water is consumed by 36 municipal and non-municipal community public water systems that are located in the Basin. By contrast, the SEO has already issued permits for 54.2 MGD of ground water development, which suggests either that the SEO believes there are sufficient quantities of ground water still available for development, or that more water is being used than is being reported.

Domestic ground water use in the Basin was estimated on the basis of the rural population, which predominately uses ground water for domestic supply. While the total population of the planning area as of 2000 has been estimated to be 85,222 people, the population of municipalities and those served by public water systems has been estimated to be approximately 59,000. To quantify the amount of ground water used for domestic purposes, the population served by municipal systems was subtracted from the total population for the area, or 26,222 people. An estimated per capita usage rate of 75 gallons per day was used to estimate daily usage. Based on this method, approximately 1.96 MGD of ground water are used to supply the rural population of the planning area.

Ground water is also used for recreational and environmental purposes in the Basin. This ground water is used to supply fish hatcheries, campgrounds, and private recreational facilities. Approximately 4.78 MGD of the total are used for recreational purposes, while 4.15 MGD are used for environmental purposes. Actual consumptive use is likely much less than these figures.

Impacts of Existing Development

The Wind River Aquifer near Riverton has been extensively developed primarily for municipal and domestic use. In the vicinity of Ten Sleep and Hyattville, the Tensleep Aquifer, Madison Aquifer, and the Flathead Sandstone have been developed not only for agricultural use, but are also used for municipal and industrial purposes. These particular areas were investigated to assess whether or not a control area designation may be warranted at this time.

According to Wyoming Water Statute § 41-3-912, a control area can be designated by the Board of Control upon the initiative of the State Engineer for the following reasons:

- The use of underground water is approaching a use equal to the current recharge rate;
- Ground water levels are declining or have declined extensively;
- Conflicts between users are occurring or are foreseeable;
- The waste of water is occurring or may occur; or
- Other conditions exist or may arise that require regulation for the protection of the public interest.

Based on SEO records, approximately 48 wells with water rights in excess of 50 gpm have been drilled within the area around Ten Sleep and Hyattville since 1945, as shown on **Plate E.1 found in appendix B of chapter 3 of the Technical Memorandum**. Most of these wells were completed in either the Madison Aquifer or the Flathead Sandstone and are flowing artesian. Used for municipal purposes, the City of Worland wells, Husky No. 1 and Worland No. 3, have the largest water rights of any wells in the area at 5,000 and 6,660 gpm respectively. In combination with the other seven municipal and quasi-municipal wells in the area, approximately 13,800 gpm of water rights have been allocated for municipal use in the area. The second largest use of ground water in the area is irrigation. This area contains eleven wells that are each permitted to produce more than 400 gpm, and are yield a combined total of approximately 13,300 gpm.

The overall impact of existing ground water development from the Paleozoic Aquifers in the vicinity of Ten Sleep and Hyattville appears to vary with time and by geographic location. In arriving at this conclusion, wellhead pressures and water level data were obtained through a June 18, 2002, meeting with local agricultural users, and by contacting Worland, Hyattville, Ten Sleep, the South Bighorn Regional Joint Powers Board, and the SEO. Cooley (1986) and Susong and others (1993) reported that periodic data from various wells in the area were collected by the USGS in 1953, 1962, 1970, 1975-1978, and 1989. While Cooley (1986) reported a decrease in the wellhead pressure of Ten Sleep No. 1 in Section 16 of T47N, R88W, between 1972 and 1977 corresponded to decreased combined flow from a well and spring at the Wigwam Fish Rearing Station east of Ten Sleep, recent data from this well and Ten Sleep No. 2 in Section 17 of T47N, R88W, suggest the static artesian pressure of the Madison Aquifer at this location has not declined. In contrast, Madison Aquifer artesian pressures appear to be declining in the vicinity of Worland's wells in T49N, R91W near Hyattville, as shown on **Plate E.1, Technical Memorandum, Chapter 3, Tab 17**. Wellhead pressures for wells completed in the Flathead Sandstone also continue to decline due to continuous production via irrigation or interaquifer leakage (Susong and others, 1993).

In contrast to the Ten Sleep and Hyattville vicinity, ground water from the Wind River Aquifer in the vicinity of Riverton is almost exclusively used for municipal or quasi-municipal purposes. Of the roughly 1,010 ground water permits issued by the SEO near Riverton, approximately 98% are used for municipal or domestic use (Gores and Associates, 1998). Only 44 of these permits are for ground water production of 50 gpm or more, and 23 of the 25 wells that are permitted for 100 gpm or more are completed at depths of 300 feet or greater. According to the SEO, all 13 of Riverton's municipal supply wells are completed at depths of 300 feet or greater. Gores and Associates (1998) reported these wells are permitted to yield a total of 4,015 gpm. The average production of these wells between 1987 and 1996 was 710 gpm.

Water level records maintained by the City of Riverton and the USGS indicate ground water levels in the Wind River Aquifer have been lowered as a result of municipal ground water production since 1924, as shown on **Plate E.2, Technical Memorandum, Chapter 3, Tab 17**. While monthly production records for Riverton's well field are only available since July 1957, these records reveal that ground water production steadily increased from 632 to 1,357 gpm per year between 1958 and 1980. Annual well production dropped to approximately 696 gpm following the City's installation of a surface water treatment plant in June 1981 (Gores and Associates, 1998). Although demands on the Wind River Aquifer between May and September have been reduced through the treatment and use of surface water from the Wind River, water levels in the Riverton area remain well below those of the 1940s. In the vicinity of the inactive municipal wells in southwestern Riverton, water levels are approximately 60 feet below 1940s levels based on static water levels reported on well completion reports, and water levels in the vicinity of Riverton's current production wells are well over 90 feet lower (Gores and Associates, 1998). Furthermore, Riverton's long reliance upon the storage capabilities of the aquifer has resulted in an area-wide lowering of the water level by approximately 30 feet.

Based on recorded declines in water levels and wellhead pressures in these areas near Hyattville and Riverton, the SEO may want to further investigate these areas and talk with local residents regarding the necessity of establishing control areas at these locations.

Future Development

Geologic conditions, drilling depths, hydrogeologic characteristics, and the ground water quality of the numerous aquifers vary throughout the planning area. Depending upon the proposed type of use and required water quantities, virtually all of the aquifers probably have some potential for development. Site specific investigations and experience will be required to assess specific possibilities to develop ground water from wells with sufficient capacity for a specific use.

While numerous hydrogeological investigations have been conducted in the planning area, there have been few, if any, regional assessments of the annual recharge, storage, and sustained yield capability of the major aquifers. General conclusions regarding the ground water development potential of several of the major aquifers are summarized below:

- Subaquifers in the Quaternary Aquifer may have local development potential. Depending upon local hydrogeologic conditions, individual well yields may typically range from 10 to 500 gpm. Water quality and susceptibility to surface water sources of contamination must be addressed.
- The Wind River Aquifer is already heavily developed within the Wind River Basin, but opportunities for additional ground water development and installation of high capacity wells may be possible in areas not currently developed. Local water quality conditions may constrain development in the planning area.
- The Madison Aquifer likely has the most development potential for high yield wells. Yields of up to 14,000 gpm have been encountered historically under flowing artesian conditions. However, declines in local hydraulic head and large variations in the fracture and karst permeability of this system will necessitate site-specific investigations to be conducted prior to drilling. Drilling depths and water quality will also constrain development at specific locations within the planning area.
- The Flathead Sandstone is another viable high yielding aquifer in areas where the formation can be drilled at reasonable depths. This aquifer generally has large artesian pressures, and has produced large artesian flows of up to 3,000 gpm. As with the Madison Aquifer, drilling depths and water quality will constrain development at many locations throughout the Basin.

Table 2 in the Wind/Bighorn Technical Memorandum "Available Ground Water Determination", Technical Memorandum, Chapter 3, Tab 17, summarizes the development potential of each aquifer within the planning area, along with its general lithologic and hydrologic character, and its general ground water quality.

Figure 3.1-1
Key Gages and Index Gages

October 2003

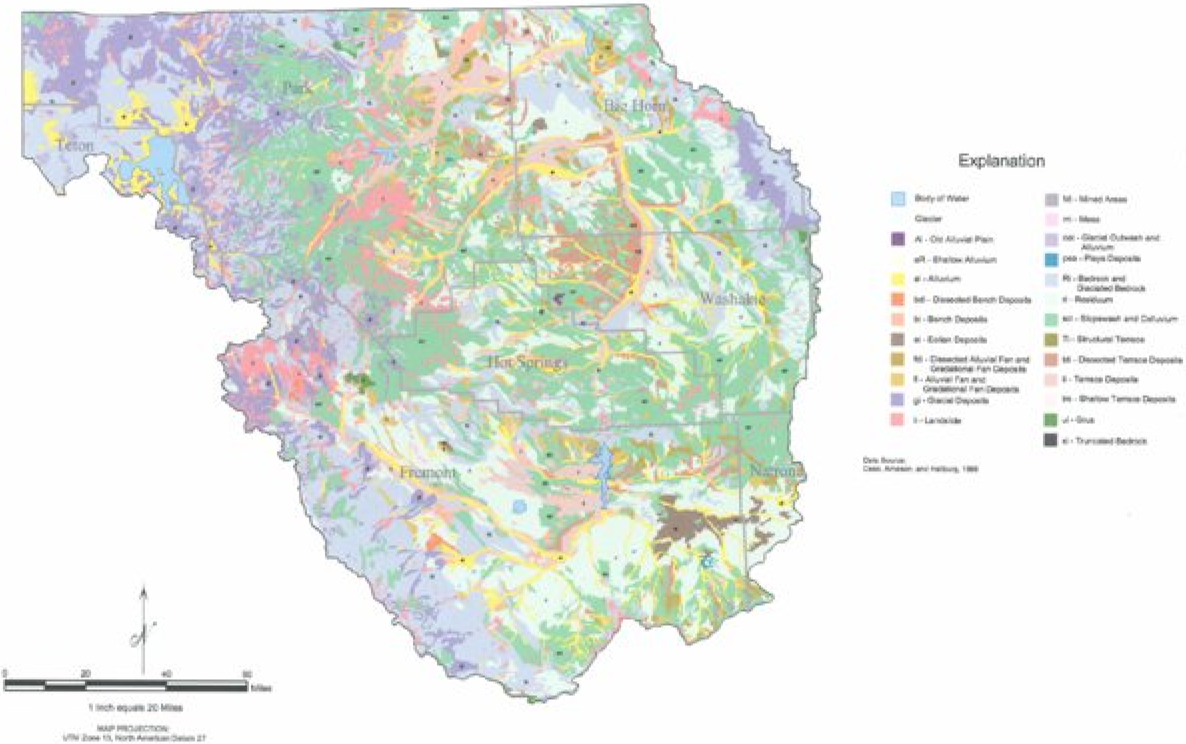

Figure 3.4-1 Surficial Geology October 2003	Wind/Bighorn River Basin Plan BRS ENGINEERING MWH Denver, Colorado TRIHYDRO

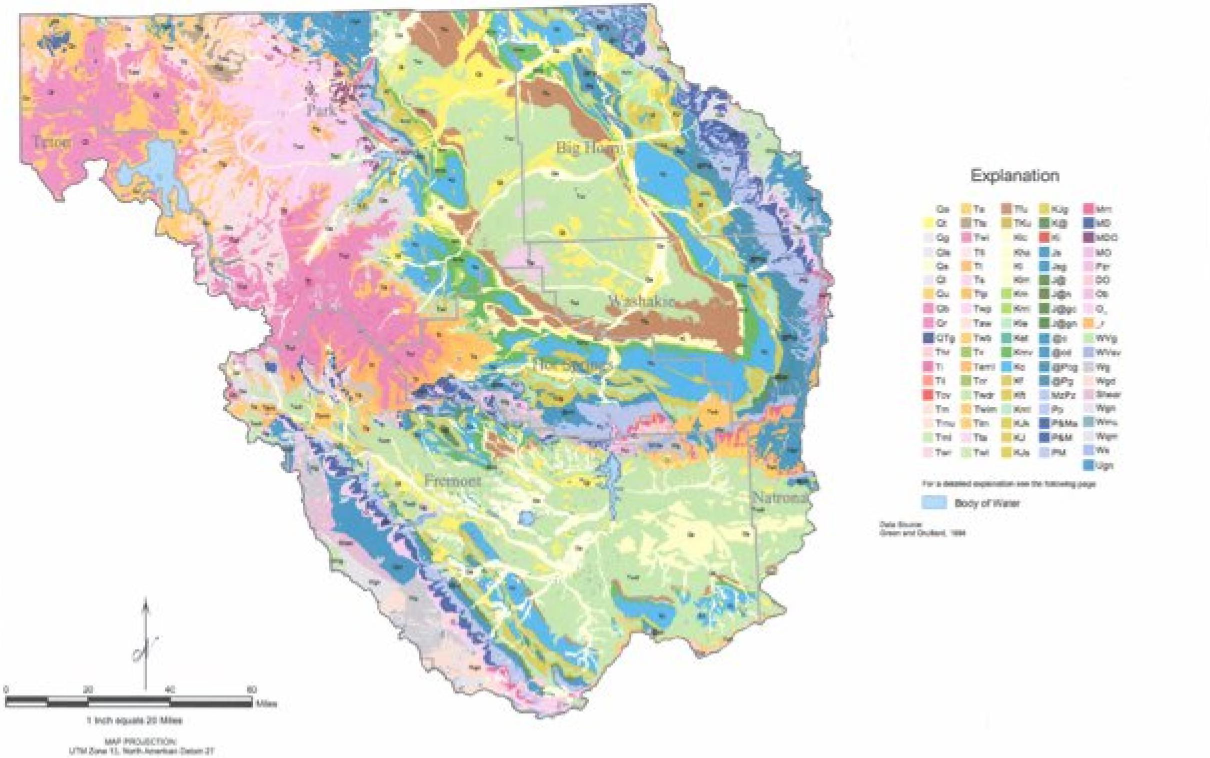

Figure 3.4-2
Bedrock Geology

October 2003

Wind/Bighorn River Basin Plan

BRS ENGINEERING

MWH
Denver, Colorado

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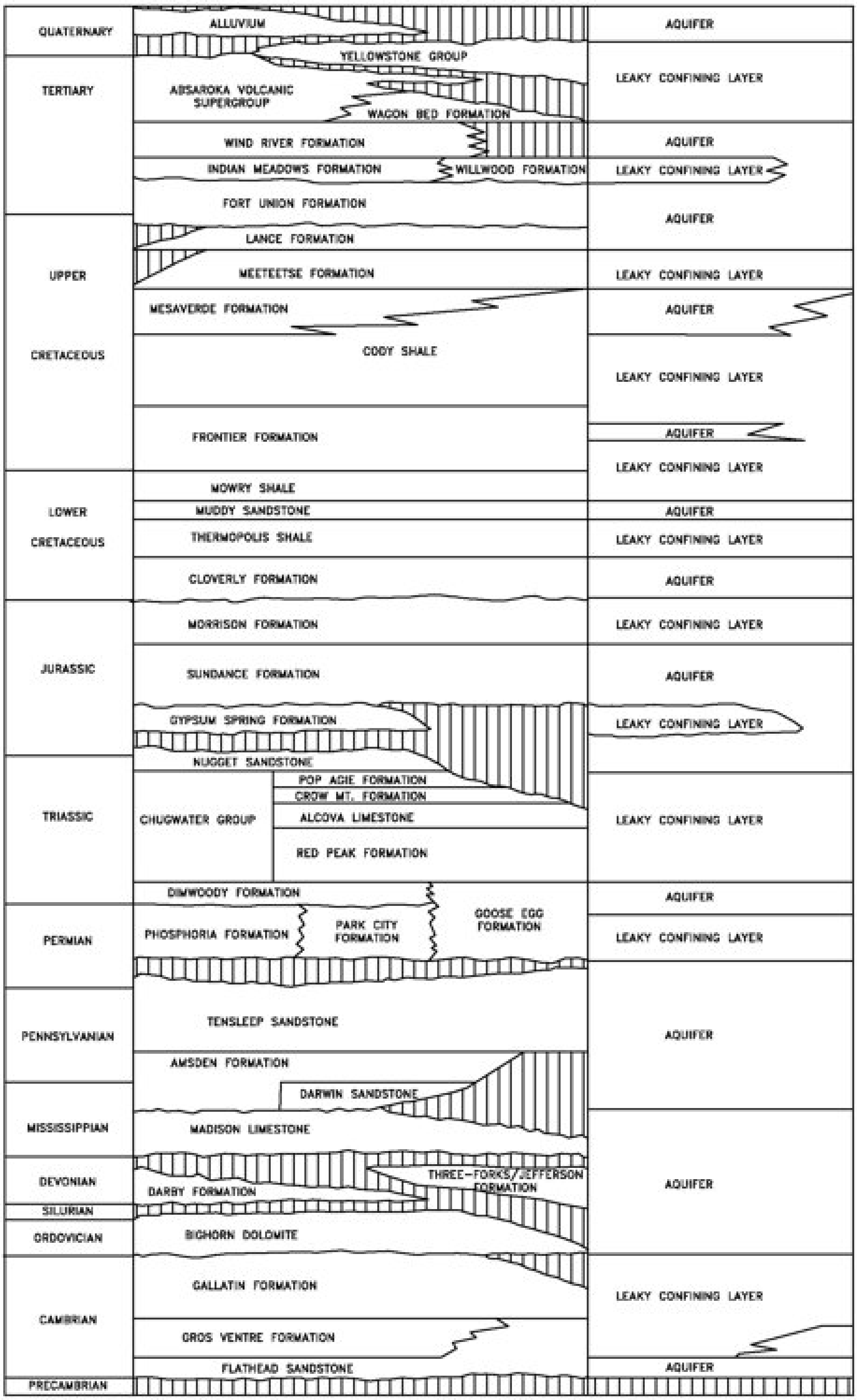


PROJECT: WYBRS105 DATE: 09/17/02 DRAWN: JHF CHECKED: MES REVISIONS: FILE: wybrs105-lithology-rock age	**NOTES/LEGEND** MODIFIED FROM RICHTER (1981). STRATAGRAPHIC RELATIONSHIPS ACROSS THE PLANNING AREA ARE APPROXIMATE.	**Figure 3.4-3** Hydrologic Roles and Ages of Rocks in the Wind/Bighorn Basin, Wyoming	Lidstone and Associates, Inc. Engineering, Geology, & Water Resource Consulting

CHAPTER 4
FUTURE WATER USE PROJECTIONS

4.1 – Socioeconomic Factors and Water Demand

4.1.1 – *Methodological Considerations*

Water demand is a function of environmental, economic, demographic, cultural and institutional variables. Among these, the first three are primary variables, but all must be considered if realistic projections are to be made. Credible projections also demand good data, both quantitative and qualitative.

Wyoming is somewhat atypical sociologically, demographically and economically, compared to most other states. The state's anomalous character is particularly clear in the nature of its economy, which is an outlier in terms of correlation with the national economy: what happens in Wyoming does not necessarily reflect what is happening nationally (Smith, 1996). If the state is anomalous, it seems even more the case in regard to analyses of sub-state entities, such as the counties of the WBHB, which differ in several ways from other regions of the state.

Still, the situations faced by the WBHB counties are not unique. A useful approach to economic and social analyses of the WBHB is the typology used by the U. S. Department of Agriculture's Economic Research Service (ERS) to analyze counties. Twenty-one of Wyoming's 23 counties are classified as "non-metro" by the ERS, Natrona and Laramie are the only two "metro" counties in the state.

The ERS classifies all five WBHB counties as "Federal lands counties." Federal lands counties (there are 270 thus classified in the United States) are those in which at least 30% of the land is owned by the Federal Government. According to ERS, "Federal lands counties (270) have land areas dominated by Federal ownership. 76% of these counties are in Western States. Counties in this type have larger land areas and are more sparsely populated than all non-metro counties. On average, population in these counties grew faster during the 1980's than in all non-metro counties. Nearly 70% of jobs in the average federal lands county are in the services or government sectors, reflecting the recreational use and land management functions of the group."(USDA, Briefing)

Federal ownership of 61% of the land in the WBHB certainly plays a crucial role in economic structure and development, in demographic characteristics, and indisputably in water demand. Beyond land ownership patterns, three other characteristics constrain the WBHB's potential for rapid, diverse economic growth: remoteness from large markets, a small labor force, and relatively underdeveloped transportation and communications infrastructures.

Many, but not all, Wyoming counties enjoy the presence of healthy minerals-related industries, which typically offer above average pay. When economic development is closely tied, as the WBHB's tends to be, to publicly owned natural resources that are not uniformly distributed across the region, intra-regional differences are often significant. Mineral resources, which have been the WBHB's major revenue source, whether coal, petroleum or gas, are declining. However, the U.S. Department of Energy's Energy Information Administration has estimated demand increases over the next two decades of 33% for oil, 62% for natural gas, and for electrical power 45%.(Barnes) Certainly such an increase in demand might spur continuing energy production in the WBHB. It could maintain existing jobs and produce new ones in energy production and distribution, as well as invigorate service industries.

In sum, current prospects for significant and diverse growth in the WBHB do not appear likely. The WBHB is far from out-of-state population centers such as Denver and Salt Lake City, the proximity to which boosts the economies of some Wyoming communities and counties. It must be understood that the WBHB's tourism and recreation-based businesses, which produce jobs mainly in the service sector, are enhanced by the very characteristic, remote and relatively "unspoiled" country that could be most threatened by large-scale economic development. Despite the many similarities among WBHB counties, it is instructive to consider demographic and economic differences among them.

It should be noted that a small area in northwest Natrona County lies within the Wind/Bighorn watershed, while a portion of the southeast corner of Fremont County lies outside the Wind/Bighorn drainage, in the Green River drainage. Both these areas are very thinly populated. The people in this area of Fremont County area are included in the demography of the WBHB Plan, though its water situation is not. In the case of the Natrona County section, its population is not incorporated in the WBHB demographic analysis. Two or three small, generally intermittent streams that head in Natrona County flow into Washakie and Fremont Counties. There are also portions of Teton County within the watershed, but they are virtually uninhabited mountain areas. It must be noted that a good-sized, but sparsely populated section of southern Fremont County is outside the Wind/Bighorn drainage. The area south of Atlantic City and South Pass City, extending east to Jeffrey City, is drained by the Sweetwater River, which flows eastward to its juncture with the North Platte, in Natrona County. For the purposes of this analysis, it has been assumed that much of the economic activity of this section of Fremont County is closely related to the rest of the County, particularly the Lander area. The population does not exceed a few hundred. Portions of Yellowstone National Park also lie within the WBHB, but consumptive surface water use within the portion of the Park in the WBHB drainage is limited.

4.1.2 – *Demographic Overview*

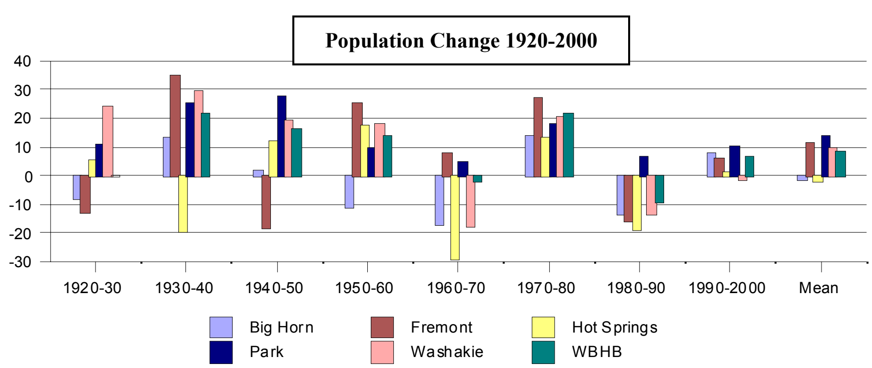
The determinants of demographic change are mortality and fertility rates, and migration patterns. Common methods of projecting populations include time-series, cohort survival, and employment-driven analyses. Projections of Wyoming's and the WBHB's future populations, however, may best be assessed by time-series and employment-driven analyses.

According to the 2000 U.S. Census, the combined population of the WBHB counties was 86,222, about 17% of Wyoming's people. For the WBHB, this is an increase over 1990, when the count was 80,562, but below the historic high of 1980, when the census recorded 87,773 WBHB inhabitants. Table 4.1-1 displays county populations from 1920 to 2000. Park County is the only county never to experience a population decline from one census to the next. Figure 4.1-1 presents population changes in terms of percentages.

Table 4.1-1 U.S. Census, by County, 1920-2000

County	1920	1930	1940	1950	1960	1970	1980	1990	2000
Big Horn	12105	11222	12911	13176	11898	10202	11896	10525	11461
Fremont	11820	10490	16905	19580	26168	28352	38992	33662	35804
Hot Springs	5164	5476	4607	5250	6365	4952	5710	4809	4882
Park	7298	8207	10976	15182	16874	17752	21639	23178	25786
Washakie	3106	4109	5858	7252	8883	7569	9496	8388	8289
Total	39493	39504	50447	60440	70188	68827	87733	80562	86222

Figure 4.1-1



4.1.2.1 – *Historical Demography*

Historical data suggests that demographic trends in Wyoming are more closely linked to economic variables that stimulate in- or out-migration than to mortality or fertility rates. The national population has increased with each decennial US Census, and Wyoming has followed suit with one exception, its 1980 census count was higher than that of 1990. Even though Wyoming reached a new population high in 2000, its growth rate lagged those of Colorado, Utah, Idaho and Montana. Wyoming's growth was comparable to Nebraska's and South Dakota's.

Although the WBHB's population peaked along with the state's in 1980, among the WBHB counties, population highs are scattered across the decades. Big Horn County's high was in 1950 (13,176), Hot Springs' in 1960 (6,365). Fremont and Washakie experienced population highs in 1980 (38,992 in Fremont; 9,496 in Washakie). Among the WBHB counties, only Park County's population peaked (at 25,786) in 2000, along with those of Wyoming and the Nation. The WBHB's 1980 population high proceeded by two decades the State's high (493,782 in 2000), and in the 1960's and 1980's the WBHB lost population.

Statistically, despite these anomalies, population trends in Fremont, Park and Washakie counties correlate reasonably well with national and state population trends. In Big Horn and Hot Springs, however, trends do not correlate significantly with each other, the other WBHB counties, the state, or the nation. Clearly population dynamics in the WBHB differ among counties. If economics is a force in population change, and the WBHB counties diverge in that respect, we should expect to find economic differences among the counties.

Since the ways in which the five WBHB counties differ may not be intuitively obvious, a WBHB wide summary might ignore important variations, which differentially affect the size and structure of county economies and populations, and therefore water demand and usage. Such a summary, therefore, must consider each county separately, as well as the WBHB as a whole.

Fremont, Park and Big Horn Counties are considerably larger in area than Washakie and Hot Springs. The two smaller counties also differ from the other three in that they each have one dominant population center, Worland and Thermopolis respectively, while the larger counties all have multiple population centers.

It is not difficult to account for most of the larger population fluctuations. Over the eighty years of change charted in Table 4.1-1, it is clear that the post-World War II years were times of rapid growth, as were the latter 1970's, while the basin wide population declined or experienced slower growth in the 1960's and later 1980's. Declining or slow growth rates primarily reflect downturns in mining, particularly uranium, oil and gas in Fremont County and coal, oil and gas in Hot Springs and Washakie.

From 1947 to 1960 Wyoming oil production increased 199%, but since 1985 Wyoming oil production has experienced a steady decline. In the latter half of the 1980's, foreign production cut into the oil market, and an oversupply of petroleum developed, lasting through the 1990's.

Despite large increases in natural gas production in Wyoming after 1985, price fluctuations and the fact that there is as yet no significant development of coalbed methane fields in the WBHB, meant that the region profited less than areas of the state with developing methane fields.

Although coal has been mined in the WBHB for many years, most production was from underground mines. After the mid-1950's, diminished underground reserves, stronger environmental laws (e.g., Clean Air Act, Water Quality Act, National Environmental Policy Act), competition from surface mines in other areas of the state, and competition from other energy sources rendered the WBHB's coal industry effectively defunct.

4.1.2.2 – *Population Forecasts*

Classical methods of population projection may not be the best way to analyze population changes in the WBHB. Wyoming's and the WBHB's birthrates are low and the population is aging. Natural population increase will not raise the population by much, if any. Migration is the key factor in the WBHB's population growth, and economic changes drive migration.

The number of babies born in Wyoming is the lowest among the states (6,252 in 1998), the state's birth rate is 40th and its fertility rate 46th among the 50 states (National Vital Statistics Report, 2000). Wyoming's birth rate is consistently below the national rate and WBHB counties have been below the state birth rate more than 60% of the time over the past five years. Only Big Horn and Fremont counties have exceeded the state rate. In 1999 Wyoming's birth rate fell to a record low of 12.8 births per 1,000 population. (Wyoming State Department of Health, 1996-2000)

The WBHB's population is aging: the median age is about 39 years, ranging from about 36 in Fremont County to about 44 in Hot Springs County. The national median age is 35.3. The U.S. Census Bureau ranks Wyoming 6th among the states in growth of the elderly (65+) population. Wyoming's birth rates are low and death rates are high.

Although the percentages of women giving birth in their 30's and 40's has increased in recent years, data suggests that only heavy immigration of young people can provide a significant boost to Wyoming's population. A net out-migration of young people constrains the job skills level of the state and of the WBHB, a disincentive for many types of companies to locate in the region, particularly in fields needing "high-tech" skills. This emigration also has an impact on population levels.

Significant immigration of young people to the WBHB seems unlikely unless there are changes in the WBHB's fundamental economic pattern, making more and better paying jobs available. The historic pattern of reliance upon mining, agriculture, and tourism does not offer many such jobs. Since this pattern is long-standing, and because there are no obvious reasons to think it will suddenly change, historic trends may well be the best indicator of the future. Wyoming's Department of Employment has projected that job growth in Wyoming will be in "the production, construction, operating, maintenance, and material handling occupations. In contrast, the greatest growth nationally will occur in the professional, paraprofessional, and technical occupations. This difference will create a labor force in Wyoming that requires less education and technical skill than that of the nation." (Wyoming Department of Employment, 2000)

4.1.2.3 – *High, Medium, and Low Growth Scenarios*

Because the river basin planning process requires the development of water demand projections three decades in the future, it is necessary to project populations for those decades. However, with respect to water demand, population changes directly impact only municipal and domestic use. Water demand projection for uses, such as industrial and agricultural, are based on specific foreseeable developments and/or projects as discussed, subsequently. Over the 80 years examined herein, the WBHB's mean population change per decade is 8.67%. (Wyoming's population grew by 8.9% during the decade of the 1990's, while the national average was 13.2%.)

Table 4.1-2, which follows, shows a variety of population projections, which could be made utilizing various methods and assumptions. For the purpose of projecting population related changes in water demand, domestic and municipal primarily, the following low, moderate, and high forecasting scenarios are recommended for the purposes of this basin plan.

Low Growth Scenario: The low growth scenario could be projected as a negative growth (projections 1 and 2) or as very slight growth (Method 3). For the purpose of the basin plan it is recommended that for the low growth scenario the population be predicted to remain the same at 86,222 for the next 30 years.

Moderate Growth Scenario: Previous basin plans utilized the state forecast as the moderate growth scenario, for consistency the WY projection (Method 4) will be used as the average growth for the WBHB (88,720 in 2010, 91,620 in 2020, and 94,600 in 2030).

High Growth Scenario: The long term percent change by county averages (Method 8) was used to project the high scenario, as this is most representative of the WBHB during both growth and decline periods (94,508 in 2010, 103,858 in 2020, and 114,407 in 2030).

The cohort by census projection could also be used for the high growth scenario. These projections vary by less than one percent over 30 years. It is noted that the projection using the Powder/Tongue growth scenario (projection 6), was presented for comparative purposes. This projection reflects the recent energy boom in that area and is similar to the recommended high growth projection.

Table 4.1-2: Results from various projection methods ranging from lowest to highest:

	Method 1	Method 2	**Method 3**	**Method 4**	Method 5	Method 6
Current	86,222	86,222	**86,222**	**86,222**	86,222	86,222
2010	76,293	83,423	**86,571**	**88,720**	90,684	93,713
2020	68,570	78,885	**87,991**	**91,620**	95,786	102,802
2030	62,632	74,593	**90,403**	**94,600**	101,241	112,773
Current	Method 7	**Method 8**	Method 9	Method 10	Method 11	Method 12
2010	86,222	**86,222**	86,222	86,222	86,222	
2020	94,390	**94,508**	96,519	99,100	103,707	110,944
2030	103,583	**103,858**	105,878	111,319	126,128	143,202
	113,927	**114,407**	116,437	125,044	153,574	185,378

Key:

- (Method 1) By county average years (Low): Taken from historical data, reflects negative growth years.
- (Method 2) Percent change by Basin averages (Low): Taken from historical data, reflects negative growth years.
- **(Method 3) Wyoming population estimate by county: Using the same percentages as the state's 2 year prediction carried out over 30 years. Used as low growth scenario. Please refer to: http://eadiv.state.wy.us**
- **(Method 4) Wyoming State projection: Based on census by county10 year projection by the state carried forward for the next thirty years. Used as moderate growth scenario. Please refer to: http://eadiv.state.wy.us**
- (Method 5) Percent change from census: This projection uses the percent change between the 1990 and 2000 census carried forward for the next thirty years. Please refer to: http://eadiv.state.wy.us
- (Method 6) Using percentages from the Powder/Tongue Basin plan: This projection is for comparative purposes only.
- (Method 7) By county average years (Moderate): Taken from historical data, reflects average years of growth in the WBHB.
- **(Method 8) Percent change by county: Uses the historical changes by county, represents both growth and decline in the Basin. Used as high growth scenario.**
- (Method 9) Cohort by census.
- (Method 10) Percent change by Basin averages (Moderate): Taken from historical data, reflects average growth years.
- (Method 11) Percent change by Basin averages (High): Taken from historical data, reflects years of high growth.
- (Method 12) By county average years (High): Taken from historical data, reflects high growth years.

4.1.3 – *The Basin's Economy*

The WBHB's economy, like Wyoming's as a whole, has long depended on a triad of industries: mining (especially coal, oil and gas), tourism, and agriculture. Mining's annual payroll in Wyoming nearly doubles that of retail trade, the nearest competing sector. In terms of numbers of jobs it trails only retail trade and accommodation, and food services (U.S. Census Bureau, 1997). Other economic sectors are, of course, significantly impacted by events in the minerals industries.

The WBHB's economy is dominated by the larger and somewhat more diverse economies of Fremont and Park Counties, which together account for about 60% of the Basin's land area and 72% of its population. In recent years these counties have accounted for 60% to 80% of retail tax collection in the Basin (Wyoming Department of Revenue). This disparity among counties is not unusual: "a third of all rural counties captured three-fourths of all rural economic gains in the 1990s" (Drabenstott). Statistical analysis indicates that Fremont County's population trends are the strongest factor in, and the best indicator of, the WBHB's overall demographic trends.

Despite the economic dominance of Park and Fremont Counties, Washakie County had (according to the 1997 model-based U.S. Census estimate) the highest median household money income ($36,386) among the WBHB counties, while Big Horn County, despite its third-place rank in household money income, had the highest home-ownership rate among the WBHB counties. Fremont County has the lowest median household money income, slightly lower than that of Hot Springs County, however, Fremont County's statistics include the Wind River Indian Reservation, where very high unemployment has been the norm. Data such as this tell us that the WBHB's socioeconomic structure is not simple, and warns against being too simplistic in the analyses of the WBHB as a whole.

As is typical in Federal lands counties, government (in its national, state and local forms) accounts for more WBHB jobs than any other category with the exception of the service industry. Government jobs, at least at federal and state levels, are among the better paid in the WBHB. In 1998 there were 13,893 jobs in the service industry, basin wide, and 9,927 government jobs. Retail jobs (part of the service industry) numbered 9,086, while mining provided 2,446 (Wyoming Economic Analysis). Yet it must be remembered that in general mining jobs are more highly paid than most other jobs in the region, and the multiplier effect of mining supports many other industries. Mineral royalties help fund state and local agencies and projects most notably, schools.

4.1.3.1 – *Mining*

In Wyoming, the peak years for oil production were 1959 to 1976, while gas production began a steep upward climb about 1976, and is still rising. Coal has experienced three major production booms, from the late 1880's until the early 1920's, during World War II, and an ongoing boom that began about 1969 (University of Wyoming, "Economic Trends in the Mining Sector").

Uranium mining began in Wyoming in the 1950's. Significant uranium mining districts of Wyoming include the Gas Hills located in the Wind River Basin, the Powder River Basin, Shirley Basin, Crooks Gap, Poison Basin, and the Great Divide Basin. The industry peaked producing uranium for the Atomic Energy Commission (AEC) around 1960. As AEC stockpiling slowed about 1964, the industry "crashed." From 1964 to 1972 a transition occurred as private sector demand, mostly for power plants, developed. Increasing oil prices, spurred by the embargo of 1974, helped uranium markets rise to another peak around 1978-80. Oversupply, compounded by the aftermath of the Three-Mile Island event, brought on another crash in uranium markets from 1982 to 1984. The future for uranium mining appears to be in-situ development, in which wells, rather than open-pit mines, produce the ores. Non-potable ground water is re-injected into ore seams as part of a reverse osmosis process, resulting in a net consumptive loss of only 5% or so. Although some of this activity will take place in Fremont County, most of it is and probably will continue to be in the Powder River Basin, rather than in the Wind River Basin.

Over the years the WBHB, as well as the state generally, benefited from mining booms. There has been oil, gas and coal production in the WBHB for more than a century. However, Wyoming's currently healthy mining activities (coal, coalbed methane, uranium or trona) have little positive impact on the WBHB's economy. In fact, the availability of jobs in the methane-booming Powder River Basin, as well as in southwest Wyoming, is draining working-age people from the Wind/Bighorn region.

Despite the vicissitudes of minerals production, mining (oil and gas) in the WBHB generally offers better-paid jobs than most other industries and remains the WBHB's economic foundation. Without the development of a major new industry in the WBHB, population size will continue to be strongly related to the economics of mineral production. Table 4.1-3 provides an overview of the WBHB's mining industry.

Table 4.1-3: Mining in WBHB Counties

County	# of Employees in Industry (1998)	% of Mining Employees per Capita (1998)	Mean Per Capita Income ($) (1998)	Per Capita Mining Income ($) (1998)	Mining Jobs gain or loss 1990-1998
Big Horn	807	13.0	17759	29612	+637
Fremont	559	2.8	19113	25943	-44
Hot Springs	139	4.5	21488	47410	-92
Park	600	3.5	23231	30627	-361
Washakie	341	6.3	21347	12014	+151
WBHB	2446	3.1	N/A	N/A	+291

(University of Wyoming, "Economic Trends in the Mining Sector")

4.1.3.2 – *Tourism and Recreation*

Tourism ranks as the second industry in the WBHB. Park County dominates the WBHB's tourism industry – 77% of the WBHB's lodging tax is collected in Park County. Fremont County collects another 14%, leaving only 9% to be collected in the other three counties. Recreation spending is not all from tourists, but in this accounting, recreation money spent by Wyoming residents are included with that spent by tourists. Park County is far and away the largest recipient of tourism and recreational spending in the WBHB.

Much of the employment created by recreation and tourism is relatively low-paid, and often seasonal. Although tourism and recreation industries do not portend much population growth for the WBHB, there is little doubt that these opportunities do spur immigration, and keep people in the WBHB who might otherwise leave.

Fishing is the most significant water-based recreational activity in the state, as it is in the WBHB. In 1998 resident anglers put $308 million into Wyoming's economy, while non-residents contributed $184 million (Wyoming Game and Fish, 2001). The Wyoming Game and Fish Commission reports that, sport fisheries in the state accounted for nearly 4.6 million recreation days, with an economic return of about $139 per day. The number of recreation days accounted for by residents far exceeds those of visitors. Fishing outfitters and guides operate out of many WBHB locations including: Dubois, Lander, Riverton, Cody, Powell and Thermopolis. Numerous stores throughout the WBHB sell fishing tackle, bait, and other supplies for anglers.

In the year 2000 more than 30,000 non-resident fishing licenses were sold in the WBHB's five counties, along with nearly 21,000 resident permits. This represents about a 9% increase in total license sales, compared to 1995. All of the increase came from non-resident sales, since resident sales actually declined slightly. Park and Fremont counties attracted the largest shares of non-resident and resident anglers. Many anglers in WBHB waters purchased their licenses in other counties.

Table 4.1-4 helps illuminate the character of the Basin's tourism and recreation industries. Since fishing is by far the most important water-based recreational activity, the ratio of non-resident to resident fishing licenses sold in each county is shown, illustrating the significant role played by visitors.

Hunting is also dependent on water, whether big game or waterfowl. Irrigation water helps provide habitat for many upland game birds, as well as helping to maintain many riparian areas. Irrigated fields and pastures are an important source of food and cover for many animals and birds.

Table 4.1-4: Tourism and Recreation in WBHB Counties

Lodging

County	**% of Basin's Total Lodging Tax Collected (2001)**	**% of Basin's Retail Tax Collected (2001)**
Big Horn	1.6	6.7
Fremont	14.1	32.6
Hot Springs	5.0	4.3
Park	76.9	29.9
Washakie	2.4	26.4

(percentage totals may not sum to 100% due to rounding)

Fishing Licenses

County	**Fishing Licenses Sold (2000)**	**% Non Resident Licenses (2000)**
Big Horn	4058	47.7
Fremont	18185	54.1
Hot Springs	2916	52.5
Park	21874	68.1
Washakie	4280	50.3
Total	**51,313**	**59.0**

4.1.3.3 – *Agriculture*

Among the five WBHB counties, the value of agricultural sales is highest in Park County, and second highest in Fremont County. In terms of agricultural sales, Park County is fourth and Fremont County fifth in the state. For the State of Wyoming, covered employment in agriculture constitutes only 1.5% of the state total. The proportion is larger in the WBHB. In terms of the proportion of jobs agriculture provides, Big Horn, Washakie and Hot Springs Counties are more dependent on agriculture than either Park or Fremont Counties. In Big Horn County, for instance, 9.4% of all jobs are agriculturally related, while in Park the figure is 3.7%. The trend in agricultural employment is down in all but two of Wyoming's Counties, Albany and Fremont Counties, the increase in those counties is due to more proprietors rather than more hired workers (Foulke, 2000). Table 4.1-5 displays basic information about the WBHB's agriculture industry.

In 2000, the total value of the output of the agricultural sector in Wyoming was $954.4 million, 75% of which was from sales of cattle and calves. Sugar beets were the number one crop in terms of sales, followed closely by hay, as these two crops accounted for $97.6 million. Cash receipts from crops in 2000 were $136.2 million statewide, while livestock, including products (milk, eggs, wool, honey, etc.) brought in $774.1 million. Net farm income was $114.2 million. In 2000, Wyoming's farm exports were valued at $37.5 million, about 4% of the $954 million total cash agriculture receipts. Clearly agriculture remains one of Wyoming's premier industries, but the number of jobs and the net profit for operators are not high.

Table 4.1-5 Agriculture in the WBHB Counties

County	Acres of Irrigated Farmland (year 2000 - Wyo Ag Statistics 2001)	Number of Farms (Wyo Ag Statistics 2001)	Value of Livestock (Million$) (Wyo Ag Statistics 2001)	Value of Crop Production (Million$) (Wyo Ag Statistics 2001)	Assessed Value of Ag lands (Million$, 1998)	Leading Crops (excludes pasture & hay other than Alfalfa)	Number of Ag Jobs (total, including proprietors; 1997)
Big Horn	88,300	495	43.4	33.2	8.9	Alfalfa, Barley, Sugar Beets	685
Fremont	109,800	983	96.9	30.3	7.5	Alfalfa, Oats, Sugar Beets	1092
Hot Springs	18,500	147	22.2	2.4	2.1	Alfalfa, Oats, Barley	182
Park	98,900	588	54.7	35.9	9.0	Alfalfa, Barley, Sugar Beets	776
Washakie	45,500	205	24.8	16.6	4.4	Barley, Alfalfa, Sugar Beets	311
WBHB	361,000	2,418	242	118.4	31.9	Alfalfa, Barley, Sugar Beets	3,046

4.1.4 – *Economic Growth Requirements*

If high population growth is to occur a number of economic pieces must fall into place. The ERS analysis suggests four important areas in which improvements might help a rural area grow economically:

- First, communications infrastructure has to be improved. This could increase development opportunities by creating better access to information, services and markets.
- Second, WBHB businesses should seek to produce goods and services for niche markets, penetrating markets located in more populous areas. Better communications would help in such endeavors.
- Third, collaboration among firms and governments in product development, production, and marketing could be helpful in overcoming the dis-economies of small scale that plague small firms in remote locations.
- Fourth, managerial and labor skills must be improved to ensure that local firms are competitive with larger, urban ones.

Even with effective responses to challenges that face the WBHB, significant growth will be difficult to attain. Moderate or low growth rates are no doubt more likely than high level growth, barring a currently unforeseen event such as a sizable boom in minerals production.

4.1.5 – *The Wind River Indian Reservation*

No assessment of the WBHB's future is complete without consideration of the 2.2 million acre Wind River Indian Reservation (WRIR). Home of the Eastern Shoshone and Northern Arapaho Tribes, the Reservation is located mostly in Fremont County as well as a relatively small area in Hot Springs County. Much of the WRIR is mountainous, its eight watersheds incorporate around 365 lakes and reservoirs, collectively containing more than 100,000 acre feet of water, and about 1,100 miles of streams and waterways. Many of these waters provide good fishing.

The populations within the WRIR numbers more than 20,000 persons, of whom fewer than half (around 7,500) are Native Americans. It is estimated, that the annual population growth rate of Native Americans in the WRIR is around 3% (U.S. Bureau of Reclamation, 1986).

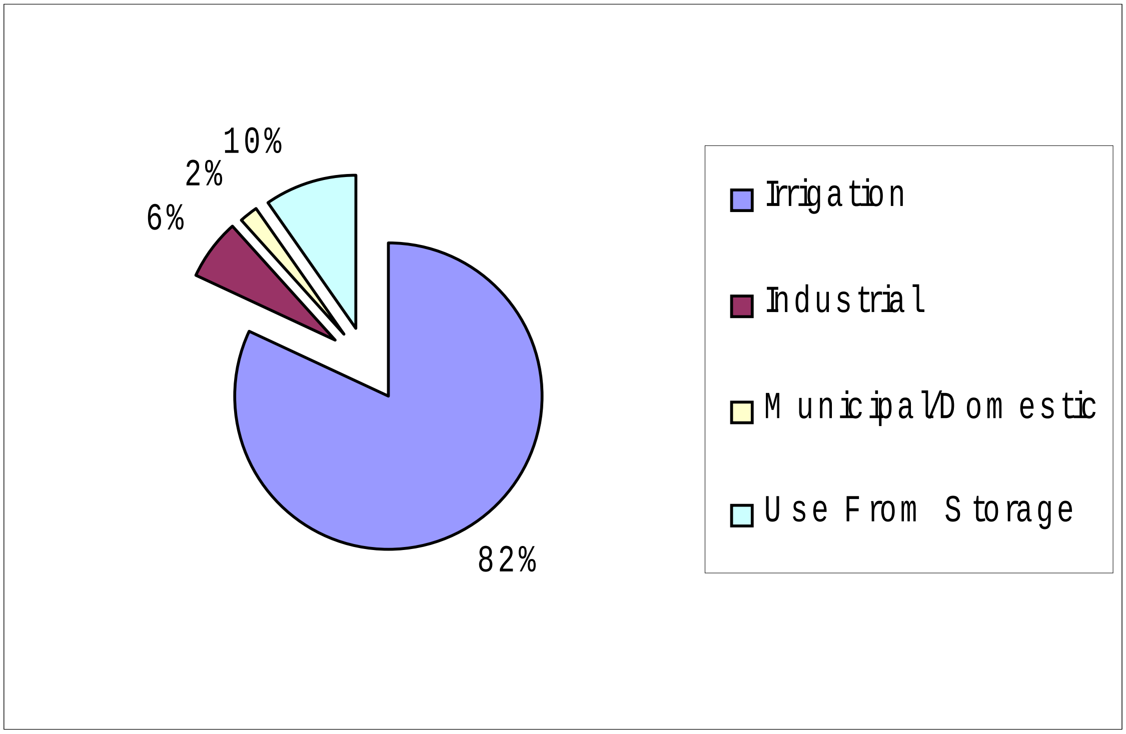
Most tribal income comes from mineral extraction, mainly oil and gas. Tribal leaders are concerned about social problems affecting their young people as well as a lack of economic opportunity, and are anxious to promote economic development on the WRIR. This could mean higher levels of water consumption, especially if more land were brought under irrigation (Collins, 2002). The Arapahos, particularly, perceive a shortage of housing and in some areas are experiencing increasing problems with domestic water supplies, such as poor quality water and contamination of individual wells (U.S. Bureau of Reclamation, 1986).

Several reservoirs have been constructed on the WRIR. Enlargements and new dams are being planned as the Tribes explore potential new beneficial uses of their water resource. For the most part, WRIR land (around 1.7 million acres) is under the joint control of the Shoshone and Arapaho Tribal Councils. Water and other natural resources are jointly owned by the two tribes. The Tribes have adjudicated rights to 500,000 acre feet of water, however, this right is tied primarily to agricultural use and could not be converted to other uses without state concurrence (Wind River Resources Control Board, 1994). Much of the water allocated for current use is not actually used but lost on the WRIR, due to leakage resulting from the poor condition of water distribution and the conveyance infrastructure in many areas.

4.1.6 – *Water Demand*

In Wyoming and in the WBHB, agriculture is the largest water user. As shown in Figure 4.1-2, agriculture accounts for some 82% of the water use in the WBHB followed by water use from storage (evaporation) at 10%, industrial water use at 6%, and municipal and domestic use at 2%. In contrast, agriculture accounts for only 1.5% of employment. With respect to water demand, population growth or decline has direct effects only on municipal and domestic use (2% of total water use) and, thus, has little effect on overall water demand. Changes in water demand with respect to agricultural and industrial use are related to other factors such as the location and availability of natural resources and the market/economics of the products and/or industries. As a result, water demand forecasts presented in subsequent sections of this report are based on foreseeable industrial and/or agricultural developments for theses sectors. Finally, although recreational and environmental demand is related to population, this use is non-consumptive and does not affect overall water demand.

Figure 4.1-2: Overview of water users in the WBHB.



4.2 – Agricultural Water Demand and Projections

4.2.1 – *Introduction*

Irrigated agriculture is the largest consumer of water within the Wind/Bighorn Basin. However, as discussed in the **Task 3D Technical Memorandum, "Available Surface Water Determination"**, there remains on average over 1,500,000 acre feet of water available in the Bighorn Basin and nearly 450,000 acre feet of water available in the Clarks Fork Basin. As described in other technical memorandums within Task 5, there are many potential uses for this excess water, and expansion of irrigated agriculture within the WBHB ranks among the highest priority uses. In fact, several studies, including the Potentially Irrigable Acres (PIA) study, which was developed for the adjudication of Tribal Reserved Water Rights, have studied the economics of additional agriculture within the WBHB and found it to be cost effective.

4.2.2 – *Potential Agricultural Development*

Two primary sources of information were reviewed to identify potential agricultural development within the Wind/Bighorn Basin Plan, the Tribal Futures Projects and a WWDC irrigable lands database. A map showing both the Tribal Futures Projects and the irrigable lands is shown in Figure 4.2-1.

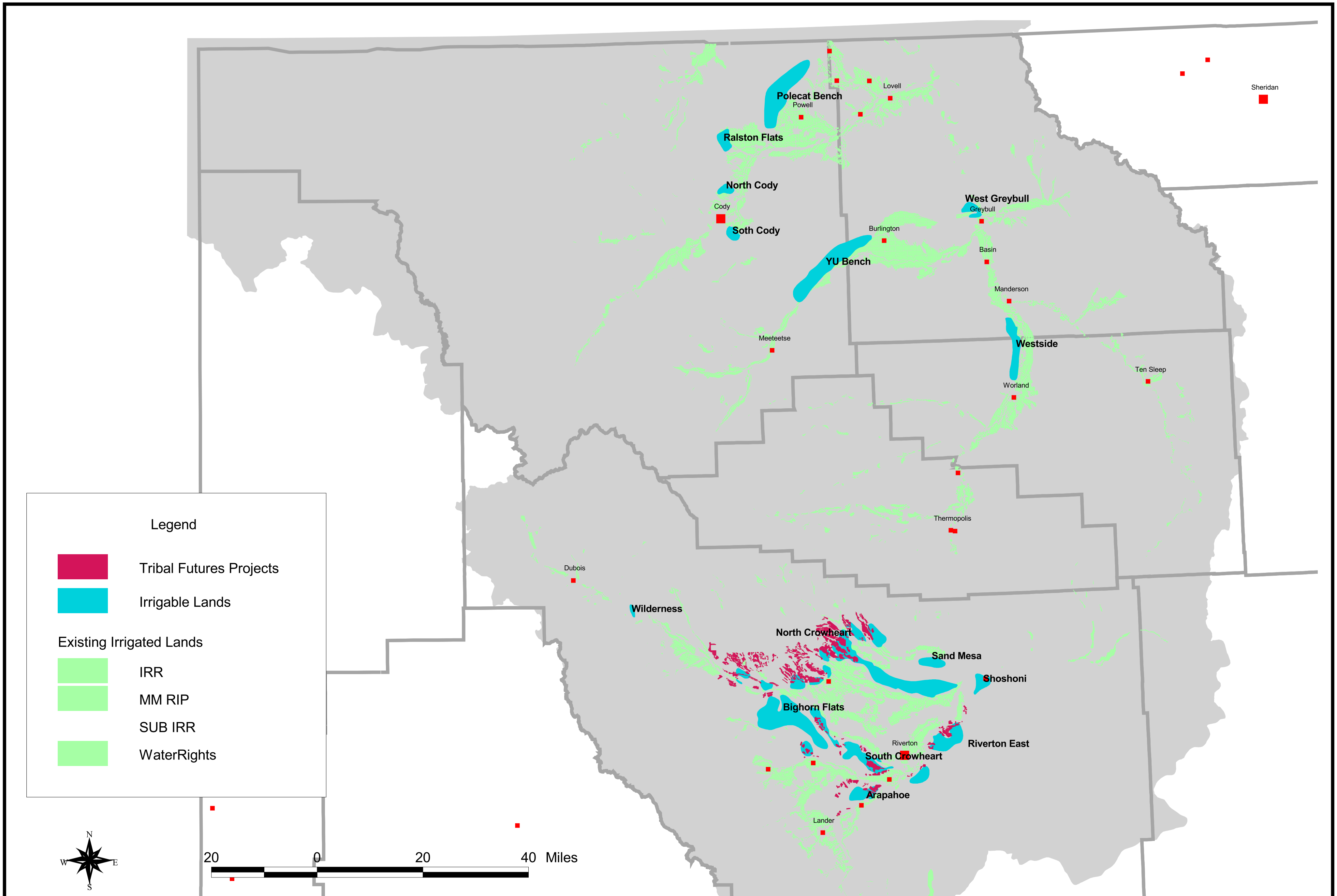


Figure 4.2-1
Tribal Futures Projects and Irrigable Lands

October 2003

Wind/Bighorn River Basin Plan

BRS ENGINEERING

MWH
Denver, Colorado

Lidstone and Associates, Inc.
Engineering, Geology & Water Resource Consultants

TRIHYDRO corporation

Future agricultural use must be viewed in the context of current water availability and water right priority. As discussed in the **"Agricultural Water Use and Diversion Requirements" Technical Memorandum, Chapter 2, Tab 5**, irrigated lands mapping and historical use data indicate that some 430,000 to 450,000 acres of land are actually irrigated in the WBHB in any given year. However, water rights data from the SEO shows that water rights are held for the irrigation of over 600,000 acres. The modeling of surface water availability considers various use options including historical diversions (approx. 450,000 acres), full supply based on water rights (approx. 600,000), and full supply plus tribal futures (approx. 650,000 acres).

4.2.2.1 – *Tribal Futures Projects*

As part of the Bighorn Decree (Roncolio, 1982), the Shoshone and Northern Arapaho Tribes were awarded Federal Reserved Water Rights for not only lands with existing irrigation, but also lands that could be economically irrigated as determined through a Potentially Irrigable Acres (PIA) study. PIA studies have become the benchmark for quantification of Federal Reserved Water Rights throughout the Western United States. The PIA study is a compilation of agronomy, engineering and economic analysis that identifies currently undeveloped land that could feasibly be irrigated. The results of the PIA study were the conceptual development of 5 projects encompassing approximately 54,000 acres on the Wind River Reservation. The projects, conceptual land area and the awarded diversion requirement are shown in Table 4.2-1.

Table 4.2-1 Tribal Futures Projects Awarded and Modeled Land Area and Diversion Requirements

	Awarded (Roncolio, 1982)			Modeled		
	Land Area	Diversion Requirement		Land Area	Diversion Requirement	
Futures Project	(acres)	(ac-ft)	(ac-ft/ac)	(acres)	(ac-ft)	(ac-ft/ac)
North Crowheart	38,773	147,767	3.8	40,839	155,064	3.8
South Crowheart	4,695	20,137	4.3	5,019	19,674	3.9
Arapahoe	3,808	16,720	4.4	3,808	16,720	4.4
Riverton East	3,814	17,536	4.6	4,057	15,098	3.7
Big Horn Flats	2,670	7,212	2.7	2,752	7,780	2.8
Total	53,760	209,372	3.9	53,760	209,372	3.9

Tribal Futures Projects were included in modeling runs to determine their general affect on streamflows and other diversions within the WBHB. The data included in the model for the Futures Projects was developed the same as the other diversion data for the model. An overall efficiency of 55% was utilized for those projects, where conveyance was proposed through open ditches, while an overall efficiency of 62%, was used for conveyance through pipelines. Both of these efficiencies assume improved on-farm applications, such as gated pipe and/or sprinklers as developed in previous studies for Riverton East and the SCS (Nelson, 2001; SCS, 1992).

As shown in Table 4.2-1, there are slight differences between the awarded and modeled acreages and diversion requirements for the Futures Projects. The information for the Wind/Bighorn River Basin plan was developed using the most current reasonable data for climate, crop water requirements and anticipated efficiencies for the Projects, thus accounting for the differences in developed values. In addition, the Wind/Bighorn River Basin model does not explicitly include the Popo Agie River Basin. However, the impacts to the Popo Agie River Basin from diversions by the Arapaho Project are implicitly included in the model results through an input node for the Popo Agie River Basin with data supplied by the Popo Agie Watershed Plan (Anderson, 2003). The information presented in the Wind/Bighorn River Basin plan regarding Futures Projects is in no way intended to infer proposed changes to the decree, nor do they suggest administrative changes to the decree. They only reflect general estimates on how Futures Projects could impact the WBHB.

In order to simulate the effects of the Tribal Futures Projects, CIR and diversion requirements were required. A summary of the diversion CIR and diversion requirements as they related to the physical nodes in the model representing the Futures Projects are presented in Table 4.2-2 and Table 4.2-3.

The effects of Tribal Futures Projects on flows within the WBHB and on other diversions within the WBHB are more fully described in the **Task 3D Technical Memorandum, "Available Surface Water Determination"**. However, as stated in the Task 3D Technical Memorandum, the model limitations need to be realized. The model does not explicitly account for water rights. Because the Futures Projects would have Federal Reserved Water Rights, the impacts from the Futures Projects would be much more severe on junior water rights within the WBHB, than the senior water rights. It should also be realized that the impacts are based on full development of the Futures Projects. The impacts of developing a portion of the Futures Projects would be less severe on the WBHB.

A brief description of each potential Futures project within the Wind/Bighorn Basin plan study area follows. The Arapahoe Irrigation Project is discussed in the Popo Agie Watershed Study (Anderson, 2003).

Table 4.2-2 CIR for Tribal Futures Project Used for Modeling

Model Sub-Basin	Irrigated Acres	Monthly CIR (acre-feet)								Unit CIR (ac-ft/ac)
		Apr	May	Jun	Jul	Aug	Sep	Oct	Annual	
North Crowheart Canal	40,839	2,856	9,096	17,150	24,243	19,044	8,256	616	81,260	1.99
Big Horn Flats Pump #1	1,029	17	174	372	570	449	182	16	1,779	1.73
Big Horn Flats Pump #2	717	12	121	259	397	313	127	11	1,240	1.73
South Crowheart Canal	5,019	388	1,155	2,221	3,011	2,383	1,058	43	10,260	2.04
Big Horn Flats Pump #3, Big Horn Flats Pump #4	1,005	17	170	363	556	438	177	16	1,738	1.73
Riverton East Pump #1	157	15	39	73	96	76	35	1	336	2.14
Riverton East Canal, Riverton East Pump #2,	3,900	376	972	1,826	2,397	1,899	864	25	8,361	2.14
Arapahoe	3,808	322	1,043	1,588	2,091	1,677	688	92	7,481	1.96
Total	56,475	4,003	12,771	23,851	33,362	26,279	11,386	820	112,453	1.99

Table 4.2-3 Diversion Requirements for Tribal Futures Projects used for Modeling

Model Sub-Basin	Irrigated Acres	Monthly Diversion Requirement (ac-ft)								Unit DR (ac-ft/ac)
		Apr	May	Jun	Jul	Aug	Sep	Oct	Annual	
North Crowheart Canal	40,839	10,518	27,115	36,214	33,206	27,575	19,018	1,419	155,064	3.80
Big Horn Flats Pump #1	1,029	56	465	703	698	581	374	33	2,910	2.83
Big Horn Flats Pump #2	717	39	324	490	486	405	261	23	2,028	2.83
South Crowheart Canal	5,019	1,430	3,443	4,689	4,125	3,450	2,437	100	19,674	3.92
Big Horn Flats Pump #3, Big Horn Flats Pump #4	1,005	55	454	686	682	568	365	32	2,842	2.83
Riverton East Pump #1	157	50	104	139	118	99	72	2	583	3.72
Riverton East Canal, Riverton East Pump #2,	3,900	1,240	2,593	3,449	2,938	2,461	1,782	52	14,515	3.72
Arapahoe	3,808	605	2,156	3,558	4,771	3,849	1,562	218	16,720	4.4
Total	56,475	13,993	36,654	49,927	47,024	38,988	25,870	1,879	214,336	3.80

Riverton East Irrigation Project

The Riverton East project has been under consideration for several years and is one of the most likely to proceed into more immediate development. This project would bring at least 3,900 new acres under irrigation and would require at least 8,361 acre feet of water annually. Additional storage in the Upper Wind River Basin for this project could be provided through projects such as the proposed Steamboat Reservoir or the proposed enlargement of Bull Lake.

North Crowheart Irrigation Project

The North Crowheart irrigation project is by far the largest of the Tribal Futures Projects and would entail up to 40,839 new acres consuming some 81,260 acre feet of water annually. This project would require the construction of upstream storage and diversions. Sighting of potential storage and diversion structures has been studied extensively. The most recent study of the Upper Wind River Storage was funded by the WWDC (Short Elliot Hendrickson, Inc., 2001)

South Crowheart Irrigation Project

The South Crowheart irrigation project includes some 5,019 new acres of irrigation and has an annual water demand of sine 10,260 acre feet. Storage for this project could be provided by the same projects as needed for the Riverton East project, the proposed Steamboat Reservoir or the proposed enlargement of Bull Lake.

Bighorn Flats Irrigation Project

Big Horn Flats has three components, which would all require pumping. The aggregate acreage of these areas is 2,751 acres and would consume approximately 5,000 acre feet of water annually.

4.2.2.2 – *Irrigable Lands*

In addition to Tribal Futures Projects, there are other potential agricultural development projects within the WBHB that have been discussed over the years. In 1991, the Wyoming Water Development Commission funded a study that developed an estimate of irrigable lands throughout the state (WWDC, 1991) that are not currently in production. Several locations were identified within the WBHB. Potentially Irrigable Lands are shown in Figure 4.2-1.

A summary of the irrigable lands is shown in Table 4.2-4. The annual Crop Irrigation Requirement (CIR) and Diversion Requirements shown in the table were developed similar to existing irrigated lands as discussed in the **Task 2A Technical Memorandum, "Agricultural Water Use and Diversion Requirements"**. An overall efficiency of 55% was utilized, which represents large canal delivery systems with improved on-farm applications, such as gated pipe and/or sprinklers, previous studies for Riverton East, and the SCS (Nelson, 2001; SCS, 1992).

As shown in Table 4.2-4, those lands that are generally associated with the Tribal Futures Projects comprise approximately 60% of the irrigable lands within the WBHB. It is interesting to note that the Tribal Futures Projects awarded acreage is approximately 38% of the total lands identified as irrigable in the study. The largest non-Futures Projects irrigable land groups are the Westside Irrigation Project in the Upper Bighorn Sub-Basin, lands on the YU Bench in the Greybull River Sub-Basin, and lands on the Polecat Bench in the Shoshone and Clarks Forks Sub-Basins.

Table 4.2-4 Summary of Potentially Irrigable Lands within the Wind/Bighorn Basin

Basin	Name	Sub-Basin	Irrigable Area (acres)	Annual CIR Total (acre-feet	Annual CIR Unit (ac-ft/ac)	Annual Div. Req. Total (acre-feet	Annual Div. Req. Unit (ac-ft/ac)
Bighorn, Clarks Fork	Polecat Bench	Clarks Fork, Shoshone	27,877	54,460	2.0	107,137	3.8
Bighorn	North Cody (1)	Shoshone	2,645	4,489	1.7	8,544	3.2
	Ralston Flats (1)	Shoshone	5,035	9,171	1.8	17,761	3.5
	South Cody (1)	Shoshone	3,318	5,632	1.7	10,721	3.2
	West Greybull (1)	Big Horn Lake, Greybull	4,352	9,430	2.2	18,717	4.3
	Westside	Upper Bighorn	11,690	23,333	2.0	46,168	3.9
	YU Bench	Greybull	28,795	48,394	1.7	93,592	3.3
Wind	Arapahoe	Little Wind, Popo Agie	6,743	13,906	2.1	26,634	3.9
	Bighorn Flats	Little Wind, Upper Wind	37,215	64,318	1.7	117,583	3.2
	North Crowheart	Lower Wind, Upper Wind	62,155	133,951	2.2	260,775	4.2
	Riverton East	Little Wind, Upper Wind	16,636	35,663	2.1	69,200	4.2
	Sand Mesa (1)	Lower Wind	5,068	12,430	2.5	24,989	4.9
	Shoshoni (1)	Lower Wind	4,815	11,807	2.5	23,738	4.9
	South Crowheart	Little Wind, Upper Wind	18,267	36,963	2.0	70,698	3.9
	Wilderness (1)	Upper Wind	1,121	1,559	1.4	2,940	2.6
Total			235,732	465,506	2.0	899,197	3.8
Total (Tribal Futures Projects)			141,016	284,800	2.0	544,890	3.9
Total (non-Tribal Futures Projects)			94,716	180,706	1.9	354,307	3.7

Note:

Project names based on general location within WBHB because they are not associated with other previously identified projects.

(1) Projects not associated with Tribal Futures Projects include all Bighorn and Clarks Fork Projects, and the Sand Mesa, Shoshoni and Wilderness Projects in the Wind River Basin.

West Side Irrigation Project

The Westside Irrigation Project has been under consideration for several years and is one of the most likely to proceed into development. This project has advanced and will require congressional approval for the transfer of federal lands associated with this project. This project would bring some 11,690 new acres under irrigation and would require approximately 23,000 acre feet of water annually. Although modeling indicates that surface water would be available for this project from the main-stem of the Bighorn River currently. Full utilization of the Tribal water rights and/or other priority water rights could limit future water availability. This potential could be offset by additional storage in the Upper Wind River Basin.

YU Bench Irrigation Project

Mapping of the YU Bench indicates nearly 30,000 acres of land that are potentially irrigable. If this project were developed, the actual acres irrigated would be expected to be less. The YU Bench is located in the Greybull drainage, above the recently constructed Roach Gulch dam. The majority of the lands within the YU Bench are federal and would require a transfer of lands similar to the action necessary for the Westside Irrigation Project. The Greybull drainage does not typically have surface water available for a project of this magnitude. In order for this project to be feasible, storage would need to be constructed on the Clarks Fork drainage and water conveyed to the Greybull drainage. The annual water demand under full irrigation for the YU Bench is estimated at nearly 50,000 acre feet. However, Wyoming has typically available some 450,000 acre feet of water in the Clarks Fork drainage, which leaves the state unused each year.

Polecat Bench Irrigation Project

The Polecat Bench is located in the Clarks Fork and Shoshone drainages northwest of Powell, Wyoming. Land ownership is mixed between federal and private. This area comprises of approximately 28,000 acres and would require upstream storage in the Clarks Fork drainage. As with the YU Bench, sufficient surface water is available in the Clarks Fork to support this project. At an elevation in excess of 5,000 feet, types of agricultural crops may be limited in this area. Crops such as alfalfa and grains, which do not require a long growing season, would be suitable for this area. Water demand would be similar to that of the YU Bench, approximately 50,000 acre feet.

4.2.3 – *Available Flow for Agricultural Development*

Available flow for all reaches within the model was calculated and is summarized in the **Task 3D Technical Memorandum, "Available Surface Water Determination"**. Using this data, diversion requirements can be compared to available surface water both annually, and by month to determine whether adequate supply exists from the primary source to fulfill the diversion requirements for the project, and whether storage is needed to store water from wetter months to drier months, or from wetter years to drier years. A summary of this analysis is presented in Table 4.2-5.

Table 4.2-5 Comparison of Diversion Requirements to Available Flow for Selected Projects

Project	Primary Source	Annual Demand	Available Surface Water from Primary Source (ac-ft)			Storage Required (ac-ft)		
			Dry	Average	Wet	Dry	Average	Wet
Riverton East	Upper Wind River	15,098	332,167	749,338	987,444	0	0	0
North Crowheart	Lower Wind River	155,064	74,652	250,832	470,680	153,645	60,743	34,085
Westside Irrigation	Bighorn River	45,783	857,888	1,286,359	1,681,003	0	0	0
YU Bench	Greybull River	92,510	39,798	95,349	86,919	88,203	36,877	52,104
Polecat Bench	Shoshone River	105,323	307,703	526,428	754,699	6,625	0	0

As shown, several of the projects could likely be developed with no or minimal storage, including the Riverton East project, the Westside Irrigation project and the Polecat Bench project. It should be noted that although the model shows that no storage is needed for these projects, to maintain required peak diversions during the peak months, small amounts of re-regulation storage may be required within the projects themselves.

The model indicates that there is available flow in the Upper Wind River for the North Crowheart Project in dry and average years. In dry years, the Crowheart Project, or other diversions in the WBHB with junior water rights, would be short. Therefore, multi-year carryover storage would be required. In addition, during all hydrologic years, some portion of storage would be required to store water in the spring and release later in the summer.

The YU Bench is located within the Greybull River Basin. As shown in the table, it is likely that there would not be enough water in the Greybull River during most years. Therefore, if the YU Bench were developed, imports from other basins, either the South Fork of the Shoshone River or the Clarks Fork River, would be required. In addition to the trans-basin diversion, a storage reservoir would be required to store high flows during the spring, and inflows year round (spring, summer and fall), so they can be released during high demand times in the late summer.

4.2.4 – *Agricultural Development Scenarios*

For purposes of the Wind/Bighorn Basin plan, three scenarios have been developed to simulate potential future irrigation development within the basin planning area. These are described as follows:

- maintenance of the status quo, represents no increase or decrease in irrigated lands;
- most likely development scenarios, represents a "most likely" near-term development scenario, which includes the Riverton East Project, the North Crowheart Project and the Westside Project;
- maximum potential development scenario, represents full development of the Tribal Futures Projects and the three larger projects in the Bighorn and Clarks Fork Basins, Westside, YU Bench, and Polecat Bench.

A summary of each scenario, their associated irrigated lands and the annual crop irrigation requirement and diversion requirement is shown in Table 4.2-6.

Table 4.2-6 Potential Agricultural Development Scenarios

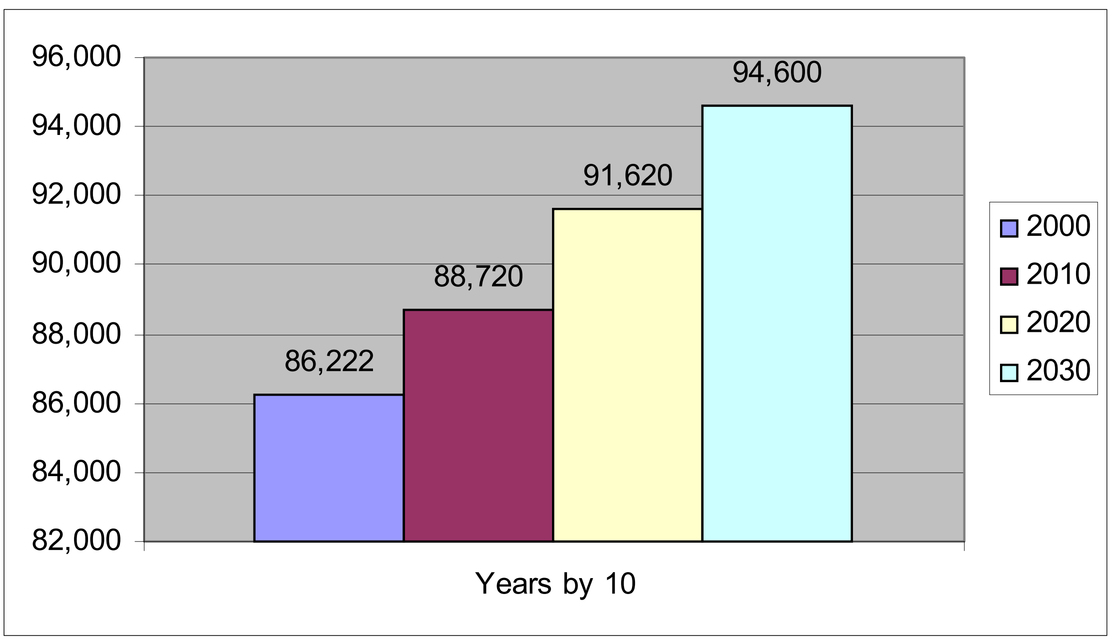
Scenario	Projects	Additional Irrigated Land (acres)	Annual CIR (ac-ft)	Annual Div. Req. (ac-ft)
Status Quo	None	0	0	0
Most Likely	Riverton East, Westside, North Crowheart	69,165	140,255	270,433
Maximum	Arapahoe, Bighorn Flats, North Crowheart, Riverton East, South Crowheart, Polecat Bench, Westside, YU Bench	209,377	410,986	791,788

4.3 – Municipal and Domestic Water Demand and Projections

4.3.1 – *Introduction*

The current population of the WBHB, according to the 2000 census, is 86,222. Statistically, zero or negative growth could be projected for the WBHB. Although this has been the case in some counties in recent years, the WBHB as a whole has remained stable or has experienced some growth in population. The following figure shows the projected population growth for the WBHB as a whole assuming moderate growth. This projection was used to project future water demand for domestic and municipal use.

Figure 4.3-1 Population Projections



Based on Total WBHB Projection for Moderate Growth

4.3.2 – *Municipal Use*

According to the U.S. Environmental Protection Agency (EPA), there are currently 58 active municipal and non-municipal community public water systems in the WBHB (Lamb, 2002).

Through its water system surveys, the Wyoming Water Development Commission (WWDC) has acquired detailed information on approximately 40 of these public water systems (WWDC, 2002). Information provided in the 2002 Water System Survey indicates these systems are capable of storing more than 36.7 million gallons of water obtained from rivers, streams, wells, reservoirs, and lakes to serve more than 63,000 people, or roughly 68% of the WBHB's population. The average daily municipal water use for the WBHB is approximately 12.2 million gallons per day (MGD), or roughly 207 gallons per day per person. 68% of the total water usage by municipalities is surface water, with the remaining 32% ground water. For a more detailed listing Refer to **Technical Memorandum "Municipal Water Use Profile", Chapter II, Tab 6.**

Current shortages and some water quality issues exist for certain municipalities in the WBHB. WWDC has sponsored and continues to sponsor numerous water supply projects in support of the municipalities and rural areas in the WBHB.

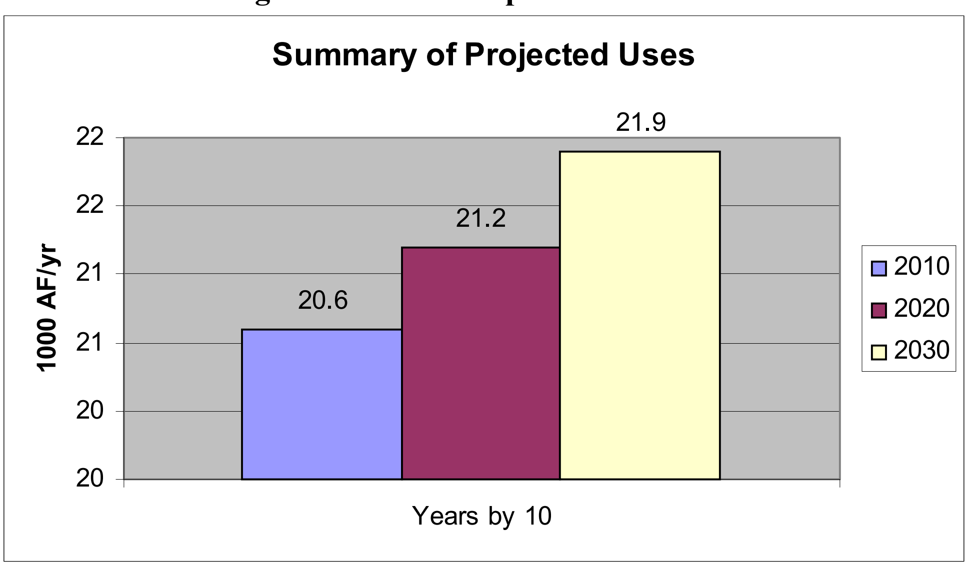
4.3.3 – *Domestic Use*

Based on rural domestic and non-municipal public water system usage, total domestic water usage in the WBHB has been estimated to range from 6.5 to 10.4 MGD. Ground and surface water supplies are utilized to meet daily domestic demands in the WBHB. Of the total domestic water usage, roughly 26% is supplied by surface water sources while 74% is supplied by ground water. Although data on water quality for private domestic water sources is generally not available, in many areas the shallow aquifers accessible to these users do not meet drinking water standards.

4.3.4 – *Projected Municipal and Domestic Use*

The following figure projects future domestic and municipal water demand based on a projection of moderate growth over the planning period. This is considered the most likely scenario.

Figure 4.3-2 Municipal and Domestic



Although population projections could statistically predict zero or negative growth, water demand for the low growth scenario is projected as flat. This scenario is not considered likely since some communities are currently experiencing shortages. The high growth scenario, previously discussed, projects a maximum population of 114,407 over the thirty year period or a 33% increase. This population growth would result in a corresponding municipal/domestic water demand of approximately 26.5 acre feet per year.

4.4 – Industrial and Mining Water Demand and Projections

4.4.1 – *Introduction*

Most industrial water users in the Wind/Bighorn Basin (WBHB) are comparatively small companies, with relatively low water needs. In most cases, these companies draw their water from municipal systems, or from their own wells. In many cases the water used from wells for industrial purposes is not suited for other uses due to poor water quality. For those industries utilizing water from municipal sources, that consumptive use is included in the WBHB as municipal use.

4.4.2 – *Industry in the Wind/Bighorn River Basin*

Manufacturing

Large manufacturing companies are rare in the WBHB, as they are in the state as a whole. In the WBHB, there are about two dozen manufacturing companies that consistently maintain a workforce of twenty-five or more. Most of the larger companies' products are related to Wyoming's overall character, products derived from minerals, products for agriculture, and products for camping, hunting and fishing. However, machinery electronic goods, and fabricated metal products are also manufactured in the WBHB.

Power Production

Hydroelectric power is produced by water driven turbines at thirteen Bureau of Reclamation sites in Wyoming, six of which are in the WBHB. Collectively the six WBHB plants have a production capacity of 47,100 kW. Currently there are no commercial fossil fuel power generation facilities in the WBHB. Small gas-fire, gas-cooled, turbine generating stations are utilized in the oil and gas industry for internal use such as powering gas pumping stations. However, as subsequently discussed there is potential for development of small coal-fired and/or gas power production based on available natural resources in the WBHB.

Mining: Oil and Gas, Coal, Uranium, Bentonite, Gypsum

Oil and gas remain important to the WBHB economy, with gas plants in all counties except Hot Springs. However, it seems unlikely that the future will offer many more jobs in the industry. The future for uranium mining appears to be in-situ development. One potential future in-situ uranium mine is permitted but not in production in the Gas Hills Uranium District, Fremont

County. The projected plant capacity is 8,000 gpm. or 12,906 acre feet per year. Of this total, 645 acre feet per year of water would be consumed (lost to evaporation) during the mineral processing. The remaining water used would be returned to the aquifer via ground water injection wells.

Bentonite processing plants are located in Big Horn (Greybull and Lovell) and Washakie (Worland) Counties. The Black Hills Bentonite plant in Worland uses about 500,000 gallons per month(18.5 acre feet per year), purchasing it from the City of Worland. Similar bentonite plants in the WBHB include WyoBen's plant near Greybull and American Colloid's plant near Lovell. Plant operators did not indicate any specific plans to expand or contract in the foreseeable future.

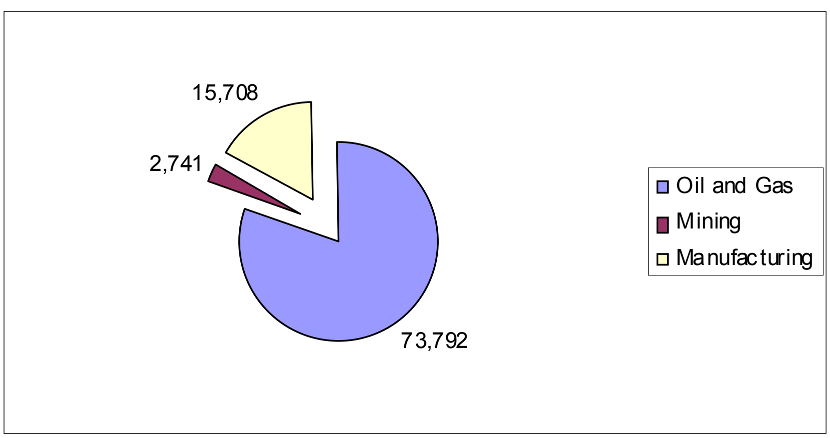
There are gypsum plants in Park and Big Horn Counties, producing wallboard. Well water is used in the process, and recycling is practiced in all plants. These plants consume 200 gpm. or 323 acre feet per year, based on water rights.

4.4.3 – *Summary of Current Consumptive Use*

Total water use based on water rights follows and is graphically displayed on the subsequent figure. Although this is the total water right, much of the usage is non-consumptive.

Oil & Gas, including pipelines	73,792 acre feet per year
Mining, dust control and mine pit waters	2,741 acre feet per year
Manufacturing and Miscellaneous Industrial	15,708 acre feet per year
Total Permitted Water Use - Industrial and Mining	92,241 acre feet per year

Figure 4.4-1 Industrial Use



All numbers in acre feet per year
Total Industrial Use is 92,241 acre feet a year

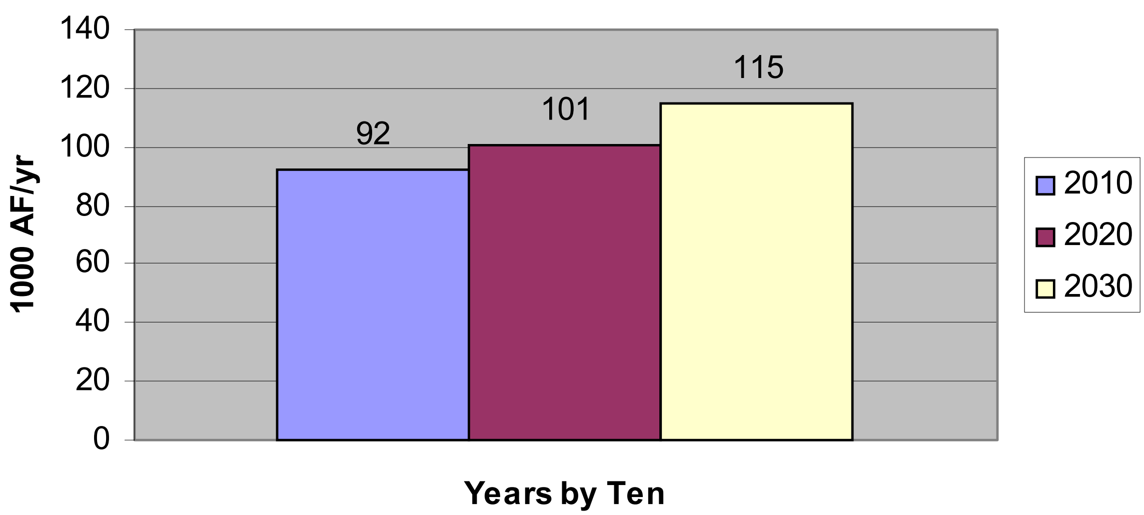
4.4.4 – *Projected Industrial Use*

Industrial growth in most sectors has remained flat or declined. Potential for future growth in manufacturing is tied to improvements in the basic infrastructure. Mining and Oil & Gas has generally declined in recent decades. Some potential for coalbed methane development and in-situ uranium does exist, however, such developments will be market driven. Coalbed methane reserves in the Powder River Basin greatly exceed those of the Wind River and Bighorn River Basins in both quantity and quality. Future uranium production is tied to global demand. As with coalbed methane, current uranium production comes from lower cost mines located outside the WBHB.

One area of potential industrial development and growth is the realm of power generation. There are several sites that could produce limited amounts of hydropower, a non-consumptive water use. Although there are currently no fossil fuels power plants in the WBHB, there is a potential reserve base for either coal or natural gas fired electric power production. It is estimated that a nominal 200 MW coal-fired steam turbine facility would require approximately 4,000 acre feet per year of water and a 500 MW gas-fired combination turbine facility would require approximately 5,000 acre feet per year of water.

As a result of the foregoing, the low growth scenario presumes no net change in industrial water demand. The moderate growth scenario assumes one coal and one gas-fired power plant. The high growth scenario assumes 2 coal and 3 gas-fired power plants. Projected industrial water demand is shown on the following figure, ranging from the current use of 92,000 acre feet to a maximum use of 115,000 acre feet annually.

Figure 4.4-2
Industrial/Mining Projections



4.5 – Recreational and Environmental Demand and Projections

4.5.1 – *Introduction*

Recreation, including tourism, is one of Wyoming's three major industries. Major recreational activities dependent on water are fishing, boating, rafting, waterfowl hunting, and swimming. Other recreational activities, such as big game and upland game bird hunting, snowmobiling, skiing, sight seeing, photography, camping, and golfing are also sensitive to water quantity and quality. Another minor environmental use of water includes consumption of water by wildlife.

In general water demand for recreational uses is non-consumptive (Jacobs and Brosz, 2000). However, some "uses" or "designations" may restrict use within and above such designations. For example, Wyoming's only congressionally designated "Wild and Scenic River" is a twenty mile stretch of the Clarks Fork of the Yellowstone River in Park County.

4.5.2 – *Future Recreational Water Considerations*

The WBHB's State Parks are estimated to attract more than a million visitor-days per year (calculated from Wyoming State Parks and Historic Fees Program). Boysen and Buffalo Bill State Parks are located on large reservoirs, Hot Springs and Sinks Canyon State Parks are located near unique water resources, and Medicine Lodge Creek adds significantly to the attractiveness of Medicine Lodge State Park. It is useful to consider future recreational demands in a basin plan study for two reasons, to asses whether potential water development projects to meet water needs will impact recreational activities, and whether future recreational demands may exceed the current capacity of existing recreational areas. The assessment of future demands is concluded from the quantification of current recreational use through out the WBHB, projecting future recreational use, and comparing future recreational use with the existing recreational areas (Harvey and Jeavons, 2000).

Table 4.5-1
Projected Annual Growth Rates in the Wind/Bighorn Basins
Population and Tourism – 2000-2003

Average Annual Growth Rate		
Scenario	Basin Population	Tourism
Low Growth	0.00%	1.00%
Medium Growth	0.32%	2.00%
High Growth	0.91%	3.00%

Note: Tourism growth rate based off of Department of State Parks and Cultural Resources estimates of the average annual increase in tourism.

<u>Boating</u>

There is no available data on the number of boats, rafts and other watercraft using the waters of the WBHB. As such, quantitative measurements of the number of boating-days and estimates of future water use demands for boating could not be determined. However, based on projective growth in the WBHB, of both residents and tourists, it can be assumed that the demand for watercraft use in the WBHB will expand.

Fishing

Fishing is one of the WBHB's major water-based outdoor recreational activities. The major source of data collected on fishing is from the Wyoming Game and Fish Commission's (WGFC) license sales and creel censuses. The available quantitative data on fishing is not readily adaptable to individual waters because angler surveys are usually conducted on major waters in response to specific needs (Annear, 2002).

In 2000, 20,942 resident and 30,372 non-resident licenses were sold in the five counties of the WBHB (Wiley, 2001). This equates to approximately 322,000 angler-days for residents and 123,000 angler-days for non residents. In comparison to 1995 resident sales have decreased by approximately 8% in the WBHB, while non-resident sales increased by about 20%. The majority of fishing licenses sold in the WBHB were in Fremont and Park Counties (Wiley). This suggests that the drainages of the Upper Wind River and the Shoshone River have the heaviest amount of stream fishing. Boysen and Buffalo Bill Reservoirs are also very popular fishing venues. In anticipation of continuing growth in demand for stream fishing venues, the WGFC notes that ensuring an adequate supply of good fishing spots "is dependant on maintaining adequate stream flows in existing good segments and restoring stream flows in streams that have the potential to support good recreational fisheries." (Annear, 2002)

Annual fishing day demand in 2030 is projected as follows:

- 2030 Low Growth Scenario
  - Residential approximately 322,000 angler-days
  - Non-residential approximately 166,000 angler-days
- 2030 Moderate Growth Scenario
  - Residential approximately 354,000 angler-days
  - Non-residential approximately 223,000 angler-days
- 2030 High Growth Scenario
  - Residential approximately 423,000 angler-days
  -Non-residential approximately 299,000 angler-days

Waterfowl Hunting

Wyoming straddles two migratory waterfowl flyways, the Pacific (west of the Continental Divide) and the Central. The WBHB is solely located east of the Continental Divide, in the Central flyway. The WBHB is divided by the WGFC into two waterfowl management areas. The majority of waterfowl hunting in the WBHB is for ducks and geese, although coot, snipe, rail, and sandhill crane are also hunted.

While data on specific locations is unavailable, the WGFC estimated that in 2000 WBHB duck hunter-days totaled 13,395, with a harvest of 19,333 ducks. Goose hunter-days were estimated to be 7,730, with a harvest of 5,331 geese. Ducks Unlimited, which has over 4,000 members in Wyoming, reported that during the 1999-2000 hunting season 11,062 federal duck stamps were sold in the state. The WGFC reported that in 2000 a total of 36,208 bird licenses were sold in the state. According to the WGFC Annual Report of Upland Game and Furbearer Harvest for 2000, licenses sales for both resident and non-resident bird licenses have increased sharply over the past five years. Maintenance and improvement of existing wetlands and riparian areas, and establishment of new areas will help maintain and improve habitat for waterfowl.

Annual waterfowl hunting-days are projected as follows:

- 2030 Low Scenario
  - Duck hunting approximately 18,050 hunting-days
  - Goose hunting approximately 10,420 hunting-days
- 2030 Moderate Scenario
  - Duck hunting approximately 39,010 hunting-days
  - Goose hunting approximately 22,510 hunting-days
- 2030 High Scenario
  - Duck hunting approximately 50,090 hunting-days
  - Goose hunting approximately 28,910 hunting-days

4.5.3 – *Future Environmental Considerations*

Environmental water uses including reservoir allocated conservation pools, instream flows, wetlands, and riparian areas are mostly non-consumptive uses of water, and are not dependant on population change and tourism, as recreational uses are.

Wildlife

There is no easy way to quantitatively estimate the amount of water required by wildlife in the WBHB. Tyrell, in a review of the topic in the Green River Basin Plan, noted that estimates of wildlife use of surface water in that WBHB ranged from 100 to 400 acre feet per year. Tyrell concluded that "while some uncertainty exists in the exact consumption value, its probable magnitude is not so high as to materially affect the water plan" (2000). Since water use by wildlife is essentially constant, there is no foreseeable impact on future water demand.

Conservation Pools

The U.S. Bureau of Reclamation (USBR) has designated "Conservation Storage" for five reservoirs in the WBHB: Bighorn Lake, Boysen, Buffalo Bill Reservoir, Bull Lake, and Pilot Butte Reservoir. Each reservoir has an allocation for an "Active Conservation Pool", which holds a reservoir of inflow to be allocated for several purposes including fisheries, wildlife, water quality and recreation. As this a non-consumptive use "Conservation Storage" does not affect the basin plan. More detailed information on conservation pools can be found in the **"Water Uses from Storage" Technical Memorandum found in Chapter 2**.

Instream Flow

The instream flow statute defines that the use of instream flows shall be for fisheries protection only (Lowry, 2002). The WGFC has since 1986 taken action to identify streams for which the filling of applications is appropriate. As of 2002, there were five permitted instream flow appropriations in various rivers totaling 280,520 acre feet per year and three applications pending approval for 277,716 more acre feet per year. However, instream flow rights are not a consumptive use and though instream flow designations can potentially cause conflict with new out-of-stream uses, they may have local constraints on water availability within the WBHB.

Wetland and Riparian Habitat

Riparian areas and wetlands are ecologically important. They help to maintain stream flows, reduce erosion, and provide habitat for wildlife. The U.S. Department of Agriculture (USDA) has a number of programs that are relevant to these areas. However, riparian areas and wetland areas are non-consumptive uses and do not affect the consumptive use of water in the WBHB.

4.5.4 – *Summary*

The largest potential affect of non-consumptive recreational and environmental uses on future consumptive uses of water in the WBHB is likely to be restrictions of water use to maintain instream flows, wetland, conservation pools, and related environmental and habitat features. Although these non-consumptive uses will generally not affect the total amount of water available in the WBHB, such uses may affect consumptive use by limiting the location of water use and/or diversion, limiting the time of year water can be consumed or diverted, and limiting the type of water usage allowed.

CHAPTER 5
FUTURE WATER USE OPPORTUNITIES

5.1 – Screening Criteria

5.1.1 – *Introduction*

The list of opportunities compiled under this task is intended to be used by individuals and organizations that need to develop a water supply to satisfy their specific needs. One must always recognize that any screening criteria, which is applied between categories, may unfairly treat the project within the adjudged "less important" category. For example a municipal water supply that provides new water to 10,000 persons may be judged more important than the agricultural water supply development for 5,000 acres of alfalfa. With population benefits as a heavily weighted criterion, the municipal projects will always rank higher than the agricultural projects. For this reason, the Wind/Bighorn Basin Planning Team developed screening criteria, which could be applied independent of category, as well as within the individual category.

A long list of future water use opportunities was developed with input from the Basin Advisory Group (BAG), and is included here as Appendix A. To assist the users of this list to identify potential opportunities to satisfy their demands, the following methodology was employed to evaluate specific opportunities on the long list relative to similar and related opportunities. This methodology evaluates opportunities according to the likelihood that they are desirable, functional, and capable of receiving the support required for development. The intent of this exercise is to provide individuals and organizations with "a place to start" in their investigation to develop a water supply to satisfy their specific needs, rather than to "rank" potential projects.

The procedure used to complete this evaluation consists of the following five steps:

1. Establish project groupings into category and sub-category;
2. Develop screening criteria to evaluate future water use opportunities;
3. Develop a long list of future water use opportunities;
4. Develop a short list of opportunities;
5. And evaluate the opportunities on the short list.

5.1.2 – *Project Categories*

Specific to the Wind/Bighorn Basin planning process, four initial categories were identified. These were Municipal, Agriculture, Environmental and Religious/Cultural.

Category 1: Municipal

This category includes the development, augmentation and improvement of public water supplies throughout the WBHB. Several regulatory and non-regulatory issues have focused attention on this issue within the 30 year planning period. Prior to the 1990's many of the municipal water systems were surface water based. In 1986, the Safe Drinking Water Act was passed and many of its requirements were promulgated during the 1990's. These requirements included watershed protection plans, extensive water treatment and disinfection requirements. In response to these new requirements, water system operation and maintenance costs became increasingly prohibitive and several municipalities moved to a deep ground water option. In conjunction with the development of new water supply sources and the increased cost of water supply, treatment and distribution, a regionalization of water systems began to occur. Finally the susceptibility of surface water based systems to drought was realized in the late 1990's through 2002 and alternate supplies became a realistic goal.

Category 2: Agriculture

This category includes the development, augmentation and improvement of agricultural storage, conveyance and distribution throughout the WBHB. Several administrative and planning issues have focused attention on this issue within the 30 year planning period. Agriculture has always been a significant player within the economy of the WBHB. Economic incentives are an essential element in maintaining agricultural production at current and future levels. Such incentives include inexpensive and available water supply, storage and distribution. Another important institutional factor in the WBHB's water management is the two million acre Wind River Indian Reservation, located in Fremont and Hot Springs Counties. Tribal surface water rights date to 1868 and are the oldest in the WBHB. Legal proceedings between the State of Wyoming and the Shoshone and Arapaho Tribes awarded the right to 500,000 acre feet of water from the Wind River system to the Tribes. Half of this allotment was designated for new irrigation projects. Downstream users, whose rights are junior to those of the Tribes, are accustomed to having this water available. Working out a future planning scheme that will allow new uses and adequately distribute the existing water resources is a formidable task. Future planning projects must address this.

Category 3: Environmental and Recreational

This category includes development and preservation of water supplies for environmental purposes and recreational uses. Within the 30 year planning period, environmental and recreational uses are anticipated to become increasingly more important. Preservation of wetlands, riparian buffers, and maintenance of minimum streamflows and minimum reservoir pools are addressed as regulatory, as well as conservation goals. Tourism and recreation are increasingly important to the Wind/Bighorn Basin economy. With nearly 71% of the WBHB under public ownership, including several national forests and Yellowstone National Park, recreation interests are a major player. Water for fish hatcheries, campgrounds and golf courses are new demands. The impact of drought conditions and an administrative water rights call on junior appropriators have made the issue of minimum flows controversial.

Category 4: Religious and Cultural

This category includes the preservation and maintenance of existing springs, lakes and water sources for religious and cultural purposes. This category for the most part applies to the 2.2 million acre Wind River Indian Reservation, home of the Eastern Shoshone and Northern Arapaho Tribes. The Reservation is located mostly in Fremont County, with a relatively small area in Hot Springs County. As active BAG members, the Tribes have identified preservation of water related natural features and sites for religious and cultural purposes as an important category.

5.1.3 – *Project Sub-Categories*

To assist in further project groupings eight sub-categories were developed as part of the Wind/Bighorn Basin planning process. These sub-categories were intended to allow comparison of projects based on the type of project and were as follows:

- **Development of New Sources**- includes the development of a new, previously undeveloped water source e.g. deep ground water.
- **Distribution of Existing Sources-** includes the construction of new canals, ditches and pipelines to improve agricultural or municipal conveyance. Regionalization of municipal systems is included in this sub-category.
- **Storage of Existing Sources**- includes the development of new storage opportunities for both agricultural and municipal purposes.
- **Water Conservation**- includes both structural and non-structural conservation measures to include municipal metering programs, use and reuse of grey water for parks and cemeteries, lining of agricultural ditches and more efficient sprinkler systems.
- **Water Management**- includes management of existing uses through water rights or storage facility administration. This sub-category includes a review of existing water rights and uses, potential abandonment of unused water rights, development of new accounting procedures such as augmentation plans and coordinated releases and reservoir schedules by the U.S. Bureau of Reclamation to meet specific WBHB needs.
- **Conjunctive Use Options**- includes the combination of several types of uses to address a water planning goal. This sub-category includes use of excess surface water to help recharge depleted ground water reserves, as well as using existing flood plain gravel pits for storage and later reuse of river flood flows.
- **Basin Transfers**-includes transfer of river flows from a basin or sub-basin with excess or underappropriated water to a basin where additional water is needed.
- **Environmental and Recreation**- includes the development and preservation of water supplies for environmental and recreation purposes. This subcategory includes water development for recreation purposes such as fish hatcheries, golf courses as well as maintenance of existing flows for environmental purposes. Finally, this category may include fencing, land purchase for preservation of riparian ecology.
- **Development of New Uses**- includes the development of new water uses within the WBHB. This sub-category includes the use of water in a fossil fuel power plant, bottled water plants, irrigating new lands and water for dust abatement.

5.1.4 – *Screening Criteria*

A significant task of the river basin planning process is the development of screening criteria and methods for evaluating future water use opportunities identified and listed for the study basins. The Wind/Bighorn Basin project team adopted the screening criteria and evaluation method, which was originally developed for the Green River Basin Plan. These criteria were presented to the BAG for consideration and comment.

Criterion 1: Need

This criterion reflects the ability of a project to meet existing and future water needs in the WBHB. A score of one is assigned if the project falls in an area of surplus. A score of ten reflects that the project will potentially benefit areas within existing shortages even during wet years.

Criterion 2: Water Availability

This criterion reflects the general ability of a project to function, given likely bypasses for environmental uses and prior rights. It is not a reflection of the relative size of the project. With respect to ground water availability, this criterion is reflective of an aquifer's likelihood to yield the anticipated project demand. A score of one indicates no dependable supply, whereas a score of ten reflects that water is available even during dry years.

Criterion 3: Financial Feasibility

This criterion reflects the effects of the combination of technical feasibility, high or low construction costs, and economic use to which the water would be put (e.g. irrigation of native meadows vs. cultivation of alfalfa or row crops). The intent of this criterion is to indicate the sponsor's ability to afford the project or meet Wyoming Water Development Commission (or other) funding source criteria. A low number, one, represents a project which is ineligible for WWDC funding or where the cost significantly exceeds the benefits. A high number represents a project that would more easily meet funding and repayment requirements.

Criterion 4: Public Acceptance

This criterion reflects the extent to which a project will encounter or create public controversy, one, versus a project that would likely engender broad public support, ten. For example, on-stream storage in environmentally sensitive areas would be very controversial, while off-channel storage in less sensitive areas would more likely be supported.

Criterion 5: Number of Sponsors/Beneficiaries/Participants

This criterion reflects the desirability of a project, that a project serving a larger segment of the population should be evaluated higher, ten, than one serving only a few, one. This criterion is problematical, when one applies it to many of the conservation or institutional/administrative options, or to projects where there is no clearly defined sponsor. Such projects could be ranked higher, since they benefit a large number of people, yet no single entity is identified as a lead or direct sponsor. As sponsors adopt these types of projects (e.g. leak detection/pipeline replacement), such projects will rise to the top of the short list.

Criterion 6: Legal/Institutional Concerns

This criterion reflects the perceived ease, ten, or difficulty, one, with which a project could be authorized and permitted under existing state and federal law. In several cases, certain long list projects received lower rankings because there was known opposition and the threat of litigation. A number one, reflects a project with known fatal flaws, whereas a number ten, reflects a project which is easily permittable, no mitigation required and has strong support from the environmental or neighborhood groups.

Criterion 7: Environmental/Recreational Benefits

This criterion reflects the positive, a number ten, environmental and recreational aspects of a project versus those projects, which have a potential negative, a number one, impact on recreation and/or the environment. If this project would result in no net gain or loss, a number five was assigned. For example a ground water development project for a small town would rate a five, since it has neither a positive or negative environmental benefit.

5.1.5 – *Weighting of Screening Criteria*

Each screening criterion was assigned a weight depending on its relative importance to assuring a successful project. Weights were assigned values between one and ten by the consulting team based on its understanding of the values and preferences expressed by BAG members during the project development. Weights are listed in the following table.

Table 5.1-1 Screening Criteria

Screening Criteria	***Relative Weight***
Need	8
Water Availability	7
Financial Feasibility	7
Public Acceptance	6
Number of Sponsors / Beneficiaries	6
Legal / Institutional Concerns	5
Environmental / Recreational Benefits	7

After the long list was developed, each long list project was evaluated for the individual criterion on the basis of one to ten. After applying the criterion weights to each number, a total "value" of the long list project was established.

5.1.6 – *Long List of Future Water Use Opportunities*

Compiling the long list of future water use opportunities began with a review of published reports available for the study basins, knowledge of the basin and recommendations received at the October 2002 BAG meeting. The level of information and data available for the projects identified through the literature review varied from very sketchy to completed conceptual designs.

Both surface and ground water development projects were identified and included on the long list. Municipal projects have and will continue to include replacement of surface water sources with deep ground water supplies. Regionalization of municipalities and rural areas are and will continue to be included in these types of projects. Water conservation projects were included on the long list and reflect a growing attitude of both the funding agencies and the people of the WBHB. Environmental, religious and cultural projects reflect the ethnic diversity of the users in the WBHB, which includes ranchers, tourists, city dwellers and members of the Eastern Shoshone and Northern Arapaho Tribe. Although hot geothermal water is present and serves as a major tourist attraction in portions of the WBHB (primarily, Yellowstone and Hot Springs County), it was not included in this study. Similarly, ground water produced in the development of coalbed methane was not included on the long list and is not considered a major player in the WBHB.

Water right permit applications have been submitted to the State Engineer for several of the projects included on the long list. Some of the applications have been approved and the State Engineer has granted permits authorizing project development. The majority of the projects, however, have not been elevated to permit status and the applications remain in the pending status. Several of the projects are in various stages of study and feasibility determination within the WWDC process. These were addressed in the long list and in some cases were elevated to the short list.

Water right information was not compiled for the projects, nor was water right status considered in the subsequent evaluations of the projects. Each of the projects on the long list were evaluated under the assumption that a water right for the project could be obtained and conflicts with competing water rights could be resolved. Consideration was given to simply compiling the water right status for information only and not for the purpose of evaluation. However, this task proved to be beyond the scope of this river basin planning study.

Another future water use opportunity in the WBHB is the establishment of instream flow water rights and minimum reservoir pools. These water rights are developed through a specified procedure that begins when the WGFC proposes a stream segment for an instream flow water right. Once submitted, the WWDC reviews the data and the stream hydrology to determine if adequate water is available to meet the proposed new water rights. The SEO then either grants or rejects the water right. Instream flow opportunities are included on the long list since not only have several reaches been granted, but a large number remain in the queue. As new segments are nominated they will be advanced through the process. Minimum reservoir pools have been proposed to sustain both recreation and fisheries. They have been included on the long list, yet specific locations (sponsors) have not been identified. This type of project will need to be reviewed and approved by the owner of the reservoir, which in many cases is the U.S. Bureau of Reclamation.

An initial long list, which included over 200 water storage projects was presented to the BAG in August of 2002. Following discussions and further input from the BAG a supplemental long list was presented to the BAG at the October meeting. These two lists were combined and amended in time for the December 2002 BAG meeting in Powell. This latter long list was broken into categories and sub-categories, which defined the type of project or project grouping. The individual long list projects were scored individually and as a category/sub-category group.

Although scoring and weighting of the individual projects did occur, the use of these multiple categories allowed projects of similar nature to be compared to each other directly. In this manner, an environmental project wasn't directly compared to a municipal project.

5.1.7 – *Short list of Future Water Use Opportunities*

Projects and opportunities on the long list were reviewed to determine if they should be included on the short list or if they should be eliminated from consideration during the 30-year planning period. Reasons to eliminate projects included:

- The project had already been constructed;
- The location of the project facilities (i.e. within an environmentally sensitive or Wilderness Area), presented major legal, institutional, and permitting constraints;
- The original demand for the project no longer existed and is not expected to appear within the planning period;
- The project had no immediate or near term sponsor; or
- The project feasibility was questionable or did not fall within the upper percentile of screening criteria.

Given the size, breadth and distribution of project needs within the WBHB planning area, an attempt was made to develop short list projects that might benefit different interests throughout the WBHB. This included an attempted geographical distribution of projects throughout the planning area.

5.1.8 – Summary of Project Evaluation Methodology

The methodology described in this section is intended to assist the user of the long/short list of future water use opportunities. The process described can be employed to establish "a place to start" in the quest to match specific water demands to future water use opportunities. There should be no question that many of the long list projects may migrate to the short list and ultimately to project status over the 30-year planning horizon.

The process begins after a project need is defined. This project need could be served from the existing long list or short list of future water use opportunities or may require a new entry. The project need should be defined by its category and/or sub-category. The screening criteria, developed under this basin planning process should be applied or, in the case where things may have changed since the creation of the original long list, be reapplied to the project. The result of the screening process will be an evaluation of opportunities in accordance with the relative likelihood that they are desirable, functional, and capable of receiving enough public support to be implemented. In general, the results should present an overall favorable future water use opportunity or project.

Finally once a project is defined and screened, the process of implementation takes place. In many cases, this will include:

- Developing a sponsor, which might include the formation of regional joint powers board, local watershed council or agricultural district.
- Establishing of board members responsibilities and establishing a method to service members, collect fees and institute operating agreements;
- Preparing project funding package, which might include project need, project sponsor and time table for implementation of the project;
- Appling for grant or grant/loan package, which allows technical analysis of feasibility, project parameters and conceptual level costs;
- Appling for grant or grant/loan, which allows for final design, plans and specifications for final project implementation.
- Appling for project funding to construct the project.

5.2 – Project Summaries

5.2.1 – *Introduction*

As part of the BAG process, the Wind/Bighorn Project Planning Team developed a long list of potential structural and non-structural opportunities to meet current and projected water demands over the 30 year planning horizon. Structural opportunities include, but are not limited to storage reservoirs, deep ground water wells, and conveyance system upgrades. Non-structural opportunities include, but are not limited to local and basin-wide conservation, meters, leak detection programs and administrative changes in water rights and water delivery.

After the long list was developed, each long list project was evaluated for the individual criterion on the basis of one to ten. After applying the weights to each number, a total "value" of the long list project was established.

Appendix A of this report presents the long list of potential future water use projects.

5.2.2 – *Development of the Long List*

The level of information and data available for the projects on the list of future water use opportunities varies significantly from very sketchy to completed conceptual designs. Therefore, the exercise of assigning weights to criterion and evaluation scores to projects is subjective and the results of the evaluation process can only be interpreted to reflect the knowledge and judgment of the individual assigning the weights and scores. In order to make the process more objective and less subjective, detailed engineering, legal, and environmental investigations would need to be completed to advance all projects to the same level of information and data.

The user is cautioned to avoid a quantitative comparison of projects solely based on their individual performance under the screening criteria and weighting process. With this in mind, the long list was presented to the BAG on a performance basis within the project category and/or subcategory. This process resulted in the establishment of four groups or quartiles as described below, and are included in Appendix A:

Group 1 – Projects that scored within the first quartile or the upper 25% of projects within a similar category.

Group 2 – Projects that scored within the second quartile or upper 25 to 50% of projects within a similar category.

Group 3 – Projects that scored within the third quartile or upper 50 to 75% of projects within a similar category.

Group 4 – All other remaining projects

As one can see from this list, water storage opportunities have been studied extensively over the years and there are over 200 potential water storage projects within the WBHB. Many of these projects are unrealistic, in that they fall in environmentally sensitive areas, may never be permitted, and/or they may not meet a basin plan, which prioritizes need, water availability and financial feasibility of the project as important parameters.

Several of the proposed long list projects are actually water administration ideas. For example "development and administration of flow augmentation plans" requires Wyoming Legislature, State Engineer and State Board of Control involvement. As more and more basin municipalities move from a surface water source to a deep Paleozoic well, more "out-of-basin" water (i.e. deep ground water) will be returned to the surface water system. This volume of water may serve as an administrative "credit" for future surface water supply development.

Other long list projects include water conservation ideas. These projects may include implementation of a Leak Detection Program for a municipality and replacement of old, leaking water lines. Although the concept will be implemented at the time of the development of the long list, no specific sponsor was identified. As such, its group weight is lower than if a sponsor was identified.

5.2.3 – *Development of the Short list*

As part of the process, the BAG members were asked to review the long list and identify potential opportunities not included on the proposed long list as well as the relative merits of the individual projects. Comments and suggestions received from BAG members and additional research led to the development of the final long list and ultimately the short list.

In the development of the short list, each project was assigned to a category: Municipal, Agriculture, Environmental/Recreational, and Cultural/Religious. Projects were then rated by category. For example, municipal projects were rated against other municipal projects. Agricultural storage projects were rated against similar projects. The final grouping of short list projects is presented in the following table.

5.2.4 – *Summary*

It must be emphasized that the short list tables reflect the knowledge and judgment of the individuals that performed the exercise. When other individuals having different opinions and a different level of knowledge of the projects being evaluated complete the exercise, different scores will result. Variable results will be achieved because different weights will be assigned to the evaluation criteria and different scores will be assigned to the projects.

One should recognize that the final Wind/Bighorn Basin short list is a reflection of the Planning Team's professional opinion and an attempted quantitative evaluation. Individual BAG members and the BAG, as an entity, may disagree or find other rationale for including certain long list projects on the final short list.

It is hoped that this short list may help initiate the required investigations leading to the selection of a future water use opportunity or it may lead to a new and completely separate evaluation. The evaluated short list is preliminary in nature and should not be used by any other funding entity to prioritize funding awards.

Table 5.2-1 Short List of Future Projects:

Category	Name of Project	Description of Project	Location of Project
I. MUNICIPAL			
Type of Project: **New Source**		Construct Deep Aquifer Supply	Regionalization: Lander/ Hudson/Riverton
	Paleozoic Well Field	Construct Deep Aquifer Supply	Regionalization: W.R. Reservation
	Paleozoic Well Field	Construct Deep Aquifer Supply	Regionalization: Hot Springs County
Type of Project: **Distribution/ Storage Opportunities**	Bighorn Regional Joint Powers Board	Storage Tanks/Redundant Transmission	HotSprings/Washakie County
	Tensleep/Hyattville	Storage Tanks/ Transmission	Washakie County
Type of Project: **Conjunctive Use**	Aquifer Storage and Retrieval	Alluvial Aquifer Augmentation	Upper Wind River/Riverton Area
Type of Project: **Water Management**	Ground Water Control District	Administration of Future Development	Riverton Area
	Ground Water Control District	Administration of Future Development	Paintrock Anticline and Hyattville
Type of Project: **Water Conservation**	Leak Detection	Municipal Survey and Repair of Leaks	Basin-wide
	Reuse of Grey Water Non Potable Water	Irrigation of Parks/Cemetaries	Basin-wide
II. AGRICULTURAL			
Type of Project: **New Source**	None		
Type of Project: **Storage Opportunities**	Bull Lake Dam Enlargement	Reservoir Enlargement	Big Wind River
	Dinwoody Lake Enlargement	Reservoir Enlargement	Big Wind River
	Steamboat	New Reservoir	Big Wind River
	Ray Lake	Reservoir Enlargement	Little Wind River
	Little Popo Agie- Off Channel Site 5	New Reservoir	Little Popo Agie
	Pumpkin Draw	New Reservoir	Owl Creek
	Neff Park (Popo Agie Study)	New Reservoir	Popo Agie
	Lake Creek	New Reservoir	Clarks Fork
	Moraine Creek No. 1	New Reservoir	Shell Creek
Type of Project: **Distribution**	Popo Agie Master Plan	Ditch Headgate and Diversion Improvements	Popo Agie Basin
	Kirby Creek Watershed	Stock Reservoirs	Kirby Creek Basin
Type of Project: **New Lands**	Riverton East	Construct New Diversions/Ditches	Wind River Basin
	Westside	Construct New Diversions/Ditches	Bighorn Basin
Type of Project: **Water Conservation**	Midvale/LeClair Riverton Valley	Ditch Linings/ Conveyance Improvements	Wind River Basin
	Wind River Irrigation Project	Ditch Linings/ Conveyance Improvements	Wind River Basin
Type of Project: **Basin Transfer**	Clarks Fork to Greybull Drainage	Storage and Pipeline	Clarks Fork to Bighorn Basin
III. ENVIRONMENTAL	Instream Flows	Admin Minimum Flows	Wind and Bighorn Basin
	Minimum Reservoir Pools	Admin Reservoir Releases	Wind and Bighorn Basin
	Watershed/Habitat Improv.	Water Quality Impaired Streams	Bighorn Basin
IV. CULTURAL/RELIGIOUS	Water Use by Tribes	Coordinated Reservoir Releases	Wind and Bighorn Basin

5.3 – Opportunities to Enhance and Protect Water Quality

5.3.1 – *Introduction*

Since the passage of the 1973 Environmental Quality Act, the State of Wyoming has empowered the Water Quality Division of the Department of Environmental Quality (DEQ-WDQ) with the authority to promulgate surface and ground water standards and regulations, and to protect water quality through the agency's permitting and enforcement processes. The Wind River Indian Reservation (WRIR) has a similar department of environmental quality. The state and tribal programs must comply with a variety federal regulations, including the Clean Water Act, Safe Drinking Water Act, and others.

Ground water quality, availability, and usage are discussed in **Chapter 3 of the Technical Memorandum, Tab 17, "Ground Water Availability"**. Currently no ground water protection or ground water control areas are designated within the WBHB, however, two areas in the WBHB have been identified for potential ground water protection due to high use.

For surface water, the DEQ-WDQ and similar tribal programs have classified streams and water bodies within the WBHB in accordance with EPA's 303 regulations and have created a 303 (d) listing of impaired streams. The Wyoming 303 (d) listing of impaired streams and water bodies for the WBHB is provided in **Appendix B of Chapter 2 of the Technical Memorandum, Tab 9, "Environmental and Recreational Use"** or can be found at http://www.deq.state.wy.us.

Watershed planning, sponsored by the WWDC, is in progress for the Popo Agie watershed and is proposed for 2003 funding for the Kirby Creek watershed. Watershed planning is also conducted within areas dominated by federal lands and by federal land management agencies such as the BLM and U.S. Forest Service under their own programs.

5.3.2 – *Inter-Agency Considerations*

Ten of Wyoming's 34 Conservation Districts are located in the Wind River, Bighorn and Clarks Fork Basin. They are the Powell, Clarks Fork, Shoshone, Cody, South Bighorn, Meeteetse, Washakie County, Hot Springs County, Dubois Crowheart, Lower Wind River, and Popo Agie Conservation Districts. These conservation districts conduct a variety of programs, which are designed to minimize agricultural related impacts to the environment and water quality.

The U.S. Department of Agriculture has a number of programs administered by its Natural Resources Conservation Service (NRCS). The Wind River, Bighorn and Clarks Fork Basins are administered through a single NRCS district office located in Worland. NRCS initiatives related to water quality and environmental protection include: the Wildlife Habitat Incentive Program (WHIP), the Environmental Quality Incentive Program (EQIP), the Conservation Resource Program (CRP), and the Wetlands Reserve Program (WRP).

Other considerations within the WBHB include: Yellowstone National Park; Wyoming's only Congressionally designated "Wild and Scenic River", a twenty-mile stretch of the Clarks Fork river near Cody; the Wind River Indian Reservation; the presence of glaciers in the Wind River mountains whose drainage is tributary to the WBHB; and federal land ownership of some 61% of the WBHB. Examples of inter-agency cooperation with respect to water quality protection and/or enhancement include; cooperative water quality sampling and analysis relative to 303 (d) by the DEQ-WDQ and various Conservation Districts, and WWDC sponsored watershed planning studies sponsored by Conservation Districts with participation by NRCS, BLM, and/or others.

5.3.3 – *Water Quality Impairments and Special Considerations*

Waters are declared "impaired" when they fail to support their designated uses after full implementation of the National Pollution Discharge Elimination System permits and "best management practices." Under the Clean Water Act, every state must update its "303(d)" list of impaired waters every two years after reviewing "all readily available data and information." **Appendix B, Chapter 2, Tab 9, "Environmental and Recreational Use" of the Technical Memorandum**, provides listing information on water bodies in the WBHB that are considered quality impaired under section 303(d) of the Clean Water Act. The 2002 303 (d) listing, includes 19 reaches of impaired streams within the Wind River, Bighorn, and Clarks Fork River Basins. Of the impaired reaches 16 are related to levels of fecal coliform. The remaining three reaches, all along the Clarks Fork, are impaired due to elevated metal concentrations. The 303 (d) listing also includes 13 threatened waterbodies. One of the impairments is related to loss of habitat and the other 12 are threatened due to fecal coliform.

5.3.4 – *Summary*

As discussed in **Chapter 3, Tab 17, of the Technical Memorandum "Ground Water Availability"**, two areas in the WBHB have been identified for potential ground water protection due to high use. These are the Upper Wind River aquifer in the vicinity of Riverton and the Madison/Bighorn Aquifer within the Paintrock Anticline near Hyattville. Surface water quality impairments are primarily due to elevated levels of fecal coliform. The source of contamination in all cases is listed as unknown. One aspect of current watershed improvement planning projects is to reduce the concentrations of livestock instream floodplains and wetland areas. If this current livestock use is contributing to the elevated levels of fecal coliform, the planned watershed improvements should reduce the fecal coliform levels. Current watershed planning also focuses on the reduction of erosion and associated contribution of sediment to the Total Maximum Daily Loads (TMDL) of the streams. In addition, various land management agencies (BLM, U.S. Forest Service, National Park Service), the Wind River Indian Reservation, conservancy districts, and agencies such as the NRCS each have programs relative to watershed improvement, which will in turn improve surface water quality.

CHAPTER 6
POTENTIAL FOR POWER PRODUCTION

6.1 – Introduction

As part of the WBHB Plan, this study evaluates the potential for power production within the basin planning study area. The analysis considers the physical and economic ability to produce power via hydropower or fossil fuels, the market potential for hydropower purchases and the economics of financing the facilities. The purpose of the report is to develop a conceptual-level evaluation of the opportunities for power development within the WBHB. The information contained herein relies heavily on previously published information, information developed in the WBHB Plan and past projects by the consulting team. The report serves as a roadmap to further studies on particular power generation types and sites.

The WBHB Planning study area incorporates the Wind, Bighorn, Clarks Fork of the Yellowstone, Yellowstone, Madison and Gallatin River Basins. Because those portions of the Yellowstone, Madison and Gallatin River Basins within the state of Wyoming are within Yellowstone National Park, no water development projects were proposed in the basin plan, and thus, no discussion of potential power projects within the park is considered in this report. All of the river basins are tributary to the Yellowstone River in southern Montana, which is subsequently tributary to the Missouri River in northeastern Montana. In general, the WBHB Plan found that there is ample opportunity for water development projects within the WBHB, including the need and availability of water for major reservoirs. These reservoir sites were used as a basis for the hydropower sites within this report.

6.2 – Power Development Opportunities and Constraints

A power market survey was performed to assess the regional market for power, particularly hydropower, in the Wind/Bighorn Basin area. The objectives of the survey were to characterize the regional power marketplace, identify potential power purchasers and to estimate the approximate pricing range available for power in the WBHB.

Three major transmission-owning utilities operate in the general vicinity of the study area. The Western Area Power Administration (WAPA) transmission facilities are generally 115kv, and parallel the Bighorn River from approximately Riverton to Lovell. PacifiCorp-East lines are generally 230kv, and can be tapped northwest of Thermopolis. Tri-State lines are generally at or below 115kv, and could be tapped west of Lovell, Thermopolis and Riverton. Black Hills Power and Light and Basin Electric Power Cooperative also own small segments of transmission facilities, primarily as generator outlet transmission or to serve isolated load areas. WAPA or PacifiCorp-East facilities would be the most suitable interconnections, since Tri-State lines have a generally radial configuration. PacifiCorp-East and WAPA indicated a willingness to allow interconnections to their system. There are, however, limitations in transmission capacity from the region to outside areas. Historically, there have been constraints moving power from Wyoming southward to the Denver area. This suggests that the power project would be most justified based on in-basin demand, rather on demand in the entire Rocky Mountain Region or beyond.

The operation of numerous hydroelectric and coal-fired plants in the region heavily influences the market for power, including market pricing. Eight parties expressed potential interest in purchasing project output, and none expressed strong interest. Four parties (WAPA, PacifiCorp-East, Wyoming Municipal Power Agency, and Tri-State) indicated a specific interest in seeing a project built with a degree of dispatchability. For a hydropower plant, this would require a reservoir with a certain amount of storage space dedicated to hydropower that could be managed for power production first, with only secondary benefits for water supply, recreation, environmental enhancement, etc. Power companies who expressed an interest in power, created from future projects, indicated a general power purchase price in the range of $0.04/kwh. Final pricing would be based on market conditions at the time contracts were negotiated, and in some cases could be indexed to the Mid-Columbia region power trading hub in Oregon.

6.3 – Hydropower Facilities

The analysis of hydropower facilities was conducted in two steps. First, a "long list" of potential hydropower sites was generated based on proposed reservoir facilities generated as part of the Wind/Bighorn River Basin Plan. Then, a screening process was used to reduce the long list to a "short list" of 11 sites. A more detailed hydropower facility and economic analysis was conducted on the short listed sites. Because the primary purpose of this study was to identify regional-scale hydropower projects that could be developed in conjunction with additional storage for water supply purposes in the WBHB, smaller hydropower installations, such as hydropower installations on canals, run-of-river installations using piped diversions and facilities on smaller reservoirs were not considered.

Developing a short list from the long list incorporated both numeric scoring of criteria, subjective scoring of criteria and other general information about the site. The criteria used during the screening process included:

- Potential hydropower score/grouping as calculated in this study;
- Water supply score/grouping as calculated using methodologies previously in Chapter 5 of this report;
- Interest in specific sites from BAG members or WWDC staff;
- Distribution of sites between basins and sub-basins;
- Availability of site specific information from other studies.

Scoring for criteria 1 and 2 were performed based upon the methodologies described previously. Once the scoring was performed, the sites were sorted based upon scores and divided into 4 groups based upon the score quartiles. Then, in general, sites were selected based upon criteria 3 through 5, with a concentration on those sites with scores in the first or second quartile. A summary of the short listed sites is shown in Table 6.3-1.

Table 6.3-1 Short list of Hydropower Sites

Site ID	Site Name	Basin	Region	Reservoir Capacity (ac-ft)	Hydropower Group	Water Supply Group
16	Bull Lake Creek No. 4	Wind	Big Wind River	159,000	1	1
16	Bull Lake Creek No. 4 (Pump-Storage)	Wind	Big Wind River	159,000	1	1
25	Dinwoody Lake Enlargement	Wind	Big Wind River	82,580	2	1
53	Steamboat	Wind	Big Wind River	36,000	2	1
61	Wind River Blue Holes	Wind	Big Wind River	375,000	1	1
62	Wind River East Fork No. 1	Wind	Big Wind River	103,000	1	2
81	Clarks Fork	Clarks Fork	Clarks Fork River	522,850	1	4
134	Little Wind River North Fork No. 3	Wind	Little Wind River	38,600	1	3
153	Kirby	Bighorn	Mainstem Bighorn River	130,000	1	2
174	Nowood River	Bighorn	Nowood River	175,000	1	4
193	Owl Creek South Fork No. 2	Bighorn	Owl Creek	20,090	2	2

Notes:
(1) Score groupings are based upon quartiles of the scores for all sites. Those sites in group 1 were in the upper 25% of scores, those in group 2 in the top 25% to 50%, those in group 3 in the top 50% to 75% of scores, and those in group 4 in the bottom 25%.

Hydropower generation is primarily a function of the head available at the site and the flow rate through the generation facility. An operational analysis of each reservoir site was conducted using the dry, average and wet year hydrology and downstream water supply demands generated in the Wind/Bighorn River Basin Plan. From this information, available head and release rates were determined. Standard methodologies and values for turbine and generator efficiency were used to size hydropower facilities and calculate hydropower generation at each site. For most sites, two turbine sizes were investigated to bracket the potential configuration at the site. A summary of the hydropower calculations is shown in Table 6.3-2.

6.4 – Fossil Fuel Facilities

The analysis shows that either coal fired or gas fired electric power generation facilities within the WBHB would be feasible. Recent advances in gas turbine technology and diminished environmental impacts, as compared to coal fired facilities, may favor gas turbine facilities. It is assumed that power developments will be modest, based on local consumption needs, due to current limitations in regional transmission capacity.

A summary of the conceptual designs and annual revenues expected from the fossil fuel facilities is presented in Table 6.4-1. The plant capacities were developed based upon estimates of the extractable coal from the representative coal fields and project life, and developed using similar facilities elsewhere in Wyoming. Unit construction costs for the facilities were taken from Idaho National Energy Laboratories published data (INEL, 2003). Annual energy production was calculated based upon an average annual generation to capacity ratio of 85%, while annual revenue was calculated based upon power prices developed in the market study.

Table 6.3-2 Summary of Average Annual Hydropower Facility Analysis

Site ID	Site Name	Turbine Flow (cfs)	Unit Size (kw)	Turbine Output (kw)	Hydropower Generation (MWh)	Power Revenue ($1,000)
16	Bull Lake Creek No. 4 (Small Unit)	500	9,300	2,471	20,104	668
16	Bull Lake Creek No. 4 (Large Unit)	600	11,000	2,469	20,100	667
16	Pumped Storage @ Bull Lake Creek No. 4 (Gen)	2,000	30,000	26,196	72,049	446
16	Pumped Storage @ Bull Lake Creek No. 4 (Pump)	2,000	38,000	25,986	94,854	
25	Dinwoody Lake Enlargement (Small Unit)	175	500	83	674	22
25	Dinwoody Lake Enlargement (Large Unit)	350	1,000	119	945	31
53	Steamboat	230	900	551	4,490	149
61	Wind River Blue Holes	920	16,500	7,306	58,144	1,930
62	Wind River East Fork No. 1 (Small Unit)	45	600	97	803	27
62	Wind River East Fork No. 1 (Large Unit)	455	6,000	616	4,979	139
81	Clark Fork No. 2 (24 Hours Operation)	800	15,000	11,616	95,370	3,166
81	Clark Fork No. 2 (8 Hours Peaking Operation)	2,400	45,000	34,405	94,100	3,556
134	Little Wind River North Fork No. 3 (Small Unit)	105	1,800	1,289	10,539	350
134	Little Wind River North Fork No. 3 (Large Unit)	150	2,500	1,324	10,639	353
153	Kirby (24 Hours Operation)	1,550	7,500	5,724	46,942	1,559
153	Kirby (8 Hours Peaking Operation)	4,650	16,000	13,082	35,884	1,356
174	Nowood River (Small Unit)	400	3,100	2,319	19,003	631
174	Nowood River (Large Unit)	500	3,800	2,383	19,310	641
193	Owl Creek South Fork No. 2 (Small Unit)	55	550	154	1,230	41
193	Owl Creek South Fork No. 2 (Large Unit)	100	900	145	1,119	37

Notes:
(1) Summary for Normal (Average) Hydrologic Year
(2) Assumed power price = $33.20 per MWh

Table 6.4-1 Summary of Potential Fossil Fuel Power Facilities

Site	Type	Capacity (MW)	Construction Cost ($ million)	Annual Generation (MWh)	Annual Revenue (million)	Project Life (years)	Employees	
							Mine	Plant O&M
Wind	Coal	200	$368.5	1,489,200	$49.4	30	55	50
Bighorn	Coal	300	$552.7	2,233,800	$74.2	30	155	50
General	Gas Turbine	500	$263.2	3,723,000	$123.6	30	---	25

6.5 – Economic Analysis

To determine the overall economic feasibility of the hydropower facilities, benefit-cost ratios were estimated for the proposed hydropower generation facilities at each site. In estimating the net cash flow for each year, the power revenue, operation and managment costs, and tax and loan payment were included in the analysis and the present worth of the net cash for each year was estimated based on the assumed discount rate. The sum of the net present worth during the project life was compared with the present total capital costs to determine the benefit/cost ratio. If the benefit/cost ratio is higher than one, the project would be economically feasible. For this analysis, the following factors were used: a 30-year and 50-year project life, a discount rate of

Table 6.5-1 Benefit/Cost Ratios for Hydropower Sites

Site ID	Site Name	Unit Size (MW)	B-C Ratio for Given Loan Life And Escalation Rate			
			30-year		50-year	
			2 percent	3 percent	2 percent	3 percent
16	Bull Lake Creek No. 4 (Small Unit)	9.3	0.119	0.193	N/A	N/A
16	Bull Lake Creek No. 4 (Large Unit)	11.0	0.119	0.194	N/A	0.475
16	Pumped Storage @ Bull Lake Creek No. 4	30.0	N/A	(-) 0.332	N/A	-0.267
25	Dinwoody Lake Enlargement (Small Unit)	0.5	(-) 0.937	(-) 1.002	N/A	(-) 0.779
25	Dinwoody Lake Enlargement (Large Unit)	1.0	(-) 0.714	(-) 0.749	N/A	(-) 0.854
53	Steamboat	0.9	0.413	0.526	N/A	0.943
61	Wind River Blue Holes	16.5	0.492	0.616	N/A	**1.069**
62	Wind River East Fork No. 1 (Small Unit)	0.6	(-) 0.769	(-) 0.812	N/A	N/A
62	Wind River East Fork No. 1 (Large Unit)	6.0	0.314	N/A	0.582	N/A
81	Clark Fork No. 2 (24 Hours Operation)	15	**1.292**	**1.521**	N/A	N/A
81	Clark Fork No. 2 (8 Hours Peaking Operation)	45	N/A	**1.126**	N/A	N/A
134	Little Wind River North Fork No. 3 (Small Unit)	1.8	0.818	0.984	N/A	**1.588**
134	Little Wind River North Fork No. 3 (Large Unit)	2.5	N/A	0.931	N/A	N/A
153	Kirby (24 Hours Operation)	7.5	**1.080**	**1.281**	N/A	N/A
153	Kirby (8 Hours Peaking Operation)	16.0	N/A	0.333	N/A	N/A
174	Nowood River (Small Unit)	3.1	**1.237**	**1.459**	N/A	N/A
174	Nowood River (Large Unit)	3.8	N/A	**1.397**	N/A	N/A
193	Owl Creek South Fork No. 2 (Small Unit)	0.6	(-) 0.540	(-) 0.553	(-) 0.551	N/A
193	Owl Creek South Fork No. 2 (Large Unit)	0.9	(-) 0.496	(-) 0.502	(-) 0.492	N/A

Notes:

(1) Bolded B/C Ratio indicates those with values greater than 1.0

(2) The B/C ratios shown in this table for the Clarks Fork and Kirby sites are for facilities built primarily for water supply purposes with secondary power benefits.

(3) N/A = Analysis not necessary based on analysis at lower rates.

(4) B/C Ratio = Annual Net Cash Flow/Annualized Capital Cost

5%, escalation rates of 2% and 3%, and loan amount 50% of the total capital costs. For those sites found feasible, other loan amounts were investigated. Table 6.5-1 presents a summary of the analysis.

Secondary economic benefits would be realized from both a hydropower facility and fossil fuel facilities. Secondary economic benefits could include decreased power costs for in-basin users due to an increase in supply, increased services provided by local companies for facility operation and maintenance and increased services supplied to facility employees. However, the primary economic benefit analyzed in this report is the increase in employment generated by the facility, both during construction and during operations. For the hydropower portion of the dam project, between 10 and 50 employees may be on-site at any given time. A majority of these employees are skilled labor and would likely be brought to the site by the contractor. However, up to 20% of the employees could possibly be hired locally. In general, once hydropower facilities are constructed and in typical operational mode, the manpower required for operations and maintenance is minimal because the dam sites are controlled from a central facility.

Typically, one person or less would be required to perform day-to-day maintenance for the size of facilities being considered.

The benefit/cost ratios for fossil fuel facilities are shown in Table 6.5-2. As shown, for escalation rates of 3%, all of the facilities are economically feasible. However, at 2% escalation rates, the coal-fired facilities are only marginally feasible. It should be noted that because operation and management costs are significant for fossil fuel facilities, the benefit/cost ratio is sensitive to the estimates that are made for operation and maintenance. Secondary benefits from employment at fossil fuel facilities were discussed in the previous sub-section.

Table 6.5-2 Benefit/Cost Ratios for Fossil fuel Sites

Facility	Capacity (MW)	30-year		50-year	
		2 percent	3 percent	2 percent	3 percent
Bighorn Basin - Coal	200	0.835	1.003	N/A	N/A
Wind River Basin - Coal	300	0.836	1.006	N/A	N/A
Typical Gas	500	1.079	1.280		

Notes:
(1) Loan amount = 50% of total costs, interest rate = 4%.

6.6 – Permitting and Environmental Issues

The proposed reservoir sites would require several federal and state permits. These permits would be required for the reservoir with or without hydropower. However, due to possible differences in release patterns, there could be slightly different impacts due to the facilities.

Federal permitting requirements associated with the enlargement of either an existing facility or the construction of a new facility are addressed under the National Environmental Protection Act (NEPA). It is likely that some form of a reservoir or retention basin would be constructed as part of the hydropower plant facility and would trigger an Army Corps of Engineers 404 permit. It is likely that an individual 404 permit would be required for the facility. The facilities would also require licensing from the Federal Energy Regulatory Commission.

The State of Wyoming and/or Shoshone and Arapaho Tribes will also require some permits to be issued. These permits would include those obtained from the Industrial Siting Administration as well as other divisions of the DEQ-WDQ. Depending upon the project site, access roads, and potential to disrupt traffic during construction, permits from the Wyoming Department of Transportation may be necessary. Diversion and beneficial use of unappropriated waters would require the appropriate permits be obtained from the Wyoming State Engineer's Office and the Tribal Water Engineer's Office. Additional issues affecting the sites are presented in Table 6.6-1.

Table 6.6-1 Site Specific Environmental Concerns

Site ID	Site Name	Wetland Acreage	Threatened Species	Rare Plants	* Cultural Concerns	Other Factors
16	Bull Lake Creek No. 4 (Conventional and Pump-Storage)	231.5	None	None	Yes	Lands affected will be tribal lands while the dam structure is under the jurisdiction of the Bureau of Reclamation.
25	Dinwoody Lake Enlargement	23.9	None	Dubois Milkvetch	Yes	Home owners may be impacted by the proposed site.
53	Steamboat	94.9	None	None	Yes	The proposed site may impact Tribal land as well as private property.
61	Wind River Blue Holes	146.2	None	Dubois Milkvetch, Rocky Monutain Twinpod	Yes	The proposed site may impact Tribal land as well as private property.
62	Wind River East Fork No. 1	19.4	None	Dubois Milkvetch, Rocky Mountain Twinpod	Yes	The proposed site may impact Tribal land as well as private property. Homeowners may be affected by the proposed dam structure.
81	Clarks Fork	23.5	None	Contracted Indian Ricegrass, Shoshonea	Nothing on record	WY Game & Fish facilities in the area may be impacted. A dam structure may impact the area upstream that is designated as Wild and Scenic.
134	Little Wind River North Fork No. 3	2.6	None	Beaver Rim Phlox	Yes	The proposed site may impact Tribal land as well as private property.
153	Kirby	41.3	None	Contracted Indian Ricegrass	Nothing on record	The proposed site may lie on federal land as well as private property. A railroad line and highway are located near the river and should be addressed.
174	Nowood River	54.4	None	Contracted Indian Ricegrass, Persistent Sepal Yellowcress	Nothing on record	The proposed site may lie on federal land as well as private property
193	Owl Creek South Fork No. 2	Unknown	None	Owl Creek Miner's Candle, Rocky Mountain Twinpod	Nothing on record	The proposed site may lie on Tribal land as well as private property.

Notes:

(1) Cultural concerns at the various locations are not presented in the table but range from petroglyphs, sheep fences, burial sites and areas with artifacts as a result of past habitation.

6.7 – Recommendations and Conclusions

The WBHB Power Study was conducted to analyze the potential for both hydropower and fossil fuel facilities within the WBHB. Several potential projects were analyzed to determine the technical feasibility of the project and the economics of project development.

- The market study generally concluded that although there is not a significant demand for baseload energy, interest was expressed in dispatchable power, or power that can be generated on demand by the power providers.
- The Nowood River site appears economically feasible for all of the economic situations analyzed. The Nowood River site could be operated to meet water supply demands. However, since few downstream shortages were identified, it would primarily be operated for hydropower purposes.
- Two of the reservoir sites, the Clarks Fork site and the Kirby site, were analyzed for two different scenarios: the facility was built for hydropower purposes alone and the facility was built primarily for water supply purposes with secondary power benefits. For both sites, building the dam for hydropower purposes alone was not economically feasible. If the dam was built primarily for water supply purposes with secondary benefits for power, the power facilities would be economically feasible.
- Three of the hydropower sites could be marginally economically feasible given optimal financing and project life: the Steamboat site, the Wind River Blue Holes site and the Little Wind River North Fork No. 3 site. However, at each of these sites, because they are primarily operated for water supply and releases, power generation could not necessarily be guaranteed and it may be difficult to contract with a power purchaser.
- Hydropower facilities do not offer significant employment benefits because of operational automation.
- Coal-fired power plants appear technically and economically feasible and can offer significantly more local employment opportunity than hydropower facilities.
- Gas turbine power plants appear to be the most economically viable alternative that was analyzed. These plants can capitalize on the abundance of natural gas within the WBHB, and offer the dispatchable power required by the power providers.

As shown above, the gas turbine power plants are the most attractive option for new power generation within the WBHB. However, if any reservoir were to be further evaluated for water supply purposes, these evaluations should include a technical and economic analysis of the potential for power generation. For development of any of the proposed projects, a sponsoring group or agency would need to be identified and formed. Then, this group would need to commence discussions with the potential power purchasers and provide a more detailed analysis of the selected alternative.

Appendix A

Long List of Future Water Use Opportunities

Development of New Resources

Sub-Category	Location, General Description	Project Description	Group
Ground Water Development	Paleozic Aquifer	Madison Aquifer vic. Of Lander	2
		Madison Aquifer vic. Of Southern Bighorn Basin	1
		Flathead Aquifer nr. Thermopolis, Hyattville	1
		Tensleep Aquifer nr. Big Trails	4
		Madison Aquifer nr. Hyattville	3
	Tertiary Aquifer	Wind River Aquifer vic. Gas Hills Area	4
		Flooded Uranium Mine Pits nr. Gas Hills	3
Flow Augmentation	Municipal Wastewater, when supplied fm. GW	Worland	1
		Greybull	2
		Basin / Manderson	2
		Hyattville	3
		Tensleep Creek	3
	Cloud Seeding / Weather Modification	Bighorn Mountains	4

Distribution of Existing Resources

Sub-Category	Location, General Description	Project Description	Group
New Canals, Ditches or Pipelines	Municipal Systems Regionalization	Bighorn Regional Joint Powers Board	1
		Lander-Hudson Proposal	1
		Town of Tensleep Regionalization	1
		Dubois Regional	1
	Agricultural Conveyance	Popo Agie River Master Plan	1
		Kirby Creek Master Plan	1
		Owl Creek/Hot Springs Conservation District	2
Storage	Varies	Varies	Varies

Construction of New Municipal Storage	Bighorn Regional Joint Powers Board		1
	Town of Tensleep Regionalization		1
	Hyattville Water System		2

Conservation

Sub-Category	Location, General Description	Project Description	Group
Structural	Municipal/Industrial Users	Meters for Unmetered Municipalities	3
		Leak Detection Program	2
		Utility Line Replacement	2
	Agricultural Users	Lining ditches to reduce seepage losses	2
		Change from open ditch to pipeline	2
		Midvale Irrigation District	1
		LeClair Laterals	1
		Riverton Valley Crossings	1
		More efficient irrigation systems	2
		Low head sprinklers	2
		Soil tensiometers and irrigation scheduling	3
Non-Structural	Municipal/Industrial Users	Reclaimed Water for Irrigation	4
		User rate schedule to promote conservation	3
		Use of raw water for irrigation	4
		Town of Greybull	1
	Agricultural Users	Change in crops to decrease consumptive use	4
		Irrigation Scheduling	4

Management

Sub-Category	Location, General Description	Project Description	Group
Administrative: WSEO	Review of Beneficial Uses		4
	Abandonment of Unused Water Rights		4

	Development and Admin. of Augmentation Plans		2
Cultural or Religious Management	Water use for cultural purposes	Coordinated Releases	1
	Water use for religious purposes	Coordinated Releases	1
Administrative: USBR	Revised Reservoir Operations Schedule	Boysen Reservoir - Lower Winter Releases	3
		Boysen Reservoir - Higher Winter Releases	3

Conjunctive Use

Sub-Category	Location, General Description	Project Description	Group
Storage and Delivery Options	Lined Gravel Pits nr. River	Opportunities near Worland, Greybull and Cody	3
	Aqifer Storage and Retrieval	Recharge of alluvial system along Bighorn River	4
		Recharge of alluvial system along Upper Wind R.	2

Basin Transfers

Sub-Category	Location, General Description	Project Description	Group
Transbasin Diversions(In-Basin)	Clarks Fork to Greybull River	Pipeline	1
	Wood River to Gooseberry Creek	Excess storage in Sunshine Res. And pipeline	2
	Wood River to Cottonwood/Grass Creek	Excess storage in Sunshine Res. And pipeline	2
Transbasin Diversions(Out-of-Basin)	Transfer to Colorado River Basin	Pipeline and Reservoir	4
	Transfer to North Platte Basin	Pipeline and Reservoir	3

Environmental and Recreation

Sub-Category	Location, General Description	Project Description	Group

Fishing/Environmental/ Rafting	In Stream or Minimum Flows		1
	Minimum Reservoir Pool		1
	River Restoration/ Habitat Improvement		2
Recreation and Tourism	Golf Courses		3
	Whitewater Parks		3
	Public Access		4

Development of New Uses

Sub-Category	Location, General Description	Project Description	Group
Municipal/Industrial	Bottled Water		1
	In-Situ Uranium		4
	Hydropower		4
	Fossil Fuels Power Generation	Wind River Reservation	4
		Grass Ck./Kirby Ck. Near Winchester	4
Agricultural	New Lands to Irrigation	Westside Irrigation Project, Washakie County	1
		Riverton East	1
		North Crowheart	2
		South Crowheart	2
		Bighorn Flats	3
	Improved Distribution of Stock Water	BLM Lands west of Big Trails	2
		Eastern Wind River Basin	3
		Muskrat Creek, Poison Creek, and Badwater Creek	3
		Kirby Creek, Hot Springs County	3
Other Uses	Dust abatement at Buffalo Bill Res.		2

Storage Projects	Location	Capacity (Af/y)	Rank
Big Wind River and tributaries above confluence with Little Wind River	Bear Creek	30,500	2
	Brooks Lake	24,500	1
	Bull Lake Dam Enlargement	48,000	1
	Bull Lake Creek No. 1	96,700	2
	Bull Lake Creek No. 2	63,700	1
	Bull Lake Creek No. 3	1,200	2
	Bull Lake Creek No. 4	159,000	1
	Caldwell Creek	45,000	2
	Crow Creek No. 1	36,060	3
	Crow Creek No. 2	43,000	3
	Crowheart No.1	106,701	1
	Crowheart No.2	7,500	2
	Dinwoody Creek No. 1	16,500	1
	Dinwoody Creek No.2	35,000	2
	Dinwoody Lake Enlargement	82,580	2
	Dinwoody Re-Regulation No. 1	40	3
	Dinwoody Re-Regulation No. 2	2,200	2
	Dry Creek No. 1	4,300	3
	Dry Creek No. 2	0	4
	Dry Creek No. 3	22,508	3
	Dry Creek No. 4	116,000	3
	Dry Creek No. 5	0	4
	Dunoir Creek	150,000	2
	Horse Creek	30,000	3
	Kinnear	8,000	2
	Kinnear Reservoir	7,102	1
	LeClair Warm Springs	3,000	2
	Meadow Creek	5,800	4
	Meadow Creek Re-Regulation No. 4	19	3
	Mud Lake	26,208	2
	Ocean Lake Enl	40,400	1
	Off-Channel (site 1)	870	3
	Off-Channel (site 2)	4,200	3
	Off-Channel (site 3)	870	3
	Off-Channel (site 7)	1,850	1
	Passup Creek	4,300	4
	Pilot Butte	0	4
	Red Creek No. 1	2,800	4
	Red Creek No. 2	2,500	4
	Re-Regulation No.3	85	4
	Sand Draw No. 1	27,000	2
	Sand Draw No. 2	40,000	2

Storage Projects Cont.	Location	Capacity	Rank
	Steamboat	36,000	1
	Tipperay	36,312	3
	Torrey Creek	24,900	2
	Torrey Lake	33,000	2
	Warm Springs Creek	5,000	2
	Wiggins Fork No. 1	325,000	2
	Wiggins Fork No. 2	270,000	2
	Willow Creek No. 1	45,000	4
	Wind River Blue Holes	375,000	1
	Wind River East Fork No. 1	103,000	2
	Wind River East Fork No. 2	25,000	3
	Wind River East Fork No. 3	31,000	2
	Wind River East Fork No. 4	53,500	3
	Wind River East Fork No. 5	68,443	2
	Wind River East Fork No. 6	41,000	3
	Wind River East Fork No. 7	122,560	3
	Wind River No. 1	113,000	1
	Wind River No. 2	112,000	1
	Wind River No. 3	230,000	1
	Wind River No. 4	195,776	1
	Wind River No. 5	62,650	1
	Wind River No. 6	70,494	1
	Wind River Phase 1	133,950	1
Little Wind River and tributaries (excluding Popo Agie River and Beaver Creek)	Grave Lake	4,500	3
	Little Wind River No. 1	22,600	1
	Little Wind River No. 2	55,080	2
	Little Wind River No.	55,080	2
	Little Wind River North Fork No. 1	16,500	3
	Little Wind River North Fork No. 2	14,800	2
	Little Wind River North Fork No. 3	0	3
	Mill Creek	3,900	3
	Raft Lake	90,000	3
	Ray Lake Enl.	41,650	1
	Sage Creek No. 1	11,700	3
	Sage Creek No. 2	3,030	1
	Sage Creek South Fork No. 1	10,860	3
	Sage Creek South Fork No. 2	12,300	3
	Sage Creek South Fork No. 3	35,000	3
	Sharp Nose Draw No. 1	2,300	1
	Sharp Nose Draw No. 3	8,500	1

Storage Projects Cont.	Location	Capacity	Rank
	South Fork Little Wind River No. 1	144,000	2
	South Fork Little Wind River No. 3	13,500	2
	South Fork Little Wind River No. 4	16,300	2
	South Fork Little Wind River No. 2	56,430	1
	St. Lawrence Creek	10,000	3
	Trout Creek No. 1	8,085	3
	Trout Creek No. 2	12,400	4
Popo Agie River	Bills Park	0	3
	Gill Park	710	2
	Little Popo Agie River	79,000	2
	Louis Lake	8,014	2
	Middle Popo Townsend	0	3
	No. 53 (not named)	9,000	2
	North Popo Agie River	103,000	3
	Off-Channel (site 5)	2,940	1
	Off-Channel (site 6)	2,400	1
	Onion Flats	10,000	1
	Pete's Lake	762	2
	Popo Agie River No. 4	102,336	2
	Popo Agie River No. 1	18,900	1
	Popo Agie River No. 2	38,781	2
	Popo Agie River No. 3	102,336	2
	Sand Hills	20,930	1
	Sharp Nose Draw No. 2	15,336	1
	Surrel Creek No. 1	9,000	2
	Surrel Creek No. 2	16,688	1
	Willow Creek No.2	9,500	1
Beaver Creek (trib. Little Wind River)	Batrum Gap No. 4	34,615	2
	Beaver Creek No. 1	8,820	3
	Beaver Creek No. 2	700	4
	Beaver Creek No. 3	1,200	3
	Beaver Creek No.4	27,324	2
	Off-Channel (site 4)	4,880	1
	Smith and Springolf	426	4
Kirby Draw	Kirby Draw	16,000	4
Muskrat Creek	King Gorm	5,390	4
	Muskrat Conant	2,039	4
	Queen Thyra	1,235	4
Badwater Creek	Badwater Creek (site 4)	1,770	4
	Okie	217	4
	Snyder Creek Detention	347	4
	Waterworks No. 3	211	4

Storage Projects Cont.	Location	Capacity	Rank
Buffalo Creek trib. Bighorn River	Buffalo Creek	2,700	3
Kirby Creek	Kirby	3,090	3
Bighorn River	Kirby	130,000	2
No Water Creek	Fruitland No. 1	7,245	2
	Fruitland No. 2	5,318	2
	Fruitland No. 4	1,050	3
Nowood River	Big Trails	18,500	4
	Medicine Lodge	2,250	4
	Nowood River	175,000	4
	Paintrock	1,300	4
	Solitude	8,570	4
	Sumit	5,820	3
	Tensleep Meadows	13,490	4
	Tensleep Meadows	13,490	4
	West Tensleep Lake	1,180	4
	Wilson No. 1	386	2
	Wilson No. 2	379	2
Shell Creek	Beaver Creek (Coyote Basin)	1,385	2
	Moberly-Stoddard	248	2
	Moraine Creek No. 1	1,150	2
	Shell Canal	2,100	3
	Shell Creek Lake	2,010	3
East Bighorn Lake Tributaries	Bethwren	1,310	4
	Crystal Creek (not named)	644	3
	Porcupine Creek	14,660	4
	Willis	2,130	3
Fivemile Creek	Five Mile Creek No.1	1,800	3
	Five Mile Creek No.2	7,776	3
	Five Mile Creek No.3	2,100	3
	Maverick Spring Draw	7,100	4
	Ocean Lake	41,931	1
	Teapot Gulch No. 1	2,000	3
	Teapot Gulch No. 2	5,022	4
Muddy Creek	Blue Draw	23,150	3
	Dry Muddy Creek	28,000	4
	East Fork Sheep Creek	3,900	4
	Muddy Creek No. 1	10,500	3
	Muddy Creek No. 2	34,000	3
	Muddy Creek No. 3	57,344	3
	Sagwup Draw No. 1	28,900	4
	Sagwup Draw No. 2	25,895	4
	Sheep Creek	16,200	3

Storage Projects Cont.	Location	Capacity	Rank
	Shotgun Creek No.1	2,700	4
	Shotgun Creek No.2	7,600	4
	W. Fork Sheep Creek	29,128	3
Cottonwood Creek trib. Boysen Reservoir	Blue Holes	351,000	4
	Cottonwood Creek	1,500	4
	Cottonwood No. 1	21,178	4
	Cottonwood No. 2	21,178	4
Owl Creek	Dempsey	1,070	1
	Mountain View	5,830	1
	Mud Creek North Fork	4,300	3
	Mud Creek North Fork	4,300	3
	North Fork Owl Creek	8,700	3
	Owl Creek Basin	5,230	3
	Owl Creek Irrigation	23,270	2
	Owl Creek South Fork	46,500	2
	Owl Creek South Fork	46,500	2
	Owl Creek South Fork No. 1	22,680	3
	Owl Creek South Fork No. 2	20,090	3
	Owl Creek South Fork Trib.	3,200	1
	Pumpkin Draw	2,000	1
	Shotgun Creek	2,700	4
	South Fork Owl Creek	15,100	3
Gooseberry Creek	Buffalo Creek	145,000	2
	Farmers	14,510	1
	Gooseberry Creek	3,690	2
	Gooseberry Creek	3,690	2
	Gooseberry No. 1	1,770	2
	Gooseberry No. 2	8,500	2
	Little Buffalo Basin	75,810	2
Fifteen Mile Creek	Fifteen Mile Creek	46,080	2
Elk Creek	Elk Creek Valley	1,140	3
Greybull River	Alpha Sandstone	579	2
	Grey Bull River	84,200	4
	Junietta	1,280	3
	Lake McKinney No. 2	202	2
	Rawhide Creek	34,738	4
	Rawhide Creek	34,738	4
	Snyder Draw	2,240	2
	Spring Creek	64,700	4
	Thayer No. 1	639	3
Dry Creek	Bench Canal	299	2
	Lithomsen	1,960	3

Storage Projects Cont.	Location	Capacity	Rank
	Oregon Basin	382,950	3
	Sage Creek	1,080	4
	Sage Creek	1,080	4
	Sage Creek Coulderwiley	2,060	3
	Thomsen	1,010	3
Clarks Fork River	Badger Basin	69,276	4
	Bald Ridge	14,600	3
	Clark	30,400	4
	Clarks Fork	750,000	4
	Clarks Fork	522,850	4
	Hunter Mountain	130,000	3
	Lagoon Lake	1,320	3
	Lake Creek	5,100	4
	Sunlight	50,000	4
	Thief Creek	200,000	3
Shoshone River and Tributaries	Beck Lake	1,000	4
	Bliss Creek Meadows	0	4
	Cody Canal	1,210	4
	Goff	663	3
	Holden	9,900	3
	Melvina Lake	937	4
	Melvina Lake	936	4
	Needle Mountain	100,000	4
	Oregon Basin (closed basin)	382,950	3
	Sage Creek	1,082	4
	Sage Creek (SCS Site No. 1)	1,580	4
	Skull Creek	641	4
	Sulphur Creek	18,480	4
	Wall Mountain	50,000	4

Appendix B

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