Final Report

Upper Green River Westside Storage Study, Level II

Submitted to:
Wyoming Water Development Commission
and
Upper Green River Joint Powers Water Board

Submitted by:
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In association with:
Leonard Rice Engineers, Inc.

February 20, 2009
I hereby certify that all portions of this report were prepared by me or under my direct supervision, and that I am a duly Licensed Professional Engineer under the laws of the State of Wyoming.

Douglas M. Yadon

Date: February 16, 2009  Lic. No.: PE-4650
Table of Contents

Certification Page
Table of Contents

Page

1.0 Introduction ................................................................................................................................... 1
  1.1 Purpose and Scope .................................................................................................................... 1
  1.2 Authorization .......................................................................................................................... 2
  1.3 Responsibility and Acknowledgements .................................................................................. 2
  1.4 Project Meetings and Conference Calls .............................................................................. 2

2.0 Literature and Model Review ....................................................................................................... 3
  2.1 Overview .................................................................................................................................. 3
  2.2 Project Geographic Information System (GIS) ........................................................................ 3
  2.3 Model Review .......................................................................................................................... 4

3.0 Access ............................................................................................................................................ 5
  3.1 Land Ownership ..................................................................................................................... 5
  3.2 Access Permission .................................................................................................................. 5

4.0 Identification of Potential Water Supply Project Alternatives ................................................... 5
  4.1 Approach and Methodology ................................................................................................... 5
  4.2 Identified Alternative Sites ..................................................................................................... 7
    4.2.1 Existing Reservoirs ............................................................................................................ 7
    4.2.2 Previously Identified Storage Sites .................................................................................. 7
    4.2.3 Newly Identified Alternatives ......................................................................................... 7
  4.3 Characterization of Alternatives ............................................................................................ 8
  4.4 Screening of Alternatives ....................................................................................................... 8
  4.5 Preferred Water Supply Project Alternatives ......................................................................... 13
  4.6 Potential Secondary (Multiple) Benefits of Storage ............................................................... 17

5.0 Alternatives Analysis ..................................................................................................................... 17
  5.1 Refine Baseline Irrigation Shortages ......................................................................................... 17
    5.1.1 Model Network ................................................................................................................ 18
    5.1.2 Base Flows ....................................................................................................................... 19
    5.1.3 Water Rights ..................................................................................................................... 21
    5.1.4 Refined Baseline Irrigation Shortages ............................................................................. 21
  5.2 Model Simulation with Preferred Alternatives ......................................................................... 22
    5.2.1 Alternative 1 - Horse Creek/Cottonwood Creek Storage .............................................. 22
    5.2.2 Alternative 2 - South Cottonwood Creek Storage ......................................................... 23
    5.2.3 Alternative 3 - North Piney Creek Storage ..................................................................... 23
    5.2.4 Alternative 4 – South/Middle Piney Creek Storage ...................................................... 24
5.2.5 Alternative 5 – Pumping to Lower Piney Creek Subbasins from Green River ......................................................... 24
5.2.6 Alternative 6 – Combination of Alternatives 1-5........................................ 24
5.2.7 Modeling Evaluation Summary, Conclusion and Recommendation.... 25

6.0 Preliminary Geotechnical Investigation .............................................................. 25
6.1 Geologic/Geotechnical Conditions - Overall Study Area ................................. 25
6.1.1 Topography......................................................................................... 25
6.1.2 Soils.................................................................................................... 26
6.1.3 Surficial Geologic Units....................................................................... 26
6.1.4 Bedrock Units ..................................................................................... 28
6.1.5 Structure ............................................................................................. 30
6.1.6 Landslides/Slope Instability................................................................. 31
6.2 Seismotectonics............................................................................................. 32
6.2.1 Known and Potentially Active Faults ................................................... 32
6.2.2 Seismicity............................................................................................ 33
6.2.3 Deterministic Site Ground Motions...................................................... 33
6.2.4 Random Earthquakes ......................................................................... 33
6.2.5 Probabilistic Site Ground Motions ....................................................... 34
6.3 Geologic/Geotechnical Conditions - Preferred Water Supply Alternatives .... 34
6.3.1 Alternative 1 – Geologic/Geotechnical Conditions............................... 34
6.3.2 Alternative 2 – Geologic/Geotechnical Conditions............................... 37
6.3.3 Alternative 3 – Geologic/Geotechnical Conditions............................... 39
6.3.4 Alternative 4 – Geologic/Geotechnical Conditions............................... 40
6.3.5 Alternative 5 – Geologic/Geotechnical Conditions............................... 42

7.0 Environmental and Permitting Issues ................................................................. 43
7.1 Environmental Considerations........................................................................ 43
7.1.1 Preliminary Consultations ................................................................... 43
7.1.2 Animal and Plant Resources............................................................... 44
7.1.3 Wetland Resources............................................................................. 47
7.2 Permitting and Mitigation Process Evaluation ................................................. 48
7.2.1 NEPA Compliance And Documentation .............................................. 49
7.2.2 Permitting/Clearances/Approvals ........................................................ 51
7.2.3 Mitigation ............................................................................................ 54

8.0 Archaeological Investigation................................................................................ 55

9.0 Conceptual Level Designs.................................................................................... 56
9.1 Key Design Considerations ............................................................................ 56
9.1.1 Anticipated Geologic Conditions ......................................................... 56
9.1.2 Flood Hydrology and Spillway Sizing .................................................. 57
9.2 Conceptual Design Methodology.................................................................... 58
9.3 Alternative 1 – Horse Creek/Cottonwood Creek Storage ............................. 59
9.3.1 Overview............................................................................................. 59
9.3.2 Reservoir ............................................................................................ 60
9.3.3 Supply Canals........................................................................................ 60
9.3.4 Delivery Canals ................................................................................... 60
9.3.5 Dams .................................................................................................. 61
9.3.6 Service and Emergency Spillways ...................................................... 64
9.3.7 Outlet Works ....................................................................................... 64
9.3.8 Miscellaneous Appurtenances ............................................................ 65
9.3.9 Access Road(s)................................................................................... 65

9.4 Alternative 2 – South Cottonwood Creek Storage ........................................... 65
9.4.1 Overview............................................................................................. 65
9.4.2 Reservoir ............................................................................................ 66
9.4.3 Delivery Canal ..................................................................................... 66
9.4.4 Dams .................................................................................................. 66
9.4.5 Service and Emergency Spillways ...................................................... 69
9.4.6 Outlet Works ....................................................................................... 70
9.4.7 Access Road(s)................................................................................... 70

9.5 Alternative 3 – North Piney Creek Storage ..................................................... 71
9.5.1 Overview............................................................................................. 71
9.5.2 Reservoir ............................................................................................ 71
9.5.3 Dam .................................................................................................... 71
9.5.4 Service and Emergency Spillways ...................................................... 74
9.5.5 Outlet Works ....................................................................................... 75
9.5.6 Access Road(s)................................................................................... 75

9.6 Alternative 4 – South/Middle Piney Creek Storage ......................................... 75
9.6.1 Overview............................................................................................. 75
9.6.2 Reservoir ............................................................................................ 76
9.6.3 Delivery Canal ..................................................................................... 76
9.6.4 Dam .................................................................................................... 76
9.6.5 Service and Emergency Spillways ...................................................... 79
9.6.6 Outlet Works ....................................................................................... 80
9.6.7 Access Road(s)................................................................................... 80

9.7 Alternative 5 – Pumping to Lower Piney Creek Subbasins from Green River . 81
9.7.1 Overview............................................................................................. 81
9.7.2 Green River Diversion ......................................................................... 81
9.7.3 Pumping Station .................................................................................. 81
9.7.4 Pressure Pipeline ................................................................................ 81
9.7.5 Delivery Canal ..................................................................................... 82
9.7.6 Access Road(s)................................................................................... 82

9.8 Alternative 6 – Combined Alternative .............................................................. 82

10.0 Cost Estimates ...................................................................................................... 82
10.1 Methodology ................................................................................................. 82
10.2 Results ............................................................................................................. 83

11.0 Economic Analysis ............................................................................................... 84
11.1 Benefits Analysis ............................................................................................ 84
11.1.1 Indirect Irrigation Benefits ................................................................... 86
11.2 Ability to Pay Analysis .................................................................................... 86
11.3 Financing Under WWDC Guidelines ............................................................... 87
11.4 Potential Funding Sources ........................................................................... 88
  11.4.1 Wyoming Water Development Program .............................................. 89
  11.4.2 Local Agencies .................................................................................... 91
  11.4.3 Other State Agencies .......................................................................... 91
  11.4.4 Federal Agencies ................................................................................ 94
  11.4.5 Non-Profit and Other Organizations .................................................... 96
12.0 Conclusions and Recommendations ............................................................. 97
  12.1 Conclusions ............................................................................................. 97
  12.2 Recommendations .................................................................................. 99
13.0 References ....................................................................................................... 100

List of Tables

Table 3.1-1 Land Ownership
Table 3.2-1 Land Owner Contacts
Table 4.3-1 Alternative Surface Water Storage Sites - Characterization and Screening Matrix
Table 4.4-1 Yearly Average Flows for the Period 1971-2006
Table 4.5-1 Detailed Characterization of Preferred Water Supply Alternatives
Table 5.1-1 Upper Green River Basin Westside Tributaries, Average Annual Baseline Irrigation Shortages (1971-2006)
Table 5.2-1 Upper Green River Basin Westside Tributaries, Average Annual Irrigation Shortage Reductions (1971-2006)
Table 5.2-2 Summary of Alternative 1 - Horse Creek/Cottonwood Creek Storage
Table 5.2-3 Summary of Alternative 2 - South Cottonwood Creek Storage
Table 5.2-4 Summary of Alternative 3 - North Piney Creek Storage
Table 5.2-5 Summary of Alternative 4 - South/Middle Piney Creek Storage
Table 5.2-6 Summary of Alternative 5 - Pumping to Lower Piney Creek Subbasins from Green River
Table 6.2-1 Quaternary Fault Data
Table 10.2-1 Summary of Estimated Costs of Alternatives
Table 10.2-2 Alternative 1 - Horse Creek/Cottonwood Creek Storage, Conceptual-Level Cost Estimate
Table 10.2-3 Alternative 2 - South Cottonwood Creek Storage, Conceptual-Level Cost Estimate
Table 10.2-4 Alternative 3 - North Piney Creek Storage, Conceptual-Level Cost Estimate
Table 10.2-5 Alternative 4 - South/Middle Piney Creek Storage, Conceptual-Level Cost Estimate
Table 10.2-6 Alternative 5 - Pumping to Lower Piney Creek Subbasins from Green River, Conceptual-Level Cost Estimate
Table 10.2-7 Alternative 6 - Combination of Alternatives 1-5, Conceptual-Level Cost Estimate
Table 10.2-8 Cost Estimate Detail
Table 11.2-1 Summary of Maximum Potential Benefits of Project Alternatives
Table 11.3-1A Ability to Pay Debt Service - 67% Grant
Table 11.3-1B Ability to Pay Debt Service - 75% Grant
Table 11.3-1C  Ability to Pay Debt Service - 90% Grant
Table 11.3-2A  Ability to Pay Debt Service (67% Grant) and OM&R
Table 11.3-2B  Ability to Pay Debt Service (75% Grant) and OM&R
Table 11.3-2C  Ability to Pay Debt Service (90% Grant) and OM&R
Table 11.3-3A  Annual Debt Service Costs - Per Acre Served and Per Acre-Foot Yield
Table 11.3-3B  Annual OM&R Costs - Per Acre Served and Per Acre-Foot Yield
Table 11.3-3C  Annual Debt Service and OM&R Costs - Per Acre Served and Per Acre-Foot Yield
Table 11.4-1  Potential Funding Sources

List of Figures

Figure 1.1-1  Study Area
Figure 3.1-1  Land Ownership
Figure 4.2-1  Alternative Surface Water Storage Sites - Long List
Figure 4.4-1  Alternative Surface Water Storage Sites - Short List
Figure 4.5-1  Preferred Water Supply Alternatives
Figure 5.1-1  Model Network Diagram, Upper Green River - Westside Storage Study, Water Resources Planning Operational Model
Figure 5.1-2  Gage Stations
Figure 5.2-1  Model Network Diagram With Alternatives, Upper Green River - Westside Storage Study, Water Resources Planning Operational Model
Figure 5.2-2  Alternative 1, Haines Flat Reservoir Simulated Storage Contents
Figure 5.2-3  Alternative 2, Mickelson Creek Reservoir Simulated Storage Contents
Figure 5.2-4  Alternative 3, Whiskey Creek Reservoir Simulated Storage Contents
Figure 5.2-5  Alternative 4, Fish Creek Reservoir Simulated Storage Contents
Figure 5.2-6  Alternative 5, Green River Pump Simulated Diversion
Figure 5.2-7A  Alternative 6, Haines Flat Reservoir Simulated Storage Contents
Figure 5.2-7B  Alternative 6, Mickelson Creek Reservoir Simulated Storage Contents
Figure 5.2-7C  Alternative 6, Whiskey Creek Reservoir Simulated Storage Contents
Figure 5.2-7D  Alternative 6, Fish Creek Reservoir Simulated Storage Contents
Figure 5.2-7E  Alternative 6, Green River Pump Simulated Diversion
Figure 6.1-1  Topography
Figure 6.1-2A  Surficial Geology
Figure 6.1-2B  Surficial Units Key
Figure 6.1-3A  Bedrock Geology
Figure 6.1-3B  Bedrock Units Key
Figure 6.1-4A  Geologic Map
Figure 6.1-4B  Geologic Units Key
Figure 6.1-5  Landslides
Figure 6.2-1  Quaternary Faults
Figure 6.2-2  Historic Seismicity
Figure 6.2-3  Peak Horizontal Ground Acceleration
Figure 6.3-1A  Alternative 1 - Geologic Map

Upper Green River Westside Storage Study, Level II
Wyoming Water Development Commission
Figure 6.3-1B  Alternative 1 – Haines Flat Dams and Reservoir Site Geology
Figure 6.3-2  Alternative 2 - Geologic Map
Figure 6.3-3  Alternative 3 - Geologic Map
Figure 6.3-4  Alternative 4 - Geologic Map
Figure 6.3-5  Alternative 5 - Geologic Map
Figure 7.1-1  Species of Concern
Figure 7.1-2  Sage Grouse Leks
Figure 7.1-3A  Crucial Habitat - Antelope
Figure 7.1-3B  Crucial Habitat - Elk
Figure 7.1-3C  Crucial Habitat - Moose
Figure 7.1-3D  Crucial Habitat - Mule Deer
Figure 7.1-4A  Parturition - Antelope
Figure 7.1-4B  Parturition - Elk
Figure 7.1-4C  Parturition - Moose
Figure 7.1-4D  Parturition - Mule Deer
Figure 7.1-5  NWI Wetlands
Figure 8.1-1  Historical Sites and Trails
Figure 9.3-1  Alternative 1 - Horse Creek/Cottonwood Creek Storage Facilities Layout
Figure 9.3-2  Alternative 1 - Haines Flat Reservoir, Dam and Appurtenances Layout
Figure 9.3-3A  Alternative 1 - Haines Flat North Dam Profile and Maximum Section
Figure 9.3-3B  Alternative 1 - Haines Flat South Dam Profile and Maximum Section
Figure 9.4-1  Alternative 2 - South Cottonwood Creek Storage Facilities Layout
Figure 9.4-2  Alternative 2 - Mickelson Creek Reservoir, Dam and Appurtenances Layout
Figure 9.4-3  Alternative 2 - Mickelson Creek Dam Profile and Maximum Section
Figure 9.5-1  Alternative 3 - North Piney Creek Storage Facilities Layout
Figure 9.5-2  Alternative 3 - Whiskey Creek Reservoir, Dam and Appurtenances Layout
Figure 9.5-3  Alternative 3 - Whiskey Creek Dam Profile and Maximum Section
Figure 9.6-1  Alternative 4 - South/Middle Piney Creek Storage Facilities Layout
Figure 9.6-2  Alternative 4 - Fish Creek Reservoir, Dam and Appurtenances Layout
Figure 9.6-3  Alternative 4 - Fish Creek Dam Profile and Maximum Section
Figure 9.7-1A  Alternative 5 - Green River Pumping Station, Pipeline and Canal (Aerial Photo Base)
Figure 9.7-1B  Alternative 5 - Green River Pumping Station, Pipeline and Canal (Topographic Base)

List of Appendices

Appendix A  Meetings
Appendix B  GIS Inventory
Appendix C  Seismotectonics
Appendix D  Environmental Permitting
Appendix E  Technical Modeling Memo
1.0 Introduction

1.1 Purpose and Scope

The purpose of the Upper Green River Westside Storage Study, Level II is to identify and evaluate preferred water supply alternatives to address existing late season and dry year irrigation water shortages within the Upper Green River Westside study area (see Figure 1.1-1 – Study Area).

The scope of this study is summarized as follows:

- Review and compile available information on existing and potential new water storage dams and reservoirs in the study area.
- Review previous hydrologic and water rights models and modeling results relevant to this study.
- Identify and screen alternative surface water dam and reservoir storage sites and other potential surface water supply alternatives (e.g., direct pumping) in the study area.
- Perform hydrologic analyses and hydrologic/water rights modeling as necessary to support selection and analysis of preferred surface water supply alternatives.
- Evaluate geologic and seismotectonic conditions in the study area to support screening of surface water supply alternatives and conceptual design and costing of preferred alternatives.
- Assess the potential environmental issues or constraints that may affect the preferred alternatives identified; and characterize the permits/clearances and any associated environmental studies and/or mitigation that may be required for those alternatives.
- Prepare conceptual-level designs of major components of the preferred water supply alternatives, including dams, spillways, outlet works, supply/delivery canals, pumping stations, etc.
- Develop conceptual-level estimates of the construction and other project costs of the preferred water supply alternatives identified in the screening study.
- Perform a conceptual-level economic analysis of the preferred project alternatives, including an evaluation of a sponsoring entity’s ability to pay and
the benefit versus cost of each project. Although not required by the scope of work, potential funding sources are also identified and evaluated.

The scope of this study as summarized above is fully responsive to the Scope of Services in Exhibit “A” of the Consultant Contract for Services.

1.2 Authorization

This project was authorized by Consultant Contract for Services No. 05SC0293264 effective June 7, 2007 between the Wyoming Water Development Commission (WWDC) and Short Elliott Hendrickson Inc. (SEH). The official contractual representative for the WWDC was Michael Purcell, Director of the Wyoming Water Development Office (WWDO). Jason Mead served as the WWDO Project Manager and primary point of contact for SEH on both technical and administrative matters.

Amendment No. 1 to the Consultant Contract for Services effective January 1, 2008 added Task 15 – Technical Modeling Memo to the original scope of services. Work under this amendment was performed solely by subconsultants Boyle Engineering Corporation, subsequently Boyle/AECOM (Boyle) and LRE, and is separately documented in a report by Boyle and LRE (2008). A copy of this report is included in Appendix E – Technical Modeling Memo. Amendment No. 2 effective June 5, 2008 extended the Contract expiration date to December 31, 2008. Amendment No. 3 effective December 16, 2008 further extended the Contract expiration date to June 30, 2009.

1.3 Responsibility and Acknowledgements

SEH’s Project Manager for this study was Douglas M. Yadon, Wyoming PE No. 4650, and except as noted below, all engineering work on the project was performed under his responsible charge. Except as described herein, the work for this project was performed by Mr. Yadon and other selected SEH staff including William R. Kelly, PE, Alan C. Jewell, PE, Aaron S. Ritter, EIT, and Christopher Wichmann. Leonard Rice Engineers, Inc. (LRE) of Denver, Colorado performed the hydrologic and water rights modeling for the project, and assisted in completion of the water rights task. The work by LRE was led by Rick Parsons, assisted by Kelly Close.

Several landowners, irrigators and ranchers, WWDC Commissioner Dan Budd, staff of the Wyoming State Engineers Office in Cokeville and Cheyenne (Jade Henderson and Sue Lowry), the Wyoming Department of Environmental Quality in Cheyenne (Vern Stelter), the U.S. Army Corps of Engineers Cheyenne office (Tom Johnson), and the BLM Pinedale office (Kellie Roadifer) all provided valuable information and assistance during the project. The participation and guidance of the members of the project sponsor Upper Green River Joint Powers Water Board (UGRJPWB) is especially acknowledged.

1.4 Project Meetings and Conference Calls

During the course of the study a total of three (3) project-specific meetings were held with the WWDO, UGRJPWB, and other project stakeholders. These included the scoping meeting on June 20, 2007, a project meeting on September 30, 2008, and a results presentation meeting on November 14, 2008. A status memorandum was prepared and submitted to the JPB for their review at their August 13, 2008 regular Board meeting. Information presented at these meetings and attendance lists for each meeting attended by SEH staff are provided in Appendix A - Meetings. In addition to these project-specific meetings, SEH attended and participated in a meeting
sponsored by WWDO on hydrologic and water rights modeling relevant to the needs of this study. This meeting was held in the WWDO Cheyenne office on November 29, 2007.

A project-specific conference call regarding project modeling was held on August 25, 2008. Participants included Jason Mead/WWDO, Dan Budd/WWDC, Ed Boe/WSEO, Doug Yadon and Bill Kelly/SEH, and Rick Parsons/LRE. Several other informal project-specific conference calls were held between SEH/LRE and WWDO staff during the course of the study.

2.0 Literature and Model Review

2.1 Overview

Available relevant and applicable background information on the key topics and tasks of this Level II study was identified and compiled. This included, but was not necessarily limited to seeking information from the following sources during the course of this study and/or during work on other recent similar WWDC projects:

- U.S. Bureau of Land Management (BLM)
- U.S. Geological Survey (USGS)
- U.S. Department of Agriculture/Natural Resources Conservation Service (NRCS)
- U.S. Fish and Wildlife Service (FWS)
- Wyoming Water Development Commission/Office (WWDC/WWDO)
- Wyoming Department of Environmental Quality (WDEQ)
- Wyoming Game and Fish Department (WGFD)
- Wyoming State Engineer’s Office (WSEO)
- Wyoming Oil and Gas Conservation Commission (WOGCC)
- Wyoming State Geological Survey (WSGS)
- Wyoming Geographic Information Science Center (WyGISC)
- Sublette County Assessors Office

Information was acquired from these agencies and entities by one or more of the following methods: download from their internet site, acquisition of published materials from the agency/entity or libraries, telephone/email contacts, and personal visits. A comprehensive list of references to published information is provided in Section 13.0.

Knowledgeable landowners, ranchers, irrigators and other individuals in the project area were also contacted for information and/or access as appropriate.

The information gathered through these efforts formed the basis for all subsequent tasks.

2.2 Project Geographic Information System (GIS)

An important element of the overall data collection effort included compilation of a number of Geographic Information System (GIS) themes/coverages from a variety of sources. Note, however, that the project scope did not intend that a complete and comprehensive collation of all available spatial data be developed. Only those
readily available themes/coverages deemed pertinent to this Level II Study and those produced as part of this study were compiled. Existing relevant GIS themes/coverages were acquired from the following sources:

- Bureau of Land Management (BLM)
- United States Geological Survey (USGS)
- Wyoming Game & Fish
- Wyoming Geographic Information Science Center (WyGISC)
- Wyoming Natural Diversity Database (WYNDD)
- Wyoming Water Development Commission (WWDC)

Information collected from these sources and included in the set of project GIS themes/coverages in shapefile format includes, but is not limited to, the following:

- Hydrography
- Public Lands Survey (PLSS)
- Sage grouse lek buffer zones
- Historic trails
- NWI wetlands
- Property ownership parcels

In addition, selected geospatial information developed during the course of the study has been converted to shapefile format including the following:

- Potential reservoir locations
- Historical Earthquakes
- Model node locations
- Potential alternative access routes

The Project Data CD contains the GIS themes/coverages; an inventory of the GIS shapefiles is provided in Appendix B – GIS Inventory.

### 2.3 Model Review

As noted in Section 1.2, an evaluation of the appropriate hydrologic/water rights modeling methodologies and tools for varying purposes was performed under Task 15 of this study. As described for the generic case in the separate report documenting Task 15 (Boyle and LRE, 2008) and specifically for this project in Section 5.0, review of the available model choices confirmed the general applicability of the pre-existing StateMod model developed in the previous Level II study of the Upper Green River Basin (Kleinfelder, 2007). Numerous refinements, enhancements and corrections were made to the pre-existing model during the course of this study as described in Section 5.1. It is the conclusion of the study team, with the concurrence of WWDO, that the updated StateMod model provides an appropriately accurate representation of the overall hydrologic and water rights conditions, behavior and interactions for the purposes of this study. As discussed in Section 5.0 and summarized in Section 12.2, further refinement of the model (based on ongoing
studies by others and future data collection) is recommended should any of the preferred alternatives advance to the next phase of study.

3.0 Access
3.1 Land Ownership
The distribution of land ownership within the study area is shown on Figure 3.1-1 – Land Ownership and is summarized on Table 3.1-1 – Land Ownership. The source of the land ownership information is WyGISC and the Sublette County Assessor’s Office. Specific private land ownership information is included in the applicable GIS shapefile attributes included on the Project Notebook CD. Note, however, that owner contact information in the County Assessor’s GIS is not necessarily fully up to date and is sometimes in error.

3.2 Access Permission
Permission was sought for access to private lands at the sites and/or along the alignments of the major facilities/features of the preferred alternative water supply alternatives identified in Section 4.5. As summarized in Table 3.2-1 – Land Owner Contacts, permission was granted to visit the Alternative 3 Whiskey Creek Dam and Reservoir site on North Piney Creek and the Alternative 4 Fish Creek Dam and Reservoir site at the confluence of South Piney Creek and Fish Creek. Permission was not received to visit the Alternative 1 Haines Flat Dam and Reservoir site or the Alternative 2 Mickelson Creek Dam and Reservoir site. Access to the vicinity of Alternatives 1 and 2 facilities and to Alternative 5 facilities was made from public roads.

4.0 Identification of Potential Water Supply Project Alternatives
4.1 Approach and Methodology
The identification of potential water supply project alternatives consisted of a three phase approach: initial alternative identification, alternative characterization and finally, screening of alternatives. As discussed below, 69 alternatives (in a total of 91 variations) were ultimately identified in the initial phase, and because of this alternative characterization and alternative screening were conducted iteratively to most efficiently filter the "long list" of alternatives into a "short list", and ultimately, a set of preferred alternatives for conceptual design. Additionally, as screening criteria became more refined, additional searches for alternatives were sometimes conducted to potentially find improved alternates to previously identified alternatives. Thus, in practice, all three phases were conducted in part concurrently, progressively and iteratively.

The overall objective of this phase of the study was to identify a set of alternatives that provided the greatest degree of overall irrigation shortage reduction for the currently irrigated lands in the Horse Creek, Cottonwood Creek and Piney Creek drainages not already served by the Green River Canal. To meet this objective, alternatives were sought that would be able to most efficiently capture as much of the physically and legally available flows in these drainages as practical. Consideration was given to sites that could store available flows from and/or serve shortages in more than one of the main tributaries in the interest of best meeting overall needs. Offstream sites were preferred if locations with adequate potential capacity and feasible means of supply and delivery could be found. Some of the previous studies of storage in the Upper Green River Westside area have tended to focus on relatively smaller reservoirs sized and located to serve only a particular area or need.
Regardless, these sites were also considered if they could be enlarged to meet the more comprehensive shortage reduction that was the main objective of this study.

**Phase 1 - Initial Alternative Identification.** The initial identification of potential storage alternatives involved the following steps:

- Collect an inventory of information on existing reservoirs
- Review Wyoming State Engineers Office (WSEO) water rights and dams databases
- Review previous studies of storage potential in the Upper Green River basin
- Review additional alternatives identified in our proposal for this study
- Review topographic mapping digital aerial photography for favorable site locations and/or existing sites not otherwise already identified

For the initial phase, criteria were intentionally limited in their restrictions of selected sites; sites had to be located within the study area and have a relatively broadly defined storage capacity within the approximately 1,000 acre-foot to 80,000+ acre-foot range. As noted above, the smaller sites were mainly retained pending evaluation of the potential to enlarge the proposed storage capacity at the site. A relatively lesser emphasis was initially placed on such factors as geologic conditions, location of storage relative to supply and demand, and other factors. In all, 57 potential or existing storage facilities were identified, and more detailed information of the analysis is presented in Section 4.2.

**Phase 2 - Site Characterization.** The second phase of the process, characterization of the 57 alternatives identified in Phase 1, began by collecting and summarizing known information, if available, as well as relating sites to other concurrently collected information such as geologic and geotechnical conditions (Section 6.0), and legally available flows, downstream shortages and more refined target storage capacities (as described in Section 5.0). This phase of the identification of potential water supply alternatives was necessarily iterative and conducted in tandem with the third phase of the process (screening) described below. As more information about project needs and site conditions became available, a more refined and selective criteria for screening storage alternatives was developed based on that information. Detailed characterization of all 57 sites was intentionally avoided in favor of utilizing available budget resources to develop and pursue more thorough evaluations of the more promising alternatives. Further details of the site characterization process are described in Section 4.3.

**Phase 3 - Screening of Alternatives.** The third and final phase of the process, screening of the 57 alternatives identified in Phase 1, began by utilizing the information collected in Phase 2 to progressively sort the more promising alternatives as more information became available. As discussed above, this process was conducted concurrently with Phase 2. Depending on the quality of basin-specific results of the screening, a more detailed, but focused Phase 1 alternative identification was often performed to identify potentially improved alternates to the screened results. Further details of the site characterization process are described in Section 4.4.
4.2 Identified Alternative Sites
A total of 57 unique alternatives in a total of 91 variations were identified and included in this study, either as an enlargement of an existing reservoir, a site identified in a previous study, or as a newly identified site as discussed in the following subsections. All sites are shown on Figure 4.2-1 – Alternative Surface Water Storage Sites – Long List along with a coding to identify the original source of the site (existing sites in black, previously studied sites in blue, and sites newly identified as part of this study in red). Details of each site are discussed in Section 4.3.

4.2.1 Existing Reservoirs
A total of four existing reservoirs within the approximate general capacity ranges discussed in Section 4.1 were located during the alternative identification: Middle Piney Reservoir, Sixty-Seven Reservoir and McNinch Reservoirs No. 1 and No. 2. Middle Piney Reservoir is the subject of an ongoing WWDC study to examine dam safety, existing operations, and enlargement potential, and was included as an initial alternative site in this study. Upon preliminary considerations it was concluded that operation of the existing Middle Piney Reservoir for irrigation supply in the Middle Piney Creek subbasin could address some of the existing shortages. However, the amount of storage and effective yield that might be made available are not presently known pending completion of the ongoing Middle Piney Reservoir Study. In accordance with direction from WWDO staff, no further consideration was given to Middle Piney Reservoir in this study. Sixty-Seven Reservoir was found to have potential for enlargement at this level of study and was included as an alternative site. McNinch Reservoirs No. 1 and No. 2 were found not suitable for direct enlargement given their very small size in comparison with the much larger storage capacity desired in this study and these sites were not further considered.

4.2.2 Previously Identified Storage Sites
Several previous studies were found that included consideration of new surface water storage in the Upper Green watershed:

- States West, 2001, Green River Ground Water Recharge and Alternate Storage, Level I Project, WWDC, December 2001
- Kleinfelder, 2007, Upper Green Level II Study

A total of 33 sites were identified by these studies, with some sites covered by multiple studies and/or in multiple variations. No permits for abandoned or proposed new storage sites of significance were found in review of the WSEO databases.

4.2.3 Newly Identified Alternatives
Digital U.S. Geological Survey (USGS) 7.5-minute topographic mapping was reviewed as part of initial site identification utilizing DeLorme XMap® 5.0 GIS Editor software. Aerial photography available on Google Earth and color infrared
digital orthophoto quarter quadrangle (CIR DOQQ) aerial coverage were also reviewed and utilized. Potentially favorable dam sites were identified primarily based on site topography and location relative to potential source(s) of supply and areas of demand/shortage.

Employing the approach and methodology described above, a total of 36 new surface water dam and reservoir sites or alternatives were identified within the study area of the Upper Green River Westside study area (see Figure 4.2-1).

4.3 Characterization of Alternatives
A wide array of relevant information about the 57 initially selected alternative storage sites was compiled from the results of the various analyses described in this report, including basin hydrologic/water rights modeling analyses described in Section 5.0, geotechnical and geologic investigations described in Section 6.0, and from information on environmental and cultural resource issues identified as part of the work documented in Sections 7.0 and 8.0. Additional analyses, conducted as part of the work described in this section, included such items as order of magnitude quantity estimation, conflicting infrastructure identification, preliminary design inflow flood estimation (utilizing similar methodologies to those described later in Section 9.0), and other relevant evaluations and analyses.

The results of these wide-ranging analyses are compiled in summary form on Table 4.3-1 – Alternative Surface Water Storage Sites – Characterization and Screening Matrix. This table is derived from an Excel spreadsheet that links the compiled site information to a number of equations and algorithms that support the screening-level conceptual design and costing provided in the lower portions of the table (including and below the heading Dam Characteristics and Hydraulic Structures).

4.4 Screening of Alternatives
In tandem with collecting the information described in the previous section during the characterization of alternatives, a qualitative and/or semi-quantitative comparative ranking of selected parameters/conditions for each of the alternative sites was performed, the results of which are shown by the color-coding on Table 4.3-1. For multiple reasons, including the large number of alternatives, the differences in size, infrastructure, and associated source of supply, and the conceptual operations for each alternative and variant, and the multiple needs of the project, it is not feasible or appropriate to employ a direct, quantitative screening methodology as the basis to select one or more preferred alternatives. Rather, the data compiled and coding applied in Table 4.3-1 has been carefully reviewed to assess the relative degree to which each site may be impacted by various factors and how well the sites are suited to their intended roles.

Methodology for Screening to Initial Short List of Alternatives. During compilation of the comparative rankings, and concurrent with the collection of additional information from the geotechnical investigation as well as the basin modeling, several high-level themes emerged that could be utilized effectively to screen for the most promising “short list” of alternatives. Specifically, these themes are as follows:

- **Storage serving each major subbasin is necessary.** As discussed later in this section, preliminary basin modeling indicated that each subbasin (North and South Horse, North and South Cottonwood, and North, Middle and South Piney...
Creeks) would generally benefit from some amount of storage in the basin to
capture legally available flows (typically spring runoff) and release captured flow
later in the irrigation season or as carryover to subsequent drier years, if possible.
Thus, at least one or more alternatives should be identified to provide storage
and/or supplemental supply to each of the subbasins if/as possible.

- **In some cases, transfer of water between subbasins is beneficial.** As discussed
  later in this section, alternatives having the potential to balance water availability
  with water demand between subbasins have the potential to be more effective in
  addressing shortages, particularly where surplus legally available flows could
  be transferred from relatively water-rich subbasins such as Horse Creek and the
  Green River to relatively water-short subbasins such as Cottonwood and Piney
  Creeks.

- **More promising storage alternatives generally lie within a discernible
  North-South corridor.** Sites within the Wyoming Range (generally defined as
  sites lying within the Bridger-Teton National Forest) tend to exhibit generally
  less favorable characteristics for a variety of reasons, including: depending on
  location, many of these sites may miss opportunities to store available flows
  because they lie well above major stream confluences lower in the basin;
  permitting sites on Forest Service lands has the potential to be more challenging,
  lengthy and costly, particularly when alternate sites lower in the drainage are
  available; geologic and geotechnical conditions are overall less favorable as
  discussed in Section 6.0. Conversely, sites lying far downstream in the study
  area, while having the ability to capture much to most of the physically and
  legally available flow in the subbasin, miss opportunities to satisfy present
  demand and shortages by gravity release. While such reservoirs can sometimes
  be effective through exchange of demand upstream, alternatives that generally lie
  above the bulk of existing shortages are often more efficient and effective at
  addressing needs.

- **Economies of scale in larger reservoirs.** In general, economies of scale are
  typically present in reservoir construction. Generally, a single larger reservoir is
  more economical than two or more smaller reservoirs of similar total capacity for
  a variety of reasons, including: in the case of onstream reservoirs or offstream
  reservoirs with large contributing drainage basins, spillways are typically
  relatively expensive and comprise a greater proportion of the cost in smaller
  reservoirs; dams that form the reservoir generally require a seepage cutoff in the
  foundation that is not necessarily a function of dam height and therefore a
  seepage cutoff for a smaller dam can be nearly as costly as one for a larger dam
  retaining a greater capacity reservoir. Thus, wherever possible, a single large
  reservoir site was preferred if otherwise equivalent to a combination of smaller
  reservoirs.

**Short List of Alternatives.** The general observations listed above were fully utilized
in refining the general search criteria to identify the most promising "short list" of
alternatives from the originally identified 57 sites (91 variations). The initial step of
detailed screening (in conjunction with more detailed site characterization described
in the previous section) generally began to focus on selecting any or all alternatives
that met the following general location and topographic criteria where possible for
each subbasin:
Located generally at the base of the Wyoming Range or further east, preferably outside of the Bridger-Teton National Forest; and

Located above the bulk of existing shortages within a given subbasin; and/or

Enabled transfer of water from the Horse Creek subbasin or Green River basin to the Cottonwood and/or Piney Creek subbasins; with

Preferably at least one candidate storage reservoir meeting the above criteria in each subbasin (Piney, Cottonwood and Horse Creeks), or alternately one storage reservoir that could serve multiple subbasins.

More refined work on the basin planning (StateMod) model during the course of the study as described in Section 5.1 resulted in further refinement of model-estimated legally available flows in each subbasin relative to demand and shortages. This work allowed target storage capacities in each subbasin to be further refined to a narrower range between approximately 10,000 acre-feet and 50,000 acre-feet, depending on the subbasin. Additional key factors influencing the screening-level effort included reservoir capacity and dam size, new facilities necessary to supply water to a given reservoir and to deliver water from the reservoir, anticipated geological conditions, flood hydrology and the associated spillway sizing, and permitting and environmental considerations and mitigation. Particular attention was given to the 24 long-list sites classified herein as offstream versus onstream sites. In general, the offstream sites tend to have significantly less potential direct wetlands and wildlife habitat impact. However, they also tend to be located where conveyance of supply from the available flows on the more prolific tributaries and/or delivery of stored water to locations of shortages would be technically challenging and expensive.

Utilizing the above methodology, the following alternatives were screened into a "short list" as follows (see Figure 4.4-1 – Alternative Surface Water Storage Sites – Short List):

- Site #SEH-1 – North Horse Creek – This reservoir alternative would capture legally available flows on North Horse Creek. It is topographically situated to deliver water to users on North and South Horse Creeks directly and to the North Cottonwood Creek basin via canal. The site lies within the Bridger-Teton National Forest as shown on Figure 4.4-1.

- Site #SEH-14 – Horse Pasture Draw – This reservoir alternative is an onstream (South Horse Creek) version of a previously studied site (Site 16). The onstream version offers the ability to store the capacity of water being considered by this study; however, many other elements are similar. The site is topographically located to capture South Horse Creek directly, and North Horse Creek via canal as well as to provide releases to the Horse Creek basin, and a portion of North Horse Creek via canal. The reservoir is situated low enough that water cannot be delivered from the reservoir to North Cottonwood Creek without extensive tunneling through the ridge separating the two basins and/or pumping.

- Site #SEH-15 – Haines Flat – This reservoir alternative is an onstream (South Horse Creek) alternative lying upstream of Horse Pasture Draw. The site is topographically located to capture South Horse Creek directly, and North Horse and North Cottonwood Creeks via canal. It can provide releases to the Horse Creek basin, and a portion of North Horse Creek via canal, and also to the North Cottonwood basin. Utilizing a pump station and canal, it can deliver water to a portion of the South Cottonwood Creek basin as well.
Sites #SEH-5, SEH-7 – North Cottonwood Creek – These reservoir alternatives would capture legally available flows on North Cottonwood Creek. They are topographically situated to deliver water to users on North Cottonwood Creek directly and to a portion of the South Cottonwood Creek basin via a long canal over relatively challenging terrain. Both reservoirs could also utilize the pump station/canal alternative described above for the Haines Flat site to deliver water to South Cottonwood Creek. Both sites lie within or partially within the Bridger-Teton National Forest as shown on Figure 4.4-1.

Sites #15 – Mickelson Creek, SEH-8, 8a and 8b – South Cottonwood Creek – These reservoir alternatives would capture legally available flows on South Cottonwood Creek. They are topographically situated to deliver water to users on South Cottonwood Creek directly. While it is topographically feasible to provide supply of water to the reservoir via canal from North Cottonwood, canal routes involve either Forest Service land and rugged terrain or lengthy routes over relatively difficult terrain, which may render such a canal economically or environmentally infeasible.

Sites #SEH-10, SEH-24a and SEH-24b – Whiskey Creek – These reservoir alternatives would capture legally available flows on North Piney Creek. They are topographically situated to deliver water to users on North Piney Creek directly and potentially to a portion of lower Middle and South Piney Creeks via canal.

Site #SEH-29 – Sand Hill – This reservoir alternative lays offstream and could potentially capture legally available flows from South, Middle, and also North Piney Creek, although a relatively long canal would be required for the latter. It is topographically situated to deliver water to a portion of lower North, Middle and South Piney Creeks via multiple canals.

Site #SEH-12 – Fish Creek – This reservoir alternative would capture legally available flows from South Piney Creek and its tributary, Fish Creek. It is topographically conceivable to also capture Middle Piney flows as well, however the route may not be economically feasible. The site is topographically situated to deliver water to a substantial portion of Middle Piney Creek via canal and South Piney Creeks directly. It could potentially deliver water to lower North Piney Creek via a long canal.

Alternative 5 - Delivery of Green River Available Flows to the Lower Piney Creek Basins via Pumping Station or Green River Supply Canal – This alternative does not involve storage (although the Green River Supply Canal option could potentially employ a small re-regulation reservoir); rather, relatively abundant legally available flows on the Green River would be utilized to provide water to the lower Piney Creek subbasins to enable a water exchange with users further upstream in the subbasins.

Refined basin planning "plumbing" model. At this point, to support more thorough screening as part of these analyses, a more refined basin "plumbing" concept was developed to provide a better understanding of how water transfers and exchanges, in tandem with in-basin storage, could function in an efficient manner to address demands and shortages.

The short-list alternatives described above were viewed with the further intent of balancing the total available resources identified within the Upper Green River
Westside study area with the individual shortages identified within each subbasin. In some situations this objective could best be achieved by the transfer of excess water from one subbasin to another water deficient subbasin, use of water directly from the Green River, or through exchange. Table 4.4-1 – Yearly Average Flows for the Period 1971-2006 presents the average yearly flow in acre-feet per year at each node in the Model Network Diagram (for the study area west of the Upper Green River) as subsequently derived and presented in Section 5.1. These flows represent baseline conditions before any improvements (alternatives) are considered. Information in the table is defined as follows:

- Inflow – flow entering the node, as shown in the left column of each creek this represents the native inflows
- Legally Available – flow leaving node which is available to a junior right and could be used for storage
- Physically Available – physical flow leaving the node
- Demand – flow which would be diverted at the node to users if sufficient water were available (no shortage at any time during year)
- Shortage – flow which was in demand but could not be supplied due to shortage at time of demand
- Available/Shortage – ratio of physically available water to water shortage leaving the system at the mouth (confluence with the Green River)

The information in Table 4.4-1 helps to identify locations with surplus or deficient water supplies. For example, on an overall average, Horse Creek is shown to have a water surplus, which can be seen in the available to shortage ratio (column in table at far right) of 3.94. This ratio suggests that on an average basis there is nearly 400 percent as much available water as need in Horse Creek. In contrast, Middle Piney has an available to shortage ratio of 0.29 indicating that it is severely deficient even if all water in the basin could be made available at the time it was needed. In summary, Horse Creek has a surplus whereas North Piney, Middle Piney and South Piney Creek have a significant deficit. Cottonwood Creek has an overall balance, but would be benefited by additional water to create a more efficient storage and delivery system since to utilize the balance would require storage carryover from lengthy wet periods through lengthy droughts.

Conceptually, the nodes in Table 4.4-1 represent generalized locations such as the inflow to the headwaters of a creek, below a confluence of two tributaries, a specific diversion (when a discrete diversion is identified), or an aggregate diversion (grouping of several diversions over a reach of the river – such as only one node for all of Middle Piney). In general, no specific physical location on a map can be assigned to a given node; however, an attempt was made to approximate the general “on the ground” locations of the nodes so that the demands, shortages and available flows presented in Table 4.4.1 could be related to potential storage sites and delivery options on a map. A working map with the stated approximations, based on the model network diagram, together with the information in Table 4.4-1 was utilized to compare to the identified "short-list" alternatives to develop a preferred list of alternatives as described in the following section.
4.5 Preferred Water Supply Project Alternatives

For purposes of further advancing selected alternatives to a point where conceptual designs (Section 9.0), conceptual level cost estimates (Section 10.0) and an economic analysis (Section 11.0) could be prepared, a preferred list of water supply project alternatives was prepared based on the "short-list" described in the previous section.

At this stage of the analyses, preliminary layouts of the alternative were prepared, with consideration of the following factors, among others, on a qualitative and/or quantitative basis: some preliminary estimates of quantities impacting costs and efficiencies; design considerations such as geologic and geotechnical factors, and feasibility of spillway construction; existing infrastructure; cultural resources, wetlands acreages and other permitting issues; and legally available supply, demand and shortage estimates. A detailed side-by-side comparison of these factors for the various short-list alternatives can be found in Table 4.3-1 and site locations are shown on Figure 4.4-1. Key factors considered in final screening of the short list of alternatives into a final preferred list of alternatives included:

- **Horse/Cottonwood Creek Basins.** The Haines Flat Reservoir (Site # SEH-15) features a key advantage over the Horse Pasture Draw (Site # SEH-14), North Horse Creek Reservoir (Site # SEH-1), and North Cottonwood Creek Reservoirs (Site #s SEH-5 and SEH-7) in that it is topographically situated such that legally available flows from three major tributaries (North Horse Creek, South Horse Creek and North Cottonwood Creek) can be captured and stored as well as delivered to either North and South Horse or North and South Cottonwood Creeks. This allows it to act as a single combined solution for Horse and Cottonwood Creeks, whereas any other solution would require some combination of two or more of the above-mentioned reservoirs to achieve the same objectives. Thus, the economy of scale screening criterion described in Section 4.3 would apply. Additionally, the Haines Flat Reservoir features a relatively attractive means of providing spillway capacity, is relatively storage efficient, lies outside the Bridger-Teton National Forest (in contrast to Sites SEH-1 and SEH-7), and allows for transfer of stored water to the Cottonwood Creek basin from the North Horse Creek basin without pumping (in contrast to the Horse Pasture Draw site SEH-1). Further benefits of the site include the ability to deliver stored water by gravity to more irrigated acreage on North Horse Creek than any site except Site SEH-1. A potential drawback to this site is the need to operate the supply canal(s) during the spring runoff to capture physically and legally available flows when snow may still be present in at least portions of the canal(s). Most of the supply flows would be diverted during May and June, although ideally diversion may start earlier if flows are legally and physically available. Although not judged a fatal flaw, this may require higher than otherwise normal operations and maintenance costs to clear snow (especially in local drifts) and repair any inadvertent damage to the canal(s) incurred during the snow removal.

- **South Cottonwood Creek Basin.** Mickelson Creek Reservoir (Site #15) features the benefit of being located outside the Bridger-Teton National Forest, while other South Cottonwood storage alternatives (Site #8a and 8b) lie within the forest boundary, which may result in a less costly permitting process. In addition, it is relatively efficient at the target storage capacity, has favorable topography to provide relatively low-cost spillways, and is generally more favorable in many of the criteria listed previously in Section 4.3. It also
compares well with Site #SEH-8 in that it has the ability to provide delivery of storage (via canal) to more irrigated acres.

- **North Piney Creek Basin.** The short-list of sites on North Piney Creek (Site #'s SEH-10, 24a and 24b) are all located relatively close together and are nearly equivalent in many respects such as location relative to demand/shortage and supply, geologic/geotechnical conditions, and other factors. Upon preliminary layout of the reservoir sites, however, the middle site (SEH-24b), Whiskey Creek Reservoir appeared more favorable for several reasons: relative to the upstream and downstream sites, it has less expected earthwork and a resultant lower expected cost; in addition, it has more favorable spillway opportunities than either site - Site SEH-10 has highly unfavorable spillway conditions and would likely require the use of an RCC overflow section to pass the PMF, resulting in a significantly higher cost than the other sites.

- **South/Middle Piney Creek Basins.** The two reservoirs on the short-list of alternatives able to serve the South and Middle Piney Creek basins were Site SEH-12 - Fish Creek Reservoir, and Site SEH-29 - Sand Hill Reservoir. The Sand Hill site is centrally located in the lower Piney Creeks basin, whereas the Fish Creek Reservoir is located higher in the basin at the confluence of Fish and South Piney Creeks. As a result, Fish Creek Reservoir is able to serve more irrigated acreage on Middle Piney Creek higher in the basin (via a delivery canal). On the other hand, Sand Hill Reservoir is able to capture both Middle Piney flows in addition to South Piney and Fish Creek legally available flows. A topographically feasible (but perhaps not economically feasible) canal could conceivably route Middle Piney legally available flows to Fish Creek Reservoir if necessary. The Sand Hill site is arguably more favorable in that it is an offstream site with minimal wetlands impacts. In comparison, the Fish Creek site would likely require mitigation of almost 200 acres of wetlands. The main negative characteristic of the Sand Hill site is the large amount of energy, transportation, utility and other infrastructure that is present at the Sand Hill site and largely absent at the Fish Creek site. The cost of site access and mitigation of the infrastructure at the Sand Hill site is expected to be very high, if not uneconomic. The historic Lander Cut-Off Trail is present at both sites and will likely require significant evaluation and mitigation.

- **Delivery of legally available flow from Green River to the lower Piney Creek subbasins.** Two short-list alternatives were identified for utilizing legally available flows from the Green River to meet demands in the lower Piney Creek basins: pumping from the Green River below the New Fork River confluence near Big Piney (Alternative 5), and delivery of legally available flows by gravity from the Green River via an upgrade to the existing Green River Canal. Either alternative has the ability to deliver water to a point far enough upstream within the lower Piney subbasins to allow a significantly beneficial exchange of water to occur with users further upstream. Delivery via the Green River Canal, however, has the significant advantage of not resulting in pumping costs which per WWDC criteria cannot be funded (but must be paid by the project sponsor). Despite this advantage, delivery via the Green River Canal has the following drawbacks:
  - **Existing Canal Capacity -** Previous studies (Nelson Engineering, 2003) indicated that the existing capacity of the canal is about 1,500 cfs. This is sufficient to provide the first cfs per 70 acre water right, but not the full
second cfs per 70 acre right for existing users of the canal. This indicates that little or no excess capacity exists during the period when water would need to be delivered to lower Piney Creek subbasin users. While a small re-regulation reservoir could be built at the tail end of the existing canal to store early season flows (for which excess capacity may exist in the canal), costs would be significantly increased. In either scenario, it is expected that a substantial enlargement of the canal to accommodate additional flow would be required at significant additional cost.

- **Existing Canal Losses** - A previous study (Nelson Engineering, 2003) conducted on the Green River Supply Canal concluded that losses in the canal were up to 50 percent from the diversion to the end of the existing canal, further exacerbating the capacity issues described above unless seepage loss mitigation provisions are included in the canal upgrade. Regardless of whether canal seepage could be economically mitigated, the canal losses would exacerbate costs.

- **Available Green River Flows** - The existing Green River Supply Canal Diversion at Daniel lies upstream of the confluence of the New Fork and Green Rivers, which reduces the available flows relative to the pumping alternative (which lies below the confluence) given that the New Fork River is a relatively prolific basin.

- **Green River Supply Canal Extension** - To deliver water to the lower Piney Creek subbasins, the Green River Supply Canal would need to be extended three miles in addition to the upgrades required above at significant additional cost.

- **Shared Operations** – Operating an enlarged/extended Green River Supply Canal for both the current users and new users in the lower Piney Creek subbasins would present significant administrative and operational challenges, including tracking of deliveries, apportioning losses, performing maintenance, etc.

Detailed evaluations beyond the scope of this study would be required to resolve the question as to which alternative to deliver mainstem Green River water is best. These evaluations would need to account for a number of factors including, but not limited to: details of cost sharing of canal enlargement if additional capacity for existing users is contemplated; estimation of actual water deliveries to the fields in the Piney Creek subbasins after accounting for conveyance losses; the economics of paying for conveyance loss reduction upfront versus accepting losses over the life of the project; balancing potential operational and administrative challenges over the life of the project against potential cost savings; etc. Based on the conceptual-level evaluations performed to date, it appears that the capital/present worth costs of providing Green River water to the lower Piney Creek subbasins by gravity using an enlarged Green River Supply Canal and of the alternative pumping concept adopted in this study are of the same order of magnitude. This would indicate that more detailed analysis and comparison of these alternatives is justified should the project advance to the next level of study.

Considering the information obtained and investigations described previously, five preferred alternatives were identified to meet the overall objectives of satisfying the water shortages within the study area. The alternatives on the short-list not selected
should be considered to serve as "backups" to the preferred alternatives should the project advance to the next level of study. In a later study, new information may be discovered that significantly reduces the attractiveness of one or more of the preferred alternatives relative to the other short-list alternatives and reinvestigation may be warranted. The preferred list of alternatives is described as follows:

- **Alternative 1 – Horse Creek/Cottonwood Creek Storage.** Alternative includes a reservoir on South Horse Creek (Haines Flat Reservoir) with supply canals from North Horse and North Cottonwood Creeks, together with delivery canals to North Horse and South Cottonwood Creeks. A pumping station is also included on the delivery canal to South Cottonwood Creek. Alternative provides water to serve both Horse and Cottonwood Creeks directly and by exchange.

- **Alternative 2 – South Cottonwood Creek Storage.** Alternative includes a reservoir on South Cottonwood Creek (Mickelson Creek Reservoir), and a delivery canal to South Cottonwood Creek. Alternative provides water to Cottonwood Creek, including North Cottonwood Creek by exchange.

- **Alternative 3 – North Piney Creek Storage.** Alternative includes a storage reservoir on North Piney Creek (Whiskey Creek Reservoir). Alternative provides water to North Piney Creek.

- **Alternative 4 – South/Middle Piney Creek Storage.** Alternative includes a reservoir at the confluence of South Piney Creek and Fish Creek with a delivery canal to Middle Piney Creek. Alternative provides water to South and Middle Piney Creeks.

- **Alternative 5 – Pumping to Lower Piney Creek Subbasins from Green River.** Alternative includes a pumping station on the Green River in the vicinity of the Piney Creeks, a pipeline to an area several hundred feet higher in elevation than the river and a canal to deliver water to the lower portion of the three Piney Creek subbasins. Although this alternative was selected and analyzed as part of the design, cost and economic analyses described later, it is recommended that the competing short-list alternative, delivery via the Green River Supply Canal, be examined as part of any follow-on study should this project advance to the next level.

- **Alternative 6 – Combination of Alternatives 1-5.** To create a complete solution to the shortage conditions in the study area and develop a balanced system in each of the subbasins would require use of a combination of the individual alternatives (such as presented in Alternative 6).

The above preferred alternatives take into consideration the following factors:

- The excess water in Horse Creek, by storing it together with water from North Cottonwood in Alternative 1 for delivery to both Horse Creek and Cottonwood Creek, helping to satisfy shortages within both basins;

- The excess water in upper South Piney Creek and the deficiency of Middle Piney Creek by storing the water from South Piney Creek and making it available to both South and Middle Piney Creeks;

- The total net deficit of water within the combined three Piney Creeks (which have a combined available/shortage ratio of 0.46 (22,817 ac-ft available, 49,821 ac-ft shortage - not shown in Table 4.4-1)) by pumping water from the Green...
River to make up the deficit within the overall Piney Creek subbasins when in-basin storage is inadequate to meet demands; and

- The individual alternatives are complimentary to each other and each solves a portion of the overall shortage problem within the Upper Green River Westside study area.

The five preferred water supply alternatives identified above were further evaluated based on simulated operation over the period of record to further refine their operation and size as described in Section 5.2.

### 4.6 Potential Secondary (Multiple) Benefits of Storage

In addition to meeting present irrigation needs, a number of other potential benefits of new storage in the Upper Green River Westside basins have been identified during the course of this study and are recommended for more detailed evaluation should one or more storage projects advance to the next level of study. These potential benefits include, but are not necessarily limited to, the following:

- Enhancement/establishment of late-season stream flows to benefit aquatic and wildlife species and riparian habitat;
- Provision of an additional direct wildlife/livestock watering opportunity at the reservoir site(s);
- Reduction of local flooding impacts to the aquatic and riparian habitats downstream of the reservoir(s);
- Establishment of a native trout, cold water lake fishery and associated aquatic habitat;
- Development of seasonal waterfowl habitat; and/or
- Development of seasonal recreational opportunities (consistent with meeting other needs and achieving other benefits including the primary need for providing supplemental irrigation water).

It is important to note that the degree to which any one or some combination of these secondary benefits could be attained would depend on the results of more detailed evaluations that should accompany the next level of study.

### 5.0 Alternatives Analysis

#### 5.1 Refine Baseline Irrigation Shortages

A river network model characterizing the Upper Green River basin from the headwaters down to the Green River near the Green River, Wyoming stream gage was originally developed for the Green River Basin Plan (GRBP; Boyle Engineering, 2000). A monthly water accounting model based on the GRBP model was developed for the Upper Green River Basin Level II Study (Kleinfelder, et al., 2007). The Level II Study used the generic water allocation model, StateMod, with a monthly time step over the 1971 to 2003 period to estimate available water supplies allocated by priority.

This Westside Storage Level II Study is focused on the Cottonwood Creek, Horse Creek, and Piney Creek tributaries on the west side of the Upper Green River basin above Fontenelle Reservoir. The study identifies potential water storage and delivery systems to reduce irrigation shortages on the Westside tributaries. The Upper Green StateMod data set developed in the Upper Green Level II Study has been updated to
improve the estimation of water shortages both with and without the infrastructure alternatives identified herein.

The Upper Green Level II Study included representation of variable hydrology and variable irrigation demands estimated with a consumptive use (CU) model. The Westside Level II Study extends the hydrologic and climate record to include data and monthly variability through 2006. The StateMod data set and modeling efforts on the Upper Green River Basin continue to be improved based on availability and inclusion of additional data and refined understanding of basin operations. The Wyoming SEO is currently completing a geodatabase effort in which water permits are being associated with permitted acreage, actual irrigated acreage, specific ditch systems and river headgate locations. This detailed information will be available for use in future studies, which may result in representation of more discrete water demands and uses than provided in the aggregate demands necessary in past and current modeling efforts due to the lack of this data.

In this study, the StateMod data set has been revised to include Westside tributary stream gage data collected by Wyoming SEO and changes to river locations and timing of return flows from irrigation uses. Base flows (i.e., virgin flows or natural flows) are estimated based on the extension of the period of record and inclusion of additional hydrologic data. The baseline irrigation shortages are also re-evaluated to help with identification of potential water supply alternatives. Details of model simulations over the extended 1971 to 2006 period that include alternative potential reservoirs and canals are discussed further below.

5.1.1 Model Network

The Westside Level II Storage Study starts with the Upper Green Level II Study model network that predominantly includes nodes representing stream gages and diversion structures. Existing reservoirs in the basin are not explicitly represented in the model. The model nodes are connected by links that represent the connectivity between nodes on the Green River and its tributaries. The South Piney Creek headwaters and Fish Creek hydrology were previously represented in aggregate. These upper basin tributaries are separated in the Westside Study to explicitly include the recorded gage flows at the South Piney Creek near Snyder Basin stream gage. The model network without the infrastructure alternatives identified herein is presented in Figure 5.1-1 Model Network Diagram Upper Green River – Westside Storage Study.

The irrigation nodes in the model network include 15 explicit structures that have long periods of historical diversion records, and 51 aggregate structures, which represent geographically similar groups of ditches for which diversion records are not available. The model nodes in the StateMod model network were previously assigned unique 7-digit water district identifiers (WDIDs). The WDIDs consist of a 2-digit water district value representing the district within Water Division IV where the river headgate for the diversion structure is located (e.g., Fremont Ditch WDID 0700904 representing water district 7). The 5-digit identifier was developed from the node number assigned in the Upper Green River Basin Planning Model with leading zeroes added, as necessary (e.g., Fremont Ditch – Node 9.04 in Upper Green River Basin Planning model). Stream gages were assigned their respective 8-digit U.S. Geological Survey (USGS) identifiers.
The reservoir, canal, and pump locations identified herein were added later to the model network to facilitate simulation of their operations to reduce irrigation shortages.

5.1.2 Base Flows

Base flows represent native stream flows absent man’s impact. The model representation of base flows available for diversion is based on recorded historical flows at stream gages, recorded and estimated diversions at upstream river headgates, tributary inflows, and estimated irrigation return flows above the gage. Infrastructure alternatives identified herein are not included in calculation of base flows since these facilities are not yet constructed and have no effect on historical operations in the river basin. Tributary inflows are represented by distributing base flow gains and losses calculated between successive stream gages to non-gaged base flow points.

Stream Flow Data. Stream gage data recorded by WSEO were reviewed and incorporated to improve model representation of tributary inflows to the model network. This included data from the North Piney Creek above Apperson Creek, WY (IV10NP1), Middle Piney above Forest Boundary, WY (IV10MP1), South Piney Creek near Snider Basin, WY (IV10SP1), South Cottonwood Creek near Big Piney, WY (IV10SC01), and North Horse Creek above Sherman Guard Station, WY (IV11NHC01) stream gage stations. The locations of the WSEO gages and other gages used in the model calibration are shown on Figure 5.1-2 – Gage Stations.

- The South Piney Creek stream flows are explicitly included into the model, as represented at node ID 1001700. Explicit representation of the South Piney Creek gage flows reduced the base flows available to the uppermost South Piney Creek aggregate irrigation structure. This node (ID1001702) previously benefited from all of the natural flows above the USGS Gage 09207500 (no longer used). The majority of the irrigated acreage above this gage is located on Fish Creek. Separating the inflows to South Piney Creek and Fish Creek thus reduced the base flows above the irrigation demand.

- The North Piney gage data was used to verify the previously developed baseflows calculated at the top of North Piney Creek based on USGS Gage 09205500 (North Piney Creek near Mason, WY) flows and estimated irrigation consumptive use above that gage on North Piney Creek.

- The Middle Piney gage data was used to verify the previously developed baseflows calculated for the top of Middle Piney Creek, which was based on flows at USGS Gage 09206000 (Middle Piney Creek below South Fork, near Big Piney, WY)

- The Cottonwood Creek gage data was used to verify the previously developed baseflows calculated at the top of North/South Cottonwood Creek based on USGS Gage 09191500 (Cottonwood Creek near Daniel, WY) flows and estimated irrigation consumptive use above that gage on North/South Cottonwood Creek.

- Comparison of the Horse Creek near/at Daniel gage streamflows to the North Horse Creek gage data indicated more of the Horse Creek basin inflows originate from the North Horse Creek basin than was previously estimated (as compared to the South Horse Creek basin). Therefore, the previous distribution of 60% of the gains down to the Daniel gage from North Horse Creek was increased to 80%.
This results in higher and lower base flows in the North Horse Creek and South Horse Creek basins, respectively.

A more significant impact on the basin hydrology and base flow calculations occurs from inclusion of actual inflow data to the top of South Piney Creek. The gains and losses calculated between gages are distributed to the top of ungaged tributaries. Inclusion of the data discussed above resulted in a shift of available flow for diversion at the top of the West Fork New Fork River to the Upper Green River and Westside tributaries. This change provided more water available for diversion for the alternatives identified herein. This change and the effect on modeling results indicates the significance of gathering and incorporating more stream flow data and diversion data in order to improve physical representation of basin operations.

**Irrigation Demands and Return Flows.** Irrigation demands at all aggregate irrigation nodes in the model have been extended over the 1971 to 2006 period. Summary irrigated acreage data from GRBP that were previously unavailable were incorporated into the Westside Level II Study model. This change resulted in a decrease of approximately 6,215 acres, including 2,387 acres for Westside tributary nodes (2,375 not including Beaver Creek). The acreage revisions represent a decrease of 3.7% over the entire basin acreage and a decrease of 3% of irrigated acreage on the Westside tributaries (3.4% not including Beaver Creek). The acreage changes are relatively minor but are considered the best data available prior to the completion of the SEO geodatabase effort. Inclusion of the data also provides more consistency between the GRBP model and the StateMod model data set.

The irrigation demands for all nodes are further revised by improving the “representative” monthly system efficiencies assigned to the aggregate nodes. Average system efficiencies are typically estimated based on historical crop demand and historical diversions. Monthly efficiencies were calculated for the 15 irrigation structures in the model with records of historical monthly diversions in relation to monthly crop irrigation water requirement. Monthly efficiencies for the remaining 51 aggregate irrigation nodes were previously estimated based on the average calculated monthly efficiencies for the explicit structures in the same water district. In addition to including three more years (2004 to 2006) of crop demand and diversion data, the estimates of monthly efficiencies for aggregate structures are now based on specific associations for each aggregate demand with explicit structures of like characteristics (e.g., explicit structure located on tributaries versus on the Green River main stem). This change is considered superior to the methodology developed in the Upper Green Level II Study because it captures the known variability of efficiencies across the system and mirrors that variability in the aggregate demands.

The changes to aggregate structure efficiencies result in changes to calculated irrigation demands (equal to the variable monthly crop demand divided by average monthly efficiency). The general effect of these changes was to increase/decrease the baseline irrigation shortages from the values used in the Upper Green Level II Study, as discussed further below.

Irrigation return flow patterns and locations in the Upper Green StateMod data set were originally incorporated based on the model representation used in the Upper Green River Basin Planning model. Return flow patterns and locations have been revised in the Westside Study for some of the Westside tributary irrigation nodes in order to improve simulated tributary gains and losses resulting from inclusion of additional WSEO gage data.
5.1.3 Water Rights
Permitted water rights from the WIRSOS model representation of the Upper Green River basin, including representation of surplus water rights, were included in the StateMod model data set as part of the Upper Green Level II Study. Due to the aggregate representation of demands and water rights, some aggregate nodes do not have sufficient water rights to meet the magnitude of the calculated headgate demands. For example, an irrigation node with a river demand of 800 acre-feet for a given month and a water right of 10 cfs, which would be equal to only about 600 acre-feet (10 cfs times 1.9835 acre-feet per cfs times 31 days per month) of total water rights, would be short approximately 200 acre-feet that month. The StateMod model simulates shortages to these nodes due to insufficient legal right to divert water. Without better understanding of actual permits available to meet irrigation demands, “free river rights” with priorities junior to all other rights in the model are included to correct this inconsistency and to allow the nodes to divert excess water supplies to meet the input model demands. Storage rights and diversion rights included to represent the alternative operations discussed below are assigned priorities junior to these free river rights. This approach is appropriate because it allows irrigators to divert water without the need to first store that available flow.

The effects of the various changes to the StateMod data set input files on estimates of base flows, baseline irrigation shortages, and effects of alternatives operations are discussed further below.

5.1.4 Refined Baseline Irrigation Shortages
The StateMod model simulates the physical supply of water (i.e., base flows) to meet river headgate demands subject to the legally available flow (i.e., available in priority to water rights of the modeled structures). The river headgate demands not met by simulated diversions, subject to Wyoming Water Law, represent the refined shortages to irrigation demands. Reasons for shortages are generally due to insufficient physical and/or legal supply.

Results of the StateMod analysis of the Westside tributaries for the 1971 to 2006 study period are summarized in Table 5.1-1 – Upper Green River Basin Westside Tributaries Average Annual Baseline Irrigation Shortages (1971-2006). Results of model simulations indicate that there are demands of approximately 275,000 acre-feet per year (column 1) on the Westside tributaries. On average, these demands are shorted approximately 87,000 acre-feet (column 2), or 32 percent.

As noted above, changes in calculation of river headgate demands resulted in increased tributary demands over the Upper Green Level II Study due to reduced efficiencies on the typically water-short tributaries. Although the available spring runoff stream flows increased in the lower Westside tributaries, shortages increased due to the increased demands.

Estimated average-year shortages over the 1971 to 2006 study period, and legally available flows summarized in Table 5.1-1 (information provided in Table 4.4-1 and previously discussed in Sections 4.4 and 4.5) were used to identify and evaluate general areas within the basin where reservoir sites could potentially reduce or eliminate estimated shortages. These general areas were then evaluated to identify specific reservoir sites within a sub-basin. Additional model simulations were performed to further evaluate the potential ability of a reservoir, canal, or pump to reduce shortages, as described in Section 5.2.
For a particular moment in time, legally available flows in excess of demands represent water that can be stored in a reservoir for later beneficial use. These flows were used to evaluate the optimum reservoir size at this conceptual level of study.

5.2 Model Simulation with Preferred Alternatives

The baseline runs generally simulated shortages on the tributaries due to either insufficient physical flows or sufficient flows but no storage to carry water over from wet years to satisfy irrigation shortages during subsequent dry years.

Additional model simulations were conducted to estimate the ability of the preferred reservoirs to reduce the baseline level of irrigation shortages. The preferred reservoirs and infrastructure alternatives were added to the river model network although model simulations were run separately with each of the five candidate reservoir/canal/pump sites identified in Section 4.5. The model network with the infrastructure alternatives identified herein is presented in Figure 5.2-1 Model Network Diagram With Alternatives Upper Green River – Westside Storage Study.

To ensure that simulated operation of the reservoirs will not injure vested water right holders in the basin, each reservoir is assigned a storage right with a priority junior to all other modeled irrigation rights. The one-fill storage rights are set equal to the proposed capacity of the reservoir with the right to fill throughout the year. Diversions to storage in supply canals identified in the alternatives are limited to operation during the generally ice-free months of March to October. Monthly storage diversions to reservoirs are limited by total un-filled capacity and physically available stream flows available to junior storage rights. Area-capacity curves developed based on USGS topographic mapping were included to represent modeled surface areas and associated evaporation losses. The evaporation losses assigned to each reservoir are estimated based on monthly net evaporation rates developed for the GRBP model.

Operating rules are added to the model to release water from storage to downstream irrigation nodes or irrigation nodes on neighboring tributaries via delivery canals identified in the alternatives. These rules are illustrated by dotted lines on the model network that includes the preferred alternatives. The release rules are assigned priorities junior to the storage rights included in the alternatives, so that storage releases are only made to meet simulated irrigation shortages after all direct flow water rights and storage rights are exercised.

Analyses were performed for each individual reservoir site, the Green River Pump alternative, and for all four sites and the pump together. Various sensitivity analyses were run for each of the alternatives, which predominantly focused on varying the reservoir, canal, and pump capacities and the relationship of construction and operations costs versus average annual reduction to shortages. The simulation results of the final infrastructure capacities for the various alternatives are summarized below.

5.2.1 Alternative 1 - Horse Creek/Cottonwood Creek Storage

Haines Flat Reservoir, with a 40,000 acre-feet capacity, was located on South Horse Creek with additional supply canals on North Horse Creek (240 cfs capacity) and North Cottonwood Creek (165 cfs capacity). The reservoir is operated to meet the demands at four nodes on Horse Creek serving approximately 14,900 irrigated acres and three Cottonwood Creek nodes serving approximately 20,200 irrigated acres. Two of the Cottonwood Creek nodes are served directly by the reservoir, with a
lower node benefiting from return flows from water released to the top of Cottonwood Creek. Reservoir deliveries are made to North Horse Creek via a 110 cfs capacity canal and to Cottonwood Creek via a 150 cfs capacity canal. Simulated storage content for Haines Flat Reservoir over the 1971 to 2006 study period is presented in Figure 5.2-2 - Alternative 1 Haines Flat Reservoir Simulated Storage Contents.

Baseline shortages of about 21,000 acre-feet per year are eliminated from operation of Haines Flat Reservoir. These reduced shortages represent approximately 47% of the baseline shortages on Horse Creek (~4,200 acre-feet) and approximately 59% of the baseline shortages on Cottonwood Creek (~16,800 acre-feet), as summarized in Table 5.2-1 Upper Green River Basin Westside Tributaries Average Annual Irrigation Shortage Reductions (1971-2006). This and other relevant information is summarized on Table 5.2-2 - Summary of Alternative 1 – Horse Creek/Cottonwood Creek Storage.

5.2.2 Alternative 2 - South Cottonwood Creek Storage

Mickelson Creek Reservoir, with a 15,000 acre-feet capacity, was located on Mickelson Creek, tributary to South Cottonwood Creek, as similarly represented in the Upper Green Level II Study. Filling and releases from Mickelson Creek in the Westside Level II Study increased due to the increased available flows that resulted from the change in base flows pursuant to addition of the Wyoming SEO gage data. Simulated storage content for Mickelson Creek Reservoir over the 1971 to 2006 study period is presented in Figure 5.2-3 – Alternative 2 Mickelson Creek Reservoir Simulated Storage Contents.

The reservoir is operated to meet the demands at all three irrigation nodes on Cottonwood Creek, serving a total of approximately 20,200 irrigated acres. Reservoir deliveries are made to Cottonwood Creek via a 100 cfs capacity canal. Baseline shortages of about 7,950 acre-feet per year are eliminated from operation of Mickelson Creek Reservoir. These reduced shortages represent approximately 28% of the baseline shortages on Cottonwood Creek, as summarized in Table 5.2-1. This and other relevant information is summarized on Table 5.2-3 - Summary of Alternative 2 – South Cottonwood Creek Storage.

5.2.3 Alternative 3 - North Piney Creek Storage

Whiskey Creek Reservoir, with a 20,000 acre-feet capacity, was located on North Piney Creek. The reservoir is operated to meet the demands at all five nodes on North Piney Creek serving approximately 17,900 irrigated acres. All reservoir deliveries are modeled to the river system to meet irrigation demands either directly or by exchange. Simulated storage content for Whiskey Creek Reservoir over the 1971 to 2006 study period is presented in Figure 5.2-4 – Alternative 3 Whiskey Creek Reservoir Simulated Storage Contents.

Baseline shortages of about 11,100 acre-feet per year are eliminated from operation of Whiskey Creek Reservoir. These reduced shortages represent approximately 47% of the baseline shortages on North Piney Creek, as summarized in Table 5.2-1. This and other relevant information is summarized on Table 5.2-4 - Summary of Alternative 3 – North Piney Creek Storage.
5.2.4 Alternative 4 – South/Middle Piney Creek Storage

Fish Creek Reservoir, with a 20,000 acre-feet capacity, was located on South Piney Creek. The reservoir is operated to meet the demands at all six nodes on South Piney Creek and one node on Fish Creek, serving approximately 11,600 irrigated acres. A 150 cfs capacity delivery canal to the approximately 8,400 irrigated acres on Middle Piney Creek is also simulated to receive reservoir releases. The releases to Middle Piney Creek were operated after water was delivered to meet irrigation shortages on South Piney Creek. Simulated storage content for Fish Creek Reservoir over the 1971 to 2006 study period is presented in Figure 5.2-5 – Alternative 4 Fish Creek Reservoir Simulated Storage Contents.

Baseline shortages of about 9,300 acre-feet per year are eliminated from operation of Fish Creek Reservoir. These reduced shortages represent approximately 25% of the baseline shortages on South Piney Creek (~2,600 acre-feet) and approximately 44% of the baseline shortages on Middle Piney Creek (~6,700 acre-feet), as summarized in Table 5.2-1. This and other relevant information is summarized on Table 5.2-5 - Summary of Alternative 4 – South/Middle Piney Creek Storage.

5.2.5 Alternative 5 – Pumping to Lower Piney Creek Subbasins from Green River.

The Green River Pump Station, with a 75 cfs pump capacity, was located on the mainstem Green River below the confluence with New Fork River and above the confluence with the Piney Creek system. The pump is operated to meet the demands at the approximately 21,000 irrigated areas nearest to the confluence of the Piney Creek tributaries to the Green River. This includes the five lower nodes on North Piney Creek (1 node serving ~7,100 acres), Middle Piney Creek (1 node serving ~8,400 acres), and South Piney Creek (3 nodes serving ~5,400 acres). The pump diversions were operated first to meet South Piney Creek demands, followed by Middle Piney Creek demands and then North Piney Creek demands. Simulated river diversion for the Green River Pump over the 1971 to 2006 study period is presented in Figure 5.2-6 - Alternative 5 Green River Pump Simulated Diversion.

Baseline shortages of about 13,700 acre-feet per year are eliminated from operation of the Green River Pump. These reduced shortages represent approximately 53% of the baseline shortages on the Piney Creek system; including the shortages on North Piney Creek (~5,000 acre-feet), Middle Piney Creek (~5,400 acre-feet), and South Piney Creek (~3,300 acre-feet), as summarized in Table 5.2-1. This and other relevant information is summarized on Table 5.2-6 - Summary of Alternative 5 – Pumping to Lower Piney Creek Subbasins from Green River.

5.2.6 Alternative 6 – Combination of Alternatives 1-5

The final analysis included simultaneous operation of all four proposed reservoir sites and the Green River Pump to store, release, and pump water to various irrigation nodes. The reservoir, canal, and pump capacities are modeled as described above. The reservoir release and pumping from the various infrastructure included in the five alternatives are operated in priority from the infrastructure described above for Alternatives 1, 3, 2, 4 and 5, respectively (Haines Flat Reservoir followed by Whiskey Creek Reservoir, Mickelson Reservoir, Fish Creek Reservoir, and Green River Pump).

Combined operation of the alternatives in the relative order described above generates fairly equitable irrigation shortage reductions, on a percentage basis, to the five Westside tributaries. Cottonwood Creek benefits most in this respect since it
receives water directly from both the Haines Flat Reservoir and Mickelson Creek Reservoir, alternative numbers 1 and 2, respectively. Simulated storage contents for the four reservoirs and the Green River Pump over the 1971 to 2006 study period are presented in Figures 5.2-7A-E which provide separate operational charts of each of the sub alternatives.

Baseline shortages of about 50,300 acre-feet per year are eliminated from the combined operation of the various alternatives. These reductions significantly benefit Cottonwood Creek (~20,500 acre-feet) and North Piney Creek (~12,900 acre-feet), with lesser magnitude benefits to Middle Piney Creek (~7,900 acre-feet), South Piney Creek (~4,700 acre-feet), and Horse Creek (~4,300 acre-feet).

5.2.7 Modeling Evaluation Summary, Conclusion and Recommendation

Each of the reservoirs was sized to provide a reasonable reduction in shortage and satisfaction of demand. Reservoir operations showing end of month contents for simulated conditions for the period of record show a reasonable balance in contents between wet periods and dry periods. Canals were sized consistent with the maximum usage resulting from the modeling. After the alternative infrastructure is considered, reduction of shortage is projected to be on the order of 50-60 percent varying from subbasin to subbasin. Associated percent of total demand met is estimated to be on the order of 85 percent. This information can be seen on Table 5.2-1.

As a further step of refinement should the project proceed, it would be appropriate to model the different components (reservoirs and canals) with incrementally reduced capacities in order to evaluate the merits in terms of benefit to cost of incremental changes in size. Although marginal reductions in percent of total demand met may be seen by reducing system capacities, cost reductions may be proportionally greater. It is our belief, that with additional modeling and cost evaluation work, some refinements could be made to further enhance the economic potential of the project. This situation appears to apply to a greater extent should the combined alternative (Alternative 6) be implemented as it appears to show mutual/overlapping benefits that could enable further reductions in capacity.

Additional modeling and cost/benefit work could also be undertaken to establish minimum pool conditions (and associated operations for irrigation practices) consistent with providing minimal pool storage for multiple benefits (i.e., recreational usage). Such operation may be considered for evaluation of an increased percentage of funding.

6.0 Preliminary Geotechnical Investigation

6.1 Geologic/Geotechnical Conditions - Overall Study Area

6.1.1 Topography

The topography of the Upper Green River Westside study area varies from the high, rugged, steep terrain of the Wyoming Range along the western side of the study area to the lower, broad, dissected benches sloping from the mountain front to the valley of the Green River (see Figure 6.1-1 - Topography). The total relief in the watershed is approximately 4,650 feet from the top of Wyoming Peak at 11,378 feet to the Green River at 6,730 feet.

The Wyoming Range forming the western boundary of the study area is oriented north-south, reflecting the underlying bedrock and overall geologic structure
described in Sections 6.1.4 and 6.1.5. From north to south, the major streams within the study area draining the east slope of the mountains are North and South Horse Creeks, North and South Cottonwood Creeks, and North, Middle and South Piney Creeks. Most of the study area lies east of the Wyoming Range and is characterized by moderately to gently east sloping benches underlain by older alluvial terrace/coalescing alluvial fan deposits. These broad benches were likely more or less contiguous in earlier geologic time, but are now heavily dissected by the east draining streams noted and their larger tributaries. The valley of the mainstem Green River and the narrow band of adjacent west sloping lands of the Green and New Fork Rivers divide form the eastern boundary of the study area.

6.1.2 Soils
Soils mapping covering the Upper Green River Westside study area is still in progress and is not available from NRCS in paper or digital/GIS format. Contact the local NRCS Service Center in Pinedale at 307.367.2257 for available information. Check the following NRCS internet link to determine if digital soils mapping data has become available online since the publication of this report: http://websoilsurvey.nrcs.usda.gov/app/.

Available soils mapping in digital format was acquired from the Bureau of Reclamation (personal communication with John Huston/BLM on September 12, 2007). The available mapping only covered limited areas in the south-central and southeastern parts of the study area. Coverage was not available at the preferred alternative water supply sites except for a small part of the proposed Whiskey Creek Reservoir inundation area of Alternative 3 as defined in Section 4.0. A disclaimer accompanying this digital data stated that “The BLM makes no guarantee to the accuracy of this data (use at your own risk). Please do not share it with others outside your organization. There appears to be no associated metadata”.

6.1.3 Surficial Geologic Units
The distribution of surficial geologic deposits in the Upper Green River Westside study area is shown on Figure 6.1-2A – Surficial Geology, a GIS product available from the WYGISC internet site (see also Figure 6.1-2B – Surficial Units Key). Each of the surficial units mapped can present challenges and/or opportunities to the siting, design and/or construction of dams and reservoirs as discussed below.

Surficial deposits are also shown on Figure 6.1-4A – Geologic Map at a larger scale than on Figure 6.1-2A (see also Figure 6.1-4B – Geologic Units Key). The following discussion of surficial geologic units is based primarily on Figure 6.1-2A given that these deposits are the focus of that mapping. Comparison of the two maps reveals generally similar types and distribution of surficial units. Note, however, that significant areas on Figure 6.1-4A with only thin to patchy surficial deposits are shown as outcropping bedrock, while on Figure 6.1-2A only areas essentially devoid of any surficial deposits are mapped as outcropping rock. Also, note that fewer landslide deposits are shown on Figure 6.1-4A than on Figure 6.1-2A, presumably due to the differing primary purposes of the two maps.

Wyoming Range. Most of the western portion of the study area within the Wyoming Range is characterized by one of three predominant surficial units: 1) outcropping bedrock with minor, local cover of residuum (deeply weathered bedrock), colluvium or slopewash; 2) glacial deposits (predominantly tills and moraines); or 3) landslide deposits.
Areas of outcropping to only shallow covered bedrock typically yield only rockfill borrow and riprap slope protection; finer grained units suitable for low permeability core and/or sand and gravel for aggregate and filter/drain materials are often scarce to absent. See Section 6.1.4 for further discussion of bedrock geology.

Glacial deposits in the Wyoming Range include mostly tills (typically compact soils that were present under the alpine glaciers) and moraine (typically less compact soils bulldozed in front of an advancing glacier or dropped as the glacier retreated, and soils carried along the flanks of the glacier). Outwash deposits are also locally present where glacial melt waters carried and then deposited moraine and possibly till materials downstream of the terminus of the glacier. The thickness of these glacial deposits varies widely, and could be many tens to locally well more than a hundred feet thick. These deposits vary significantly in terms of their suitability as foundation or borrow materials. For example, well graded, dense glacial tills with substantial fines can provide a strong, low permeability foundation for an earth dam. On the other hand, glacial moraines and especially outwash deposits can contain local highly pervious zones that may prove difficult and expensive to cut-off beneath a dam or seal adequately against seepage loss through a reservoir floor or rim. The typically wide range of grain sizes present in many glacial till and moraine deposits may result in high processing costs to produce aggregate and/or filter/drain materials. Both glacial tills and moraines can serve as suitable borrows for shell material in zoned earth dams; tills with sufficient clayey fines can also serve as suitable core material in a zoned earth dam. If present in sufficient quantity, glacial outwash deposits typically provide a better target for aggregate and/or filter/drain borrow material.

As noted on Figure 6.1-2A, much of the Wyoming Range is characterized by landslide deposits. Note, however, that the mapping of areas of landsliding at this scale may not accurately reflect conditions at any given site, and may overstate the areas of landsliding. See Section 6.1.6 for additional discussion of the implications of these deposits on potential dam sites within the Wyoming Range.

**Dissected Benchlands.** Surficial deposits overlying the broad dissected benchland characterizing most of the study area (i.e., the area east of the Wyoming Range) include mainly: 1) alluvium in the larger stream and tributary valleys; 2) alluvial terrace deposits and other gravelly deposits of uncertain origin covering many of the benches between the streams; and 3) various surficial deposits covering bedrock on benches and slopes to variable, but typically fairly shallow depths (including residuum, colluvium and slopewash).

Alluvial deposits in this area range from predominantly finer-grained silts and sands to locally coarse gravels and small cobbles. The thickness of these deposits varies widely, generally increasing in the lower reaches of larger streams. Depths of alluvium are estimated by Welder (1968) to range up to about 50 feet. In general, alluvial deposits beneath at least the core of an earth dam would have to be removed to limit seepage and high downstream foundation pore pressures, and to mitigate the potential for foundation strength loss during a large earthquake. However, these deposits can typically be used in earth dam construction, including as core material if they contain sufficient fines. Based on available information and site reconnaissance it appears that coarser-grained alluvium (sand and gravel) will be present in sufficient quantities to serve as a primary borrow source for aggregate and/or filters/drainages. If necessary, large quantities of high-quality aggregate are available in the floodplain of the mainstem Green River.
Terrace deposits formed on broad upland benches during previous episodes of alluvial deposition with much higher streamflows than at present (possibly during wetter interglacial periods). The thickness of these deposits is unknown, but may be from a few to a few tens of feet typically (locally depths up to as much as 70 feet have been penetrated according to Welder, 1968). Where observed locally in cuts and eroded slopes these deposits contain a wide range of sizes from silty fines to small boulders. These terrace deposits (and other gravels) are typically suitable as shell material in an earth dam where strength of the compacted fill is the primary requirement. Where relatively extensive and containing less fines and fine sands, these deposits may provide a source of aggregate and/or filter drain material with moderate to significant processing.

Landslide deposits are mapped on some steeper slopes in this dissected benchland portion of the study area, but are much less common than in the Wyoming Range (see Section 6.1.6 for additional discussion of slope stability).

6.1.4 Bedrock Units

The bedrock geology exposed at or near the surface and underlying the Upper Green River Westside study area to great depths spans a substantial portion of geologic time from the Mississippian/Pennsylvanian boundary to as young as the Eocene (+ 168 million years). Figure 6.1-3A – Bedrock Geology is a GIS-based product derived from the 1:500,000 scale Geologic Map of Wyoming (Love and Christenson, 1985) showing the general distribution of outcropping or near surface bedrock (and major surficial geologic units) within the watershed (See also Figure 6.1-3B – Bedrock Units Key). Figure 6.1-4A provides more detailed geologic mapping (at 1:250,000 scale) of most of the study area; this mapping is taken from Oriel and Platt (1980). The following discussion of bedrock geology is based on this more detailed mapping.

Most of the Upper Green River Westside study area is underlain near surface by bedrock of two major members of the lower Eocene-age Wasatch Formation. These include the informally named “conglomerate member” or diamictite and the La Barge Member. The coarser-grained diamictite (Twd on Figure 6.1-4) crops out in a relatively narrow north-south band at the base of the Wyoming Range. Diamictite is described by Oriel and Platt (1980) as “Unsorted boulders and blocks in mudstone matrix; grades into other members of the formation. Apparently several hundred meters thick in places; thins basinward”. Oriel (1962) describes the “conglomerate unit” as “composed mainly of dark brownish and brick red interbedded diamictite…conglomerate, sandstone and mudstone…Blocks as long as 7 feet long were seen in exposures west and southwest of La Barge…the unit contains relatively abundant, moderately well sorted conglomerate, sandstone and mudstone…which may exceed poorly sorted diamictite in volume”. Based solely on these descriptions, it appears that this bedrock unit would be generally suitable as a foundation and borrow source for the shells of a zoned earth dam. Areas containing large blocks of harder rock may be less suitable for shell borrow depending on the size and frequency of the larger pieces. Care should be taken in founding sensitive concrete structures on this unit due to the potential for differential stresses and settlement.

The diamictite grades eastward (i.e., basinward) into the La Barge Member of the Wasatch Formation (Twl on Figure 6.1-4). The La Barge Member is described by Oriel and Platt (1980) as “Red and brown mudstone and conglomerate, yellow sandstone, and minor pisolitic limestone. As much as 30 m thick”. Oriel (1962) describes this unit as “a heterogeneous unit that includes mudstone, siltstone,
sandstone, conglomerate, marlstone, and limestone...mudstone is dominant...Thin lenses of marlstone and limestone are...irregularly bedded...small lenses and sheets of sandstone...are cross-bedded in most places...Conglomerate occurs locally in discrete lenses representing old channel deposits and sporadically near the base of individual sandstone beds...the proportion of coarse detritus in the La Barge Member increases westward...Sandstone becomes more abundant, locally exceeding mudstone, and conglomerate beds increase in number and thickness. The La Barge Member grades into and intertongues with the part of the conglomerate member of the Wasatch Formation.” Based on these descriptions and observations in road cuts and eroded slopes, this bedrock unit appears generally suitable as a foundation for an earth dam and its appurtenances. Although possible, it does not appear that potentially much weaker units (e.g., subbituminous coal, carbonaceous shale, claystone, etc.) are common in this part of the Wasatch Formation. (Note that these weaker interbeds are more common in the upper portion of the Wasatch Formation not present within the study area.) Borrow for shell material and possibly core material (where mudstone is predominant) should be available from the La Barge Member.

Exposures of the New Fork Tongue of the Wasatch Formation and lower Eocene-age Fontenelle Tongue of the Green River Formation crop out locally in the hills immediately west of the Green River and in the low divide between the Green and New Fork Rivers at the easternmost margin of the study area. However, these units are not located in the vicinity of any potential dam sites evaluated in this study and are not considered further.

Bedrock underlying the Wyoming Range includes units ranging from upper Cretaceous- to Upper Mississippian-age. As seen on Figure 6.1-4A, the outcrop pattern of these units is complex in detail due to the geologic structure of the Wyoming Range as discussed in Section 6.1.5.

A narrow band of Jurassic- to Upper Triassic-age units is locally present along the lower slopes of the Wyoming Range adjacent to the western contact of the Wasatch diamictite described above, and locally along the southern approximately one-half of the westernmost study area boundary (along the range divide). These units include the Nugget Sandstone, Twin Creek Limestone, Stump Formation and Preuss Redbeds. These units are all comprised of relatively competent sedimentary rocks, predominantly sandstone, siltstone and limestone. In general, these units should provide relatively competent foundations for earth dams and appurtenances. Borrow for shell material and/or rockfill is available, but low permeability material for an earthen core may be scarce to absent in these units. Potentially problematic lithologies (rock types) include local claystone beds (potentially low foundation strength) and irregular zones of gypsum (soluble in water) in the Preuss Redbeds.

A relatively continuous, wider band of Cretaceous-age bedrock units occur west of the Jurassic-Triassic units described immediately above. Taken together these units comprise more than half of the bedrock outcrop in the Wyoming Range. In order from youngest to oldest, these units (or groups of individual units) include: 1) Blind Bull Formation (Kbb on Figure 6.1-4A); 2) Aspen Shale (Ka on Figure 6.1-4A); 3) Bear River Formation (Kbr on Figure 6.1-4A); 4) Ephraim Conglomerate (Ke on Figure 6.1-4A); and 5) an unnamed red unit, Draney Limestone, and Bechler Conglomerate (Kwd on Figure 6.1-4A). These units are comprised of a wide range of sedimentary lithologies from very fine-grained claystone to coarse-grained
conglomerate. Foundation conditions and borrow suitability will vary significantly depending on the specific units and lithologies present at a given dam and reservoir site. Potential low strength lithologies that could affect foundation stability include claystone, coal and bentonite in the Blind Bull Formation, claystone in the Aspen Shale, and black shale and bentonite in the Bear River Formation.

The oldest rocks in the study area range from Mississippian- to Triassic-age. These rocks crop out in a north-south band located south of the headwaters of South Cottonwood Creek near the western edge of the study area. Units include, from youngest to oldest: 1) Ankareh Formation (Tₐ on Figure 6.1-4A); 2) Woodside Shale (Tₕ on Figure 6.1-4A); 3) Dinwoody Formation (Tᵣ on Figure 6.1-4A); 4) Wells Formation (Pᵦ on Figure 6.1-4A); 5) Amsden Formation (IPMa on Figure 6.1-4A); and 6) Madison Limestone (Mᵦ on Figure 6.1-4A). These units are comprised of sedimentary rocks; limestone, siltstone and sandstone are most common, with other lithologies locally present (including shale, dolomite, cherty limestone, and conglomerate). All of these units should generally provide adequately strong foundations for earth dams and their appurtenances, and most should be adequate in terms of seepage. However, the Dinwoody Formation and Madison Limestone are known in some locations to contain karst features (open solution cavities) that can result in high to even fatal-flaw reservoir seepage. These units should provide adequate sources of rockfill and/or shell material for zoned earth/rockfill dams, but low permeability core zone borrow will be scarce to not available.

6.1.5 Structure

The Wyoming Range portion of the Upper Green River Westside study area lies at the eastern margin of the Wyoming salient of the Western Overthrust Belt of Dixon (1982). This is a regional structural province characterized by a series of west-dipping thrust faults, contemporaneous and later normal faults, and associated folding interpreted as having formed by overall east-west compression of the earth’s crust. Of significance to this study are the results of the long history of structural deformation on the rocks at potential dam and reservoir sites in the Wyoming Range, and the ongoing structural (seismotectonic) activity discussed in Section 6.2.

As shown on Figure 6.1-4A, there are several north-south trending bedrock thrust faults present within the study area. The easternmost of these faults, the Darby Thrust Fault, is present along the toe of the eastern slope of the Wyoming Range. None of these faults are believed to be active (i.e., capable of generating earthquakes or undergoing surface rupture). The prior tectonic (earth) forces that formed these faults also resulted in locally significant folding of the sedimentary rocks between faults (as evidenced in part by the outcrop pattern within the Wyoming Range). When sedimentary rocks are deformed to the degree common within much of the Wyoming Range, joints, fractures and small-scale, local faults are typically the result. These discontinuities in the rock mass tend to be more open at and near the surface and tighter at depth. Where more open, the broken rock mass is weaker, prone to more rapid weathering (and resultant deterioration), and more permeable (allowing easier passage of water through the rock mass). These local conditions can affect details of the foundation treatment required for dams, seepage potential from the reservoir area, and possibly design of sensitive concrete structures (e.g., spillways and outlet works).

The majority of the study area lies on the western flank of the Green River Basin. The Green River Basin is a broad area of downwarp to the east of the Wyoming
Thrust Belt filled with relatively younger (post latest-Cretaceous, Tertiary-age) sedimentary rocks formed by erosion of older rocks in uplifted areas at the margins of the basin and subsequent deposition within the basin. The sedimentary bedding of these units in the study area generally dips gently to the east, with slightly greater dips closer to the Wyoming Range front. It is estimated that dips are less than 10 degrees, and more likely in the range of 1-5 degrees based on the regional geology. Some shallow, broad folds probably occur locally in these beds but structural deformations (joints, fractures, faults) are believed to be minor in these units within the study area.

6.1.6 Landslides/Slope Instability

Figure 6.1-5 – Landslides shows the location of mapped landslides within the Upper Green River Westside study area from the work by Case, et al. (http://www.wrds.uwyo.edu/wrds/wsgs/hazards/landslides/landslides.html). This mapping is more detailed and accurate than the mapping of landslides shown on Figures 6.1-2A and 6.1-4A, and is the basis for assessing slope stability issues in this study. As seen on Figure 6.1-5, landsliding of significant scale and/or density of occurrence is most prevalent in the steeper, glaciated slopes of the Wyoming Range, and is most common in sedimentary rocks of Cretaceous age and Quaternary-age glacial deposits. Landslides are next most common in a north-south trending zone about five (5) miles wide extending east from the toe of the Wyoming Range. These slides occur on steep stream valley slopes eroded into the relatively weak mudstones common in the diamictite and La Barge Members of the Wasatch Formation. Landsliding is much less common in the remainder of the study area to the east.

The depth, age of original movement, and degree of recent or current activity for the mapped landslides are unknown. The landslides shown on Figure 6.1-5 represent many different types and combinations of failure from small, shallow debris slides and mudflows to very large, deep bedrock block slides. Potential triggering mechanisms that could explain the existing landslides within the study area and conceivably accelerate or reactivate movement on these features include: unloading (undercutting) the toe of the slope by natural erosion (caused by glaciation and/or stream flow); periods of intense and/or sustained precipitation increasing the unit weight of and pore pressures within the susceptible soil and/or rock mass; and/or strong ground shaking from nearby earthquakes (as discussed further in Section 6.2). These mechanisms can also result in new landsliding of susceptible deposits where none was present before.

Issues that need to be considered relative to existing landslides and the potential for future additional or new slope instability relative to dam, reservoir and appurtenances siting and design include, but are not necessarily limited to:

- Low strength, high compressibility, low density, and/or high permeability conditions in facility foundations;
- Reactivation of movement by loading, undercutting and/or increases in seepage and pore pressures;
- Large-scale failures into a reservoir resulting in erosive and/or overtopping waves;
- Smaller scale failures into the reservoir resulting in accelerated sedimentation and loss of storage; and
Formation of new failures by saturation of the lower portions of metastable slopes, especially when subject to significant earthquake shaking.

The potential landsliding/slope stability hazard at any given site depends on a wide array of site-specific conditions (e.g., topography, geology, hydrology, climate, and proposed temporary and permanent earthwork). In general, smaller slides can be removed during construction or dealt with as a maintenance issue if/as necessary during project operation. If possible, large landslides and metastable slopes should be avoided during facility siting. If this is not feasible, detailed studies are required to properly assess the risk posed by the slide/instability and the technical and cost feasibility of structural mitigation.

6.2 Seismotectonics

The Upper Green River Westside study area lies at the eastern margin of the Intermountain Seismic Belt (ISB), a zone of significant historic and active seismicity extending from Arizona to Montana and including the westernmost portions of Wyoming. Although the study area, at the margin of the ISB, is characterized by relatively low historically recorded seismicity, it is subject to potentially high earthquake-induced ground motions due to known and potentially active faults to the west within the Wyoming Overthrust Belt and unassociated or random earthquake occurrence as discussed in the following subsections.

6.2.1 Known and Potentially Active Faults

Earthquakes and the accompanying strong ground motions and secondary seismic effects (e.g., landsliding, soil liquefaction, etc.) are produced by movement on active faults within the earth’s crust. Sufficiently large earthquakes can result in enough movement on the causative fault to produce offset at the ground surface. Thus, it is important to evaluate the presence, and if present, the potential activity of faults in the area within and surrounding the Upper Green River Westside study area. Figure 6.2-1 – Quaternary Faults shows the location of mapped faults within 100 km of the approximate center of the study area that are judged to be of Quaternary age or younger (movement within the last approximately 1.6 million years) and thus classified as active or potentially active. Table 6.2-1 – Quaternary Fault Data summarizes key information for these potential earthquake producing structures (static maps: http://earthquake.usgs.gov/regional/qfaults/wy/index.php; interactive maps: http://gldims.cr.usgs.gov/qfault/viewer.htm).

There are no known active or potentially active faults judged capable of surface ground rupture that might affect any of the alternative dam and reservoir sites identified in the study area. This conclusion should be confirmed as part of more detailed seismotectonic studies should any of the preferred alternative projects advance to the next level of study.

Of the faults shown on Figure 6.2-1 those judged most likely to produce future earthquakes that would result in potentially strong ground motions within the study area due to their proximity and estimated age of last movement are the Greys River fault and the Star Valley section of the Grand Valley fault (see Table 6.2-1). The other faults on Figure 6.2-1 show evidence of less recent movement, have lower slip rates, are shorter (and thus likely less capable of generating large earthquakes), and/or are further removed from the study area. The potential magnitude of future ground motions within the study area from these faults is judged significantly lower.
than from the Greys River and Grand Valley faults. More detailed information on selected of the above noted faults is included in Appendix C – Seismotectonics.

6.2.2 Seismicity

A total of 530 earthquakes have been historically reported or instrumentally recorded within 100 km radius of the approximate center of the study area since 1917. Of these, 357 were $> \text{magnitude 3.0}$, 67 $> \text{magnitude 4.0}$, and 6 $> \text{magnitude 5.0}$. All but six (6) of the 530 events have been recorded since 1973 (see National Earthquake Information Center (NEIC) Earthquake Search Results extracted from the following website http://neic.cr.usgs.gov/neis/epic/ in tabular form in Appendix C). The approximate locations of earthquakes of magnitude greater than 3.0 are shown on Figure 6.2-2 – Historic Seismicity. The largest instrumentally recorded earthquake within the search area was a magnitude 5.8 event on February 3, 1994 located in Star Valley between Afton and Grover about 36 miles west of the center of the study area. No other events $\geq M4.0$ (the approximate threshold for even local damage) are known to have occurred closer to the center of the study area.

The historic seismicity of Sublette County, including the Upper Green River Westside study area, is discussed in some detail by Case, et al. (2002) in a report titled Basic Seismological Characterization for Sublette County, Wyoming (copy included in Appendix C). Other maps and catalogs of historic seismicity in and around the study area are available from the State of Wyoming in Case, et al. (1997); and at: http://www.wrds.uwyo.edu/wrds/wsgs/hazards/quakes/quake.html.

It is important to recognize that the low to moderate historic seismicity within and near the study area is not necessarily a reliable indicator of the potential future scale of earthquake hazard. The fact that the first historically reported earthquake within a 100 km radius of the study area occurred in 1917 is evidence of the brevity of the historic earthquake record for the study area (i.e., only 91 years). This is an extremely brief period relative to even the recent geologic past that is relevant to the potential for damaging future earthquakes in or near the study area.

6.2.3 Deterministic Site Ground Motions

If any of the alternatives identified herein advance to the next level of study, a detailed evaluation of the potential ground motions at the site(s) from an estimated maximum credible earthquake (MCE) on each known or potential earthquake source (i.e., fault) identified in Table 6.2-1 should be performed. The deterministic evaluation of the MCE would be based on available information about each active and potentially active fault within 100 km of the site, including but not limited to potential fault rupture length/area, age of last movement, associated seismicity, etc. Appropriate published attenuation relationships would then be used to estimate the relevant ground motions at a given site from an MCE event on each fault. At a minimum this would include estimation of peak horizontal ground acceleration (PHGA).

6.2.4 Random Earthquakes

Because fairly large earthquakes can and do occur where no known source structure (e.g., an active fault or fold) is known to be present, it is prudent to design critical structures such as high hazard dams assuming that a “floating or random” earthquake could occur near the facility. A previous study for the Bureau of Reclamation (Geomatrix Consultants, Inc., 1988) recommended that a M6.25 event be assumed at a distance of 15 km to address this potential in the seismotectonic province that
includes the Upper Green River Westside study area. Such an event would result in peak horizontal accelerations on the order of 0.15g anywhere in the study area. (Case, et al., 2002) This level of shaking could result in some effects such as triggering metastable landslides or weakening loose, saturated silty to sandy soils. However, as discussed in the next section future strong ground motion in this area will more likely be controlled by the nearby active or potentially active faults than by a random earthquake event of the size estimated here.

6.2.5 Probabilistic Site Ground Motions
The U.S. Geological Survey has developed an interactive program that predicts probabilistic levels of ground shaking in a given area based on the presence of the surrounding known or suspected active earthquake generating structures and the potential for a floating or random earthquake event. This program can be accessed at: http://earthquake.usgs.gov/research/hazmaps/products_data/2008/. For the purposes of this study, a map showing the predicted peak horizontal ground accelerations within the Sublette Creek watershed with an annual probability of 2 percent of not being exceeded within any 50-year period was generated (see Figure 6.2-3 – Peak Horizontal Ground Accelerations). The recurrence interval for ground shaking of this probability of occurrence is 2,500 years. This probability of occurrence represents the minimum probabilistic basis for earthquake-resistant design of critical facilities (including high hazard dams).

As shown on Figure 6.2-3, maximum probabilistic accelerations range from about 0.16g at the eastern boundary of the study area to about 0.5g in the Wyoming Range at the western edge of the study area. Anticipated probabilistic PHGA at each preferred alternative dam site is provided in Table 4.5-1. It is possible, but not certain, that deterministic ground motions developed as described in Section 6.2.3 would be even higher. These are significant ground motions and will require full attention to earthquake resistant design of any significant to high hazard dam in the study area.

6.3 Geologic/Geotechnical Conditions - Preferred Water Supply Alternatives
Geologic conditions anticipated at each of the preferred alternative dam and reservoir sites and for the Green River pumping system are summarized on Table 4.5-1 and described in more detail in this section. These descriptions are based on the geologic mapping and characterization presented and discussed in Section 6.1, applicable references listed in Section 13.0, and geologic reconnaissance of the study area.

6.3.1 Alternative 1 – Geologic/Geotechnical Conditions
Geologic conditions at the Haines Flat Dams and Reservoir site and the associated supply and delivery canal alignments are shown on Figure 6.3-1A – Alternative 1 - Geologic Map and Figure 6.3-1B – Alternative 1 – Haines Flat Dams and Reservoir Site Geology (after Oriel and Platt, 1980; see Figure 6.1-4B for a key to geologic units). Conditions relevant to each of the major components of the alternative are described below.

Dams and Reservoir Site. The topography of the Haines Flat Reservoir site is dominated by the South Horse Creek valley and an unnamed, tributary valley (with only intermittent channels) within the North Cottonwood Creek subbasin. Haines Flat is a broad, gently overall east-sloping alluvial valley floor encompassing these two valleys. Reservoir rim slopes range widely from low (less than one percent) in the upper reservoir valley floor to moderate (up to 3H:1V) locally on valley slopes.
There is a very subtle, broad divide on the order of 20 feet high between the two valleys comprising Haines Flat that would need to be breached to maximize the flexibility of operational releases from the reservoir to South Horse and/or North Cottonwood Creek.

As shown on Figure 6.3-1B, most of the reservoir area and much of the foundations at both the north and south dam sites are underlain by recent alluvium in the valley bottom. The depths of these deposits are not known due to the absence of subsurface exploration at this level of study. Based on the topography and geomorphology of the site and experience at other similar sites, it is estimated for purposes of this study that the alluvium is a maximum of about 40 feet deep in the South Horse Creek valley and about 30 feet deep in the unnamed upper North Cottonwood tributary valley. The gradation of the recent valley alluvium is known only where it has been observed in the general vicinity during site reconnaissance. In available exposures the alluvium varies from silt to silty fine sand with little clay to sand and gravel with variable percentages of fines. It is assumed that the alluvium is at most moderately dense to dense where deepest. Given the nature of the surrounding bedrock, it is not anticipated that clayey alluvium will be abundant although it may be locally present.

Although not shown at this scale of mapping, it is very likely that at least some colluvium/slopewash is present on nearly all but the steepest valley slopes where bedrock crops out locally. Depths of slopewash/colluvium are assumed to vary from less than a foot to 15 feet maximum depth at the base of slopes where these deposits likely interfinger with or overlie the adjacent alluvial deposits. The gradation of slopewash/colluvium varies widely and depends on the nature of the upslope units from which it was derived (e.g., mudstone bedrock to sand and gravel terrace deposits). The slopewash/colluvial deposits should be assumed to be loose to only slightly dense.

Only two relatively small landslides have been mapped in the dams and reservoir site area: 1) a mudflow on the south valley wall of the southern leg of the reservoir just above the proposed high water elevation; and 2) a block slide on the south valley wall of the southern reservoir leg just downstream of the right abutment of the proposed south dam. Neither of these existing landslides is expected to influence the design or operation of the dams and reservoir at this site. However, these failures suggest that there is some potential for future failures due to saturation of the lower valley slopes and/or the occurrence of large earthquakes in the region. Even if such future failures were to occur, they are not thought likely to have a major impact on the proposed dams and reservoir. This conclusion should, however, be verified or modified as part of subsequent geologic studies should this alternative advance to further consideration.

Surficial deposits including older alluvium, alluvial terrace, and coarser-grained deposits of uncertain origin are widespread on the upper valley slopes and bench surfaces surrounding the dams and reservoir site as shown on Figure 6.3-1B. These deposits may also locally underlie portions of the abutments of the dam sites. The depth of these deposits varies widely; depths are estimated to range from as little as a few feet (especially near the edges of benches where they have been eroded) to many tens of feet as discussed in Section 6.1.3. Gradations are predominantly coarse (sand and gravel), but may contain significant percentages of typically low- to non-plastic silty fines. These deposits should be suitable for shell material for a zoned earth dam. Based on currently available information, it is assumed that areas of sufficiently
coarse-grained material of adequate quantity could be found in the general vicinity to serve as borrow for aggregate. It is anticipated, however, that significant processing would be required to meet gradation specifications for filter, drain and/or concrete aggregate.

The Haines Flat dams and reservoir site of Alternative 1 are underlain by bedrock of the La Barge Member of the Wasatch Formation. The lithologies (rock types) comprising this unit are described in some detail in Section 6.1.4, and structure within this unit is discussed in Section 6.1.5. In general, finer-grained bedrock (e.g., mudstone or siltstone) that is cropping out at the surface or only shallowly buried will be weathered to depths assumed as on the order of 10 feet maximum. The upper portion of the weathered zone is likely degraded to residuum (bedrock weathered in place to soil). Little to unweathered La Barge Member bedrock is assumed to range from weak to moderately strong, soft to moderately hard, and closely to moderately fractured/jointed, with quality improving with depth. Weathered bedrock at this site should be able to be excavated with common equipment, possibly with light ripping required locally. Unweathered bedrock may require heavier ripping, but blasting is not expected to be required. In general, the bulk permeability of La Barge Member bedrock is expected to be relatively low, but local permeability in jointed/fractured zones and more granular zones (sandstone, conglomerate beds/lenses) could be moderate to high.

North Horse Creek Supply Canal. The conceptual-level alignment of this supply canal traverses varied topography, from moderate slopes at the northern end (up to about 5H:1V) to very low slopes along most of the alignment. It is likely that slopewash/colluvium, recent alluvium, and alluvial terrace deposits will be encountered to the anticipated depths of excavation along the current alignment, although La Barge Member bedrock may be encountered locally. Seepage losses are expected to be moderate to locally high for an unlined canal founded on these materials. There is a fairly large landslide complex mapped on the slope immediately above the alignment near the north end. Care will be required to either avoid disturbing this existing slope by routing the canal away from the toe of the slide zone, or implement local slope stabilization if adjusting the route is not feasible.

North Cottonwood Creek Supply Canal. This canal is conceptually aligned along the moderately steep to steep (ranging from about 3H:1V to as much as 1.5H:1V locally) north valley slope of North Cottonwood Creek. It is estimated that La Barge Member bedrock will be encountered at excavation depths over as much as about half of the alignment. The remainder of the alignment is underlain by colluvium, recent alluvium, and alluvial terrace or other gravelly deposits. Seepage of an unlined canal is expected to be minor in areas founded in bedrock and moderate to locally high where the alignment traverses surficial deposits. A total of six landslides of varying type and size are present along the conceptual alignment. If these existing areas of slope failure cannot be avoided (e.g., by using a pumped supply system rather than a gravity canal), then slope stabilization and special design will be necessary (perhaps including utilizing pipe instead of open cut canal locally).

Horse Creek Delivery Canal. This supply canal alignment traverses relatively flat valley bottom land over most of its length. There are three creek crossings, Horse Pasture Draw Creek, North Horse Creek and Lead Creek. Most of the alignment is underlain by recent or older alluvium; some colluvium and/or terrace deposits may be encountered along the base of the north slope of the South Horse Creek valley. No
landslides are present along the currently envisioned alignment, and slope stability is not anticipated to be an issue for this canal. Seepage may be relatively high given the anticipated gradation of the surficial deposits crossed, but high groundwater may act to minimize losses along much of the alignment.

**North Cottonwood Creek Pumping Station/Delivery Canal to South Cottonwood Creek.** The proposed pumping station site on North Cottonwood Creek is underlain by recent alluvium and/or colluvium derived from alluvial terrace deposits. The short pipeline reach of the delivery conveyance system locally traverses a moderately steep slope of 2.5H:1V in terrace deposits. The delivery canal alignment is underlain for nearly its full length by terrace deposits or gravelly deposits of uncertain origin present on the bench surface traversed. Seepage is expected to be moderate to heavy over most of the alignment in an unlined canal. No existing landslides are present and no slope stability issues are anticipated.

### 6.3.2 Alternative 2 – Geologic/Geotechnical Conditions

Geologic conditions at the Mickelson Creek Dam and Reservoir site and the associated delivery canal alignment are shown on Figure 6.3-2 - Alternative 2 - Geologic Map (after Oriel and Platt, 1980; see Figure 6.1-4B for a key to geologic units). Conditions relevant to each of the major components of the alternative are described below.

**Dam and Reservoir Site.** The topography of the Mickelson Creek Reservoir site is dominated by the convergence of South Cottonwood Creek and Mickelson Creek valleys. The area where the creeks merge is a broad, gently overall east- to northeast-sloping alluvial valley floor. The Mickelson Creek Dam site is at a narrow constriction where South Cottonwood Creek has breached a northeast trending ridge that rises above the surrounding valley floors at the edge of the elevated benchland to the south. Reservoir rim slopes range widely from low (less than one percent) in the valley floor to moderate (up to a maximum of about 3H:1V, but more typically about 4-5H:1V) locally on valley slopes. There is a swale in the ridge north of the reservoir that would need to be blocked by a saddle dam if the reservoir pool is higher than about elevation 7730 feet. This swale may also provide a site for an emergency and/or service spillway depending on reservoir normal and flood pool levels.

As shown on Figure 6.3-2, most of the reservoir area and some of the foundation at the main dam site are underlain by recent and older alluvium in the valley bottoms and overbank areas. The depths of these deposits are not known due to the absence of subsurface exploration at this level of study. Based on the topography and geomorphology of the site and experience at other similar sites, it is estimated for purposes of this study that the alluvium is a maximum of about 40 feet deep in the South Horse Creek valley. The gradation of the recent and older alluvium is known only where it has been observed in the general vicinity during site reconnaissance. In available exposures the alluvium varies from silt to silty fine sand with little clay to sand and gravel with variable percentages of fines. It is assumed that the alluvium is at most moderately dense to dense where deepest. Given the nature of the surrounding bedrock, it is not anticipated that clayey alluvium will be abundant although it may be locally present.

Although only shown in thicker deposits at this scale of mapping, it is very likely that at least some slopewash/colluvium is present on all of the valley slopes. Depths of slopewash/colluvium are assumed to vary from less than a foot to 15 feet maximum
depth at the base of slopes where these deposits likely interfinger with or overlie adjacent recent or older alluvial deposits, respectively. The gradations of slopewash and colluvium vary widely and depend on the nature of the upslope units from which they were derived (e.g., mudstone bedrock to sand and gravel terrace deposits). The slopewash/colluvial deposits should be assumed to be loose to only slightly dense.

No landslides have been mapped in the dam and reservoir site area, although a number of small to moderate size mudslides and mudflows are mapped on the slopes of the dissected ridge upstream of the reservoir site. None of these existing landslides is expected to influence the design or operation of the dam and reservoir at this site. However, these failures suggest that there is some potential for future failures due to saturation of the lower valley slopes at the reservoir rim and/or the occurrence of large earthquakes in the region. Even if such future failures were to occur, they are not thought likely to have a major impact on the proposed dam and reservoir. This conclusion should, however, be verified or modified as part of subsequent geologic studies should this alternative advance to further consideration.

Surficial deposits including alluvial terrace deposits and coarser-grained deposits of uncertain origin are widespread on the upper valley slopes and bench surfaces surrounding the dam and reservoir site as shown on Figure 6.3-2. These deposits may also locally underlie portions of the abutments of the main dam site and the saddle dam or spillway site beyond the left abutment. The depth of these deposits varies widely; depths are estimated to range from as little as a few feet (especially near the edges of benches where they have been eroded) to many tens of feet as discussed in Section 6.1.3. Gradations are predominantly coarse (sand and gravel), but may contain significant percentages of typically low- to non-plastic silty fines. These deposits should be suitable for shell material for a zoned earth dam. Based on currently available information, it is assumed that areas of sufficiently coarse-grained material of adequate quantity could be found in the general vicinity to serve as borrow for aggregate. It is anticipated, however, that significant processing would be required to meet gradation specifications for filter, drain and/or concrete aggregate.

The dam and reservoir site of Alternative 2 are underlain at some depth by bedrock of the La Barge Member of the Wasatch Formation. The lithologies (rock types) comprising this unit are described in some detail in Section 6.1.4, and structure within this unit is discussed in Section 6.1.5. In general, finer-grained bedrock (e.g., mudstone or siltstone) that is cropping out at the surface or only shallowly buried will be weathered to depths assumed as on the order of 5-10 feet maximum. The upper portion of the weathered zone is likely degraded to residuum (bedrock weathered in place to soil). Little to unweathered La Barge Member bedrock is assumed to range from weak to moderately strong, soft to moderately hard, and closely to moderately fractured/jointed, with quality improving with depth. Weathered bedrock at this site should be able to be excavated with common equipment, possibly with light ripping required locally. Unweathered bedrock may require heavier ripping, but blasting is not expected to be required. In general, the bulk permeability of La Barge Member bedrock is expected to be relatively low, but local permeability in jointed/fractured zones and more granular zones (sandstone, conglomerate beds/lenses) could be moderate to high.

South Cottonwood Creek Delivery Canal. This delivery canal alignment traverses the lowermost slope of the ridge north of the dam and reservoir site for about the first third of its length, and then relatively flat valley overbank and bottom land over most
of the rest of the alignment. There is one perennial creek crossings at Killpecker Creek, and two small, intermittent creek crossings. The central portion of the alignment is underlain by older alluvium, while the southern and northern portions traverse terrace deposits and possibly shallow to outcropping bedrock along the base of the north slopes of the South Horse Creek and Killpecker Creek valleys. Seepage of an unlined canal is expected to be minor in areas founded in bedrock and moderate to locally high where the alignment traverses surficial deposits. A total of five (5) landslides of varying size and type (mudslides, mudflows, a slump and a debris flow) are present along the conceptual alignment. If these existing areas of slope failure cannot be avoided (e.g., by using a pumped supply system for part of the alignment rather than a gravity canal), then slope stabilization and special design will be necessary (perhaps including utilizing pipe instead of open cut canal locally).

6.3.3 Alternative 3 – Geologic/Geotechnical Conditions

Geologic conditions at the Whiskey Creek Dam and Reservoir site are shown on Figure 6.3-3 – Alternative 3 - Geologic Map (after Oriel and Platt, 1980; see Figure 6.1-4B for a key to geologic units). Conditions relevant to each of the major components of the alternative are described below.

**Dam and Reservoir Site.** The *topography* of the Whiskey Creek Reservoir site is dominated by the valley of North Piney Creek. The dam site is located where the valley is about 2,800 feet wide; less than two miles downstream the valley is more than twice as wide. Reservoir rim slopes range widely from low (less than one percent) in the valley floor to moderate (up to a typical maximum of about 3H:1V on valley slopes) to locally steep (up to 1.5H:1V) along the southern valley wall at and for about three-quarters of a mile upstream of the proposed dam site. A relatively low ridge extending south from the right dam abutment may provide a site for an emergency and/or service spillway depending on reservoir normal and flood pool levels.

As shown on Figure 6.3-3, most of the reservoir area and foundation at the proposed dam site are underlain by *recent alluvium* in the valley bottom. The depth of these deposits is not known due to the absence of subsurface exploration at this level of study. Based on the topography and geomorphology of the site and experience at other similar sites, it is estimated for purposes of this study that the alluvium is a maximum of about 40 feet deep in this reach of the North Piney Creek valley. The gradation of the alluvium is known only where it has been observed in the general vicinity during site reconnaissance. In available exposures the alluvium varies from silt to silty fine sand with little clay to sand and gravel with variable percentages of fines. It is assumed that the alluvium is at most moderately dense to dense where deepest. Given the nature of the surrounding bedrock, it is not anticipated that clayey alluvium will be abundant although it may be locally present.

Although only shown in thicker deposits at this scale of mapping, it is very likely that at least some *slopewash/colluvium* is present on all but the steepest valley slopes where bedrock crops out locally. Depths of slopewash/colluvium are assumed to vary from less than a foot to 15 feet maximum depth at the base of slopes where these deposits likely interfinger with or overlie the adjacent recent alluvial deposits. The gradations of slopewash and colluvium vary widely and depend on the nature of the upslope units from which they were derived (e.g., mudstone bedrock to sand and gravel terrace deposits). The slopewash/colluvial deposits should be assumed to be loose to only slightly dense.
Four (4) landslides have been mapped on the north valley slope above the proposed reservoir high water elevation, and other landslides are present on both the north and south valley slopes upstream. The landslides above the reservoir pool area are small to moderate size block slides, a slump and a debris flow. None of these existing landslides is expected to significantly influence the design or operation of the dam and reservoir at this site. However, these failures suggest that there is some potential for future failures due to saturation of the lower valley slopes at the reservoir rim and/or the occurrence of large earthquakes in the region. Even if such future failures were to occur, they are not thought likely to have a major impact on the proposed dam and reservoir. This conclusion should, however, be verified or modified as part of subsequent geologic studies should this alternative advance to further consideration.

Surficial deposits including alluvial terrace deposits and coarser-grained deposits of uncertain origin are widespread on the upper valley slopes and bench surfaces surrounding the dam and reservoir site as shown on Figure 6.3-3. These deposits likely also locally underlie portions of the upper abutments of the dam site and the potential spillway site beyond the right abutment. The depth of these deposits varies widely; depths are estimated to range from as little as a few feet (especially near the edges of benches where they have been eroded) to many tens of feet as discussed in Section 6.1.3. Gradations are predominantly coarse (sand and gravel), but may contain significant percentages of typically low- to non-plastic silty fines. These deposits should be suitable for shell material for a zoned earth dam. Based on currently available information, it is assumed that areas of sufficiently coarse-grained material of adequate quantity could be found in the general vicinity to serve as borrow for aggregate. It is anticipated, however, that significant processing would be required to meet gradation specifications for filter, drain and/or concrete aggregate.

The dam and reservoir site of Alternative 3 are underlain at some depth by bedrock of the La Barge Member of the Wasatch Formation. The lithologies (rock types) comprising this unit are described in some detail in Section 6.1.4, and structure within this unit is discussed in Section 6.1.5. In general, finer-grained bedrock (e.g., mudstone or siltstone) that is cropping out at the surface or only shallowly buried will be weathered to depths assumed as on the order of 10 feet maximum. The upper portion of the weathered zone is likely degraded to residuum (bedrock weathered in place to soil). Little to unweathered La Barge Member bedrock is assumed to range from weak to moderately strong, soft to moderately hard, and closely to moderately fractured/jointed, with quality improving with depth. Weathered bedrock at this site should be able to be excavated with common equipment, possibly with light ripping required locally. Unweathered bedrock may require heavier ripping, but blasting is not expected to be required. In general, the bulk permeability of La Barge Member bedrock is expected to be relatively low, but local permeability in jointed/fractured zones and more granular zones (sandstone, conglomerate beds/lenses) could be moderate to high.

6.3.4 Alternative 4 – Geologic/Geotechnical Conditions

Geologic conditions at the Fish Creek Dam and Reservoir site and the associated delivery canal alignment are shown on Figure 6.3-4 – Alternative 4 - Geologic Map (after Oriel and Platt, 1980; see Figure 6.1-4B for a key to geologic units). Conditions relevant to each of the major components of the alternative are described below.
**Dam and Reservoir Site.** The *topography* of the Fish Creek Reservoir site is dominated by the convergence of South Piney Creek and Fish Creek valleys. The area where the creeks merge is a broad, gently overall southeast-sloping alluvial valley floor. The Fish Creek Dam site is at the narrowest portion of the combined valleys; the South Piney Creek valley widens rapidly below this confluence. Reservoir rim slopes range from very low (less than one percent) in the upstream valley floor to moderately steep (up to a maximum of about 1.5-2H:1V, but more typically about 3H:1V) on valley slopes. The bench extending beyond the left dam abutment may provide a site for an emergency and/or service spillway depending on reservoir normal and flood pool levels.

As shown on Figure 6.3-4, most of the reservoir area and the foundation at the dam site are underlain by *recent alluvium* in the converged valley bottoms. The depths of these deposits are not known due to the absence of subsurface exploration at this level of study. Based on the topography and geomorphology of the site and experience at other similar sites, it is estimated for purposes of this study that the alluvium is a maximum of about 50 feet deep at the Fish Creek Dam site. The gradation of the recent alluvium is known only where it has been observed in the general vicinity during site reconnaissance. In available exposures the alluvium varies from silt to silty fine sand with little clay to sand and gravel with variable percentages of fines. It is assumed that the alluvium is at most moderately dense to densest. Given the nature of the surrounding bedrock, it is not anticipated that clayey alluvium will be abundant although it may be locally present.

Although only shown in thicker deposits at this scale of mapping, it is very likely that at least some *slopewash/colluvium* is present on all of the valley slopes. Depths of slopewash/colluvium are assumed to vary from less than a foot to 15 feet maximum depth at the base of slopes where these deposits likely interfinger with or overlie adjacent recent or older alluvial deposits, respectively. The gradations of slopewash and colluvium vary widely and depend on the nature of the upslope units from which they were derived (e.g., diamictite bedrock to sand and gravel terrace deposits). The slopewash/colluvial deposits should be assumed to be loose to only slightly dense.

A number of moderate to larger *landslides* have been mapped in the dam and reservoir site area. These existing landslides mostly classify as mudslides, mudflows, and debris flow/alluvial fans. These failures all occur within swales on the valley slopes where runoff is concentrated and weathering of the underlying relatively lower strength, finer-grained bedrock is deepest. The proposed conceptual-level dam centerline alignment should be selected to avoid a mudslide/mudflow deposit in the right abutment area. Two of the existing failures would be partially inundated by the currently envisioned normal high water level of the Fish Creek Reservoir. These failures will be buttressed by the reservoir pool when full but subject to delayed drainage and potential reactivation during lower pool levels. This could result in adding some additional sediment load to the reservoir but is not considered a serious dam safety concern based on currently available information. All of the other failures are above the currently anticipated normal high water level of the reservoir and thus are not expected to significantly influence the design or operation of the dam and reservoir at this site. However, all of these failures at and near the site suggest that there is some potential for future failures due to saturation of the lower valley slopes at the reservoir rim and/or the occurrence of large earthquakes in the region. Even if such future failures were to occur, they are not thought likely to have a major impact on the proposed dam and reservoir. This conclusion should, however,
be verified or modified as part of subsequent geologic studies should this alternative advance to further consideration.

Surficial deposits including alluvial terrace deposits and coarser-grained deposits of uncertain origin are locally present on the upper valley slopes and bench surfaces surrounding the dam and reservoir site as shown on Figure 6.3-4. These deposits may also locally underlie portions of the abutments of the dam site and the potential spillway site at or beyond the left abutment. The depth of these deposits varies widely; depths are estimated to range from as little as a few feet (especially near the edges of benches where they have been eroded) to many tens of feet as discussed in Section 6.1.3. Gradations are predominantly coarse (sand and gravel), but may contain significant percentages of typically low- to non-plastic silty fines. These deposits should be suitable for shell material for a zoned earth dam. Based on currently available information, it is assumed that areas of sufficiently coarse-grained material of adequate quantity could be found in the general vicinity to serve as borrow for aggregate. It is anticipated, however, that significant processing would be required to meet gradation specifications for filter, drain and/or concrete aggregate.

The dam and reservoir site of Alternative 4 are underlain at some depth by bedrock of the “conglomerate member” or diamictite of the Wasatch Formation. The lithologies (rock types) comprising this unit are described in some detail in Section 6.1.4, and structure within this unit is discussed in Section 6.1.5. In general, predominantly finer-grained bedrock (e.g., mudstone) that is cropping out at the surface or only shallowly buried will be weathered to depths assumed as on the order of 5-15 feet maximum. The upper portion of the weathered zone is likely irregularly degraded to residuum (bedrock weathered in place to soil). Little to unweathered diamictite bedrock is assumed to range from weak to moderately strong, locally soft to moderately hard, and closely to moderately fractured/jointed, with quality improving with depth and where larger blocks of harder rock and/or sandstone matrix are present. Weathered bedrock at this site should be able to be excavated with common equipment, possibly with light to moderate ripping required locally. Unweathered bedrock may require heavier ripping, but blasting is not expected to be required unless especially large blocks of hard rock are encountered. In general, the bulk permeability of La Barge Member bedrock is expected to be relatively low, but local permeability in jointed/fractured zones and more granular zones (sandstone, conglomerate beds/lenses) could be moderate to high.

**Middle Piney Creek Delivery Canal.** This delivery canal alignment traverses the mid-slope of a broad, gently sloping, coalescing alluvial fan (derived from alluvial terrace deposits to the north) merging with the alluvial valley of South Piney Creek for all but about the last one-fifth of its length. The rest of the alignment is on relatively flat overbank and bottom land of Middle Piney Creek. Seepage of an unlined canal is expected to be moderate to locally high as essentially all of the alignment traverses surficial deposits. No existing landslides are mapped along the canal alignment and slope stability is not expected to be an issue of significance for this feature.

### 6.3.5 Alternative 5 – Geologic/Geotechnical Conditions

Geologic conditions at the Green River pumping station and along the associated delivery pipeline and canal alignments are shown on Figure 6.3-5 – Alternative 5 - Geologic Map (after Oriel and Platt, 1980; see Figure 6.1-4B for a key to geologic
Units. Conditions relevant to each of the major components of the alternative are described below.

**Pumping Station/Diversion.** The topography of the proposed pumping station and its associated diversion structure is dominated by the floodplain and overbank of the mainstem Green River and the nearby confluence of the Muddy Creek valley. Slopes are very gentle, except locally at the edge of the floodplain where a moderately sloped bank up to about 10-15 feet high is locally present. Recent alluvium of significant depth (very likely greater than 50 feet) is present at this site. The alluvium in eroded banks and visible in the river bed is predominantly sand, gravel and cobbles with varying amounts of fines. However, finer grained silty to fine sandy overbank deposits are also present, and the possible presence of some clay beds/lenses cannot be discounted. It is assumed that the alluvium is at most moderately dense to dense where deepest.

**Pipeline.** The conceptual-level pipeline alignment first traverses the alluvial overbank of the Green River/Muddy Creek confluence and then climbs to the gently sloping surface of a broad alluvial terrace adjacent to the incised valley of Muddy Creek. The alignment is underlain by recent alluvium for the first approximately one-fifth of its length, and then by alluvial terrace deposits for the remainder of its length. Both the recent alluvium and the alluvial terrace deposits are likely predominantly coarse-grained (sand and gravel), but with varying to locally significant percentages of mostly low- to non-plastic fines. These deposits should be readily excavated by common earthmoving equipment (e.g., backhoe or tracked hoe); the alluvial terrace deposits will likely be somewhat denser and may be lightly to moderately cemented by carbonate at least locally.

**Canal.** The range of topographic and geologic conditions along essentially all of the conceptual-level canal alignment is judged similar to those described for the pipeline alignment. About two-fifths of the alignment is underlain by recent alluvium of North, Middle and South Piney Creeks with the remainder underlain by alluvial terrace deposits. Seepage is expected to be moderate to heavy in an unlined canal along this alignment, unless ground water is near enough to the surface to at least partially balance seepage heads.

### 7.0 Environmental and Permitting Issues

#### 7.1 Environmental Considerations

##### 7.1.1 Preliminary Consultations

A memorandum was prepared and submitted to several resource/permitting agencies describing the general location, size and nature of the preferred water supply alternatives identified during this study and seeking initial feedback as to potentially significant environmental issues and related permitting requirements. The alternatives included the four (4) preferred new dam and reservoir sites and the Green River pumping concept described in Sections 4.5 and 5.2. Agencies contacted included the U.S. Department of the Interior, Fish and Wildlife Service (FWS), the Wyoming Game and Fish Department (WGFD), the U.S. Department of the Interior, Bureau of Land Management (BLM), and the U.S. Army Corps of Engineers (USACE). Responses to the memorandum were received from BLM by email dated October, 20, 2008 (BLM, 2008), from USACE by letter dated October 30, 2008 (USACE, 2008), from WGFD by letter dated October 31, 2008 (Wyoming Game and Fish Department, 2008), and by FWS by letter dated November 4, 2008 (FWS, 2008).
Covers of these responses are provided in Appendix D – Environmental Permitting. Identification of potential environmental issues and related permitting considerations described in the following subsections are based on the results of these preliminary consultations and on compilation and review of other relevant publicly available information.

### 7.1.2 Animal and Plant Resources

The Wyoming Natural Diversity Database (WYNDD) identifies documented occurrences of 75 species of concern within the Upper Green River Westside study area, including some within or in the vicinity of the preferred alternative water supply project sites as shown on Figure 7.1-1. These are species that are rare, endemic, disjunct, threatened, or otherwise regarded as biologically sensitive due to their rarity (restricted distribution, small population size, low population density), inherent vulnerability (e.g., specialized habitat requirements, restrictive life history), and/or threats (e.g., significant loss of habitat, sensitivity to disturbance).

The potential exists for some of these species to occur within appropriate habitats within the study area. Although none of these species currently receive federal or state protection, it may be necessary and appropriate to further evaluate their occurrence and potential impacts from the preferred water supply alternatives should any of these projects continue.

More detailed information on certain key species is available in the Draft Biological Assessment for the Pinedale Resources Management Plan/Draft Environmental Impact Statement (BLM, 2007). These include the Black-footed Ferret, Grizzly Bear, Canada lynx, Gray Wolf, Bald Eagle, Western Yellow-billed Cuckoo, Kendall Warm Springs Dace, Ute’s Ladies Tresses Orchid, Colorado Pikeminnow, Razorback sucker, Bonytail, and Humpback chub.

WGFD recommends evaluation of the presence of certain U.S. Forest Service (USFS) sensitive avian species at any sites characterized by forested north-facing slopes, including: northern goshawk, great gray owl, boreal owl, flammulated owl, and northern three-toed woodpecker.

**Proposed, Threatened, Endangered and Experimental Species.** Certain listed species if potentially affected by any of the project alternatives would trigger a requirement for formal consultation with FWS under the Endangered Species Act (ESA). These include the Black-footed ferret (status – endangered), Canada lynx (status - threatened), Gray wolf (status – experimental), and Ute ladies’-tresses (status – threatened). Although requiring further evaluation at a subsequent level of study, the potential for impacts to any of these species at any of the preferred alternative dam and reservoir sites under consideration in this study is judged relatively low with the possible exception of the gray wolf.

WGFD notes that the Wyoming Range may be the most important future recovery area in Wyoming for Canada lynx if adequate habitat can be maintained (including especially winter foraging habitat). Thus, any alternatives considered within historically occupied habitats in the Wyoming Range (Townships 30-35, Ranges 114-115) will receive special attention to assess the potential for current and future impacts to this threatened species. Note that all four of the preferred dam and reservoir alternative projects identified in this study fall within or along the eastern margin of the historically occupied habitat as defined by township and range above.
Migratory Birds. Bald eagles are known as year round residents of Wyoming. Their main food sources are fish, carrion, and small to medium sized mammals. They tend to be associated with riparian areas, lakes and reservoirs where mature trees provide roosting opportunities. Winter roosting occurs in areas with high density of large mature trees that protect them from the prevailing winds. If the proposed project or identified dam and reservoir site contains suitable habitat, a bald eagle survey may be needed prior to any construction activities occurring. As seen on Figure 7.1-1, the presence of bald and golden eagles may be anticipated within the study area.

Although recently removed from the list of threatened and endangered species, bald eagles are still protected under the provisions of the Bald and Golden Eagle Protection Act (BGEPA) and Migratory Bird Treaty Act (MBTA). FWS publishes national guidelines to advise land managers when and under what circumstances the provisions of these acts may apply to activities under their jurisdiction. FWS, in cooperation with WGFD, is preparing local guidelines and has proposed a permit structure under BGEPA for implementation when impacts to either bald or golden eagles are unavoidable.

In addition to bald and golden eagles, FWS encourages providing continued protection for mountain plover even though the proposal to list this species under the ESA has been withdrawn.

Sage Grouse. Sage grouse are identified as a sensitive species/species of concern and merit special attention as discussed in some detail in the following paragraphs. The two-mile radius buffers around a number of sage grouse leks (breeding grounds) as shown on Figure 7.1-2 – Sage Grouse Leks is a clear indication that this species utilizes significant portions of the study area as habitat.

The greater sage grouse (Centrocercus urophasianus) is a native species to much of Wyoming including the Upper Green River basin. This species is almost totally dependent on open sagebrush plain as its primary habitat. The males will gather in the early spring to lek (breeding ground) locations to start their elaborate courtship rituals (strutting). They are considered omnivores, eating insects, sagebrush and seeds; but are most reliant upon sagebrush for both cover from predators and for food.

The greater sage grouse is listed as a sensitive species by BLM, and a species of concern by WGFD. The BLM definition of a sensitive species is as follows: species that could easily become endangered or extinct in the state, including: (a) species under status review by the FWS/National Marine and Fisheries Service; (b) species whose numbers are declining so rapidly that Federal listing may become necessary; (c) species with typically small or fragmented populations; and (d) species inhabiting specialized refugia or other unique habitats. WGFD lists the greater sage grouse as: species that are widely distributed, with population status or trends unknown but suspected to be stable; habitat restricted or vulnerable but no recent or on-going significant loss; species likely sensitive to human disturbance. The sage grouse is not listed as a Threatened or Endangered species and does not receive any protections from the Endangered Species Act; however, BLM and WGFD have developed restrictions/recommendations to help protect the sage grouse. Furthermore, FWS is currently conducting a review to determine if the greater sage grouse warrants listing.

BLM has recommended that there be no surface occupancy within 0.25-mile radius of any known lek location or a 2-mile radius during the breeding season (March 15 to
July 15), on BLM land or lands adjacent to BLM lands. Recent studies have shown
that the 2-mile radius may not be sufficient, showing declines in the number of males
returning to the leks with activities occurring beyond the 2-mile radius. Thus, the
current recommendations may change over time.

It is recommended that close coordination be maintained with BLM (as applicable to
sites on BLM managed land) and WGFD regarding any proposed or alternative
project that has the potential to impact sage grouse habitat. WGFD recommends
detailed analysis of potential impacts to sage grouse based on recommended studies
to identify lek locations, nesting habitats, brood rearing areas, and wintering locations
at and in the vicinity of any preferred alternative projects advancing to further
consideration.

**Big Game.** The study area contains crucial big game habitat and parturition
(birthing) habitat for antelope, mule deer, elk and moose as seen on Figures 7.1-3A
through 3B – Crucial Habitat and Figures 7.1-4A through 4B – Parturition,
respectively. WGFD maps the seasonal ranges by herd unit for each big game
species and makes special note of areas listed as crucial habitat. Crucial habitat or
range is defined as those seasonal ranges or habitats (mostly winter range) that have
been documented as the determining factor in a population’s ability to maintain itself
at a certain level over a long period of time. The preferred alternative dam and
reservoir project sites are mostly outside of areas mapped as crucial habitat or
parturition areas, with the exception of crucial moose habitat at or near all of the
sites. Of particular concern to WGFD is the potential for impacts to the Sublette
moose herd, including loss of willow habitat in crucial winter range. WGFD also
note that the study area is occupied by black bears and mountain lions during spring,
summer and fall.

Recommended seasonal stipulations relevant to human activity and surface
disturbance in big game crucial habitat and parturition areas (and near sage grouse
leks) are provided for applicable portions of the study area by WGFD in their
response to the request for input noted previously (see Appendix D). The response
also recommends careful analysis of road design and placement so as to minimize big
game displacement and increased illegal hunting.

Ongoing coordination with WGFD will need to occur in order to fully assess and
evaluate potential impacts and potential mitigation measures for crucial big game
habitat/range should the project advance to the next level of study.

**Fisheries and Other Aquatic Resources.** WGFD has provided a substantial
preliminary characterization of aquatic considerations relative to the proposed
preferred water supply project alternatives in their response to a request for input (see
Appendix D). Rather than repeat that discussion here, a brief synopsis of key points
and issues is provided as follows:

- Creation of a native sport fish reservoir may be beneficial, but development of a
  non-native trout reservoir fishery is not a high priority to WGFD.
- Listed fish species of concern at this time that may occur within the study area
  and/or be impacted by changes in flow regimes within the study area include
  Colorado River cutthroat trout, flannelmouth suckers, bluehead suckers, and
  roundtail chub.
- Amphibian species of concern are the boreal toad, northern leopard frog, and Columbia spotted frog, all of which have been spotted in the Wyoming Range; little is known about their distribution within the preferred alternative dam and reservoir sites.

- Potential effects of changes in stream flow regimes by reservoir operations should be considered, including impacts on riparian habitat, streambanks, spawning habitat and other stream-related geomorphologic factors.

- Impacts related to transfer of nuisance aquatic species with delivery of water across natural divides should be evaluated.

- Issues related to riverine connectivity (passage or entrapment) for fish and other aquatic organisms need to be considered.

- Potential impacts of increased water temperatures to aquatic organisms and recreational opportunities should be considered, and use of a multiple-level outlet is encouraged to better manage the temperature of releases.

- Address instream flow, or minimum flow, for any potential site to be carried forward to further study.

- Consider the appropriate maximum reservoir depth and minimum pool capacity to achieve potential benefits of a recreational fishery.

- Evaluation of changes to and associated potential impacts of return flows is encouraged.

FWS concurs with WGFD regarding the need for formal consultation for any project that may lead to depletions of water to the Colorado River system related to the endangered fish species noted above. They also indicate that the NEPA analyses for any project should include an assessment of naturally-occurring trace element contamination (particularly selenium) that could result in impacts to fish and aquatic birds. Finally, an analysis of potential impacts to reservoir water quality from oil and gas development in the study area is recommended.

It will be especially important to continue ongoing communication and coordination with WGFD and FWS on fisheries and aquatic concerns should any of the project alternatives advance.

7.1.3 Wetland Resources

USACE has provided a response to a request for preliminary identification of known and potential issues and regulatory process requirements related to compliance with Section 404 of the Clean Water Act (see Appendix D). It is recommended that the USACE response be read and considered together with the following discussion.

Formal wetland delineation in accordance with the USACE guidelines was beyond the scope of this study and was not conducted. GIS digital mapping from the National Wetland Inventory (NWI) was acquired to preliminarily identify wetland habitats in the study area. The various locations identified as potential alternative reservoir storage sites are all located on what are considered intermittent to perennial riverine systems. These systems are associated with streambeds and their associated wetland/riparian habitat. Riparian habitats are considered to be valuable habitat for both mammals and birds, along with assisting in reducing flooding. The creation of a reservoir on the drainage would inundate the basin bottoms changing the landscape/habitat.
The wetland habitats inferred to be present within the project area based on NWI mapping are shown on Figure 7.1-5 – NWI Wetlands. The total acreage of NWI-mapped wetlands within the preliminary footprint of each of the dam and reservoir storage project alternatives has been calculated and is presented in Table 4.5-1.

Some of the areas identified on the NWI maps as wetlands may in fact not qualify as jurisdictional wetlands upon subsequent detailed examination in the field. This is due to inherent limitations in the aerial photography-based methodology used to prepare the NWI maps. It was noted during the study that significant portions of the areas mapped as wetlands on the NWI maps are currently irrigated hayfields. It is anticipated that appropriate future field studies (should a project advance) will find that some to potentially a substantial portion of the irrigated lands are not jurisdictional wetlands. This would be the case for those lands did not exhibit the necessary characteristics as wetlands in the absence of irrigation. Lands that are outside of (above) the current active floodplain of a stream (and thus separated from the waters of the United States), not subject to seasonally high ground water, would not develop hydric soils in the absence of irrigation, and would not support wetlands vegetation in the absence of irrigation would not be classified jurisdictional. A very preliminary estimate of such lands has been made at each of the preferred storage sites and used to adjust the estimated cost of wetlands mitigation for the sites.

Formal wetlands delineation would be necessary prior to construction at any proposed reservoir storage site, and in any other areas of proposed disturbance (e.g., off-site borrow areas or quarries) to determine the level of impacts to wetlands located in the alternative project area and to identify and quantify any necessary mitigation of those impacts. More formal consultation should be initiated with USACE in the next level of study to ensure wetlands delineations are acceptable and to begin discussing the nature and extent of any required mitigation. Consultation should also be carried forward with WGFD, if applicable BLM, who have expressed significant concern with the potential ripple effects of loss of wetland or riparian habitat on moose (parturition or birthing habitats), songbirds, raptors, and other species.

7.2 Permitting and Mitigation Process Evaluation

The following discussion presents the results of an early regulatory process analysis for the alternative dam and reservoir projects identified and characterized in Sections 4.5 and 5.2. The purpose of this analysis is to characterize the known and likely environmental processes, permits and related requirements and conditions associated with the alternative projects, including identification of environmental documentation, permits, agency clearances and approvals, and agency coordination steps that would be required for implementation of the proposed actions and alternatives.

Any of the potential projects described in this plan would be subject to the National Environmental Policy Act (NEPA) and other federal environmental regulations administered by federal agencies such as the EPA, Bureau of Land Management (BLM), Army Corps of Engineers (USACE), and/or the U.S. Fish and Wildlife Service (FWS). The Wyoming agencies which may have environmental, landuse, and other regulatory approval requirements include, but are not necessarily limited to the Department of Environmental Quality (WDEQ), State Engineer's Office (WSEO), State Historic Preservation Officer (SHPO), Board of Land Commissionersthrough
the State Lands and Investments Board (SLIB), and Game and Fish Department (WGFD).

NEPA compliance and documentation is presented in Section 7.2.1, permitting and approvals are discussed in Section 7.2.2, and environmental issues were discussed in Section 9.1. Mitigation is discussed in Section 7.2.3, and cultural resources are addressed separately in Section 8.0. These discussions are based upon various assumptions about the proposed actions and alternatives. These assumptions may change as project planning progresses from this study. Ultimately, the applicability of the individual federal and Wyoming permits, clearances and approvals to the project(s) will depend upon the alternative(s) selected and their implications.

7.2.1 NEPA Compliance And Documentation

NEPA applies to any of the proposed actions for which the project site is located on federal land, federal funds may be used, and/or when formal federal agency actions are necessary for the project to move forward. One of the primary intentions of the NEPA process is to avoid, minimize and mitigate adverse environmental consequences of federal actions. NEPA requires analysis and documentation of potential adverse and beneficial effects of a proposed action and alternatives and an open public involvement process.

For this project, it is likely that USACE would be the lead federal agency for implementation of the NEPA process given the known impacts to wetlands at each of the alternative sites, with BLM as a potential cooperating agency representing the interests of potentially impacted resources on and around lands under their administration. If an alternative located in the Bridger-Teton National Forest were to be considered, then it is likely that the U.S. Forest Service would be the lead federal agency.

The following discussion characterizes the basic steps of the NEPA process applicable to a reservoir storage project.

**Prepare a Purpose and Need Statement for the Project.** It is important to develop an accurate and defensible Purpose and Need statement for the project as one of the first steps in the NEPA process. The Purpose and Need statement provides an overall or basic purpose for the proposed action and presents details supporting various needs for the project. The Purpose and Need statement should provide enough information to develop and support a “reasonable range” of alternatives. More specifically, the Purpose and Need statement guides the alternative development and screening process. With the USACE as the lead agency, the Purpose and Need would include a reference to finding the “least damaging practicable alternative.” This reference relates to the Clean Water Act Section 404 requirements that are under the jurisdiction of the USACE and is an important part of the NEPA process for a reservoir storage project. Additional details about the Section 404 process are provided in Section 7.2.2. The project sponsor, WWDC, other project participants, and the public should all be part of the process of defining the Purpose and Need statement.

**Develop Project Alternatives and NEPA Documentation Determination.** The NEPA process requires analysis of the No Action alternative and a reasonable range of alternatives that fully address the project’s purpose and need. The reasonable range of alternatives may include one or more “build” alternatives, depending on the
nature and extent of anticipated project impacts and level of NEPA documentation to be provided.

For a new reservoir storage project, key issues associated with alternative development will or may include:

- Loss of wetland and riparian habitat from direct inundation by the reservoir;
- Indirect effects on wetland and/or riparian habitat upstream and/or downstream of the reservoir due to changes in stream flows associated with reservoir operations
- Potential impacts on threatened and endangered species;
- Potential impacts on fish and other aquatic species of concern; and
- Potential impacts on other wildlife (e.g., sage grouse; big game)

Given these issues and risk management considerations, the project team anticipates that an EIS will almost certainly be the appropriate NEPA documentation for reservoir storage projects. An EIS involves analysis of more than one build alternative and may take up to several years to complete. An Environmental Assessment (EA) may or may not involve analysis of more than one build alternative and can typically be completed in less than 18 months. The outcome of an EA is either a Finding of No Significant Impact (FONSI) or a recommendation to prepare an EIS. If an EA is prepared, there is a possibility that the outcome might be that an EIS is needed. This could occur as a result of “significant impact findings” or as a result of substantial public controversy over the project’s effects. If this occurs at the end of the EA process, the EIS process would need to start from the beginning, wasting a considerable amount of time and money. At this time, it appears it would be prudent to assume that an EIS process would be applicable, while leaving the option open for an EA/FONSI (especially if a much smaller project is advanced than those recommended in this study), rather than to proceed with an EA and take the risk that an EIS will ultimately be needed. This decision should be reviewed during a subsequent study (should the project advance) when more detailed information is available on a preferred proposed action and its appropriate alternatives.

Conduct a Proactive Public Involvement Program. The NEPA process begins with public and agency outreach and related input focused on alternatives and potential impacts. Education about the project’s purpose and need, project details and issues is provided and input is solicited in various ways. It is very important that the public have a clear understanding of the benefits and potential adverse impacts of the proposed action and alternatives. Public involvement is continuous throughout the project and can influence alternative development, alternative screening, issues addressed, mitigation measures, the level of NEPA documentation to be prepared (EA or EIS), and the selection of the preferred alternative.

Collect and Analyze Environmental Baseline Data. It is important to carefully identify environmental constraints and considerations early and incorporate them into alternative development efforts as a means of avoiding and minimizing potential impacts. Early field investigations and agency consultation and coordination efforts help to focus this effort and streamline subsequent analysis methods, schedule needs, and budget requirements. Creating “self-mitigating” alternatives is highly advantageous and fully consistent with the intent of NEPA.
Many NEPA analyses relate to compliance with various laws and regulations. Integrating the NEPA, National Historic Preservation Act, Endangered Species Act and other compliance processes will reduce overall permitting timeframes and costs, and streamline agency decision-making. These issues are discussed in Section 7.2.2.

**Prepare the Draft and Final Environmental Impact Statement.** The Draft EIS would be prepared in two versions. A Preliminary Draft EIS would be prepared for internal review. The Draft EIS would respond to comments on the Preliminary Draft EIS. The Draft EIS would be circulated for public review and would be the subject of a public hearing. The Final EIS would also be prepared in two versions. A Preliminary Final EIS would be prepared for internal review. The Final EIS would respond to comments on the Preliminary Final EIS. The Final EIS would be circulated for public review and would be the subject a public hearing. A Record of Decision would be prepared to complete the NEPA process.

### 7.2.2 Permitting/Clearances/Approvals

Presented below are the primary permits, clearances and/or approvals that would be required for any of the alternative dam and reservoir projects under consideration.

**Section 404 Permit.** Like all water development projects, any dam and reservoir storage project in the Upper Green River Westside study area will face environmental permitting issues. Typically, a very significant environmental permit to be secured is a Section 404 Dredge and Fill permit from the U.S. Army Corps of Engineers (USACE), Omaha District. Even when impacts are anticipated to be modest, the process of obtaining a Section 404 permit for new storage projects may take several years from initiation of the NEPA process.

The primary guidance in embarking on the permitting process for a new dam and reservoir storage project is the development of a defensible Purpose and Need for the project. The NEPA process dictates that the least environmentally damaging practicable alternative that addresses the purpose and need be pursued. This is the alternative most likely to be successfully permitted.

**Endangered Species Act (Section 7 Consultation).** The lead agency would prepare a biological assessment to determine project effects on threatened and endangered plant and animal species listed or proposed for listing (candidate species) under the Endangered Species Act (16 U.S.C. § 1531 et seq.). U.S. Fish and Wildlife Service (FWS) would then issue an opinion on whether federal actions are likely to jeopardize the continued existence of a threatened or endangered species, or destroy or adversely modify critical habitat. FWS must approve the preparation of a biological assessment to comply with the Endangered Species Act in order to render its decision. If FWS determines that the preferred alternative would jeopardize the continued existence of a species, it may offer a reasonable and prudent alternative that would preclude jeopardy.

**Fish and Wildlife Coordination Act.** The Fish and Wildlife Coordination Act requires federal agencies involved in actions that will result in the control or structural modification of any natural stream or body of water for any purpose to take action to protect the fish and wildlife resources which may be affected by the action. It requires federal agencies or applicants to first consult with state and federal wildlife agencies to prevent, mitigate and compensate for project-caused losses of wildlife resources, as well as to enhance those resources.
**Laws and Regulations Addressing Cultural Resources.** Because federal approvals are likely involved with any of the identified alternatives, a consideration of effects on cultural resources must be undertaken (Section 106 consultation), as required under the following laws and regulations: the National Historic Preservation Act (NHPA) of 1966 (16 U.S.C. § 470 et seq.); the National Environmental Policy Act (NEPA) of 1969 (42 U.S.C., § 4321); the Archaeological Resources Protection Act (ARPA) of 1979 (16 U.S.C. § 470aa et seq.); the National Park Services (NPS) procedures concerning the National Register of Historic Places (NR) (36 CFR Part 60); the Advisory Council on Historic Preservation's Procedures for the Protection of Cultural Properties (36 CFR Part 800); the Treatment of Archaeological Properties of 1980: Determination of Eligibility for Inclusion in the NR (36 CFR 63); the Secretary of Interior’s Standards and Guidelines for Archaeological Historical Preservation of 1983; Reservoir Salvage Act of 1960; and the 1974 Amendment to the Reservoir Salvage Act of 1960. The State of Wyoming Historic Preservation Office (SHPO) coordinates with federal agencies in determining the significance of cultural resources potentially affected by ground disturbing activities.

In addition, consultation with relevant Native American groups concerning traditional cultural properties is required under the American Indian Religious Freedom Act of 1978 (AIRFA, P.L. 95-341.42 U.S.C. § 1996) and Section 4 of ARPA of 1979. Guidelines for evaluation of traditional cultural properties are contained in Bulletin 38 issued by the National Park Service.

**Wyoming Board of Land Commissioners.** The Wyoming Board of Land Commissioners through the State Lands and Investments Board (SLIB) is responsible for regulating all activities on state lands, including granting of rights-of-way. Any facility, utility, road, railroad, ditch or reservoir to be constructed on state or school lands must have a right-of-way, as required in the “Rules and Regulations Governing the Issuance of Rights Of Way” (W.S. 36-20 and W.S. 36-202).

**Wyoming State Engineer’s Office Surface Water Permits.** The State Engineer’s Office administers the water rights system of appropriation within the state. The Applicant must obtain the necessary water rights permits from the State of Wyoming for the diversion and storage of the State’s surface water.

**Wyoming State Engineer’s Office Permit to Construct/Dam Safety Review.** The Wyoming Dam Safety Law (W.S. 41-3) requires that any persons, public company, government entity or private company who proposes to construct a dam which is greater than 20 feet high or which will impound more than 50 acre-feet of water, or a diversion system which will carry more than 50 cubic feet of water per second, must obtain approval for construction of the dam or ditch from the Wyoming State Engineer's Office. The approval by the State Engineer's Office of a dam's construction is contingent upon the Office's review and approval of all dam plans and specifications, which must be prepared by a registered professional engineer licensed in Wyoming. Design, construction, and operation of jurisdictional dams must also comply with dam safety regulations promulgated pursuant to the Dam Safety Act. At present, these regulations are in final draft form and formal issuance is anticipated in the not distant future.

**Wyoming Department of Environmental Quality – National Pollution Discharge Elimination System (NPDES) permit and Section 401 Certification.** The federal Clean Water Act is administered in Wyoming by the Department of Environmental
Quality (WDEQ), Water Quality Division (WQD) consistent with the Wyoming Environmental Quality Act. The Section 401 Certification is the State’s approval to ensure that the activities authorized under Section 404 meet state water quality standards and do not degrade water quality. Any discharge of pollutants into the broadly defined “waters of the state” requires application to and permit issuance by WQD in accord with WQD’s Rules and Regulations. This body of regulations sets forth classification of surface and groundwater uses and establishes water quality standards (Wyoming Water Quality Standards). The WQD administers the NPDES permit system including storm water permits and construction-related, short-term discharge permits. EPA has oversight responsibility for federal Clean Water Act programs delegated to and administered by the State Water Quality Division. EPA also may intervene to resolve interstate disputes where discharges of pollutants in an upstream state may affect water quality in a downstream state.

**Wyoming Department of Environmental Quality - WYPDES Individual Storm Water Permit.** Any of the alternative dam and reservoir storage projects evaluated during this study would classify as a large construction activity for purposes of storm water permitting since the overall area of land disturbance is greater than five (5) acres. As a result, an individual WYPDES discharge permit from WDEQ will be required. The application and implementation requirements for this permit are provided in W.S. 11-10-2004, Chapter 2 – Permit Regulations for Discharges to Wyoming Surface Waters.

**Mining Permit.** A Wyoming mining permit is not required for development of an aggregate and/or borrow material source solely for use in construction of one of the various reservoir alternatives and whose product is not for commercial sale. Commercial sources of aggregate, rock, or other mined materials are responsible for obtaining and maintaining all required permits and clearances for their operations.

**Special Use Permits/Rights-of-Way/Easements.** Special use permits, rights-of-way (ROW) or easements will be required wherever access across the lands of others (private, state or federal) is needed for construction and/or operation of the project facilities. These may be temporary (e.g., access to a temporary borrow area or quarry site to be closed and reclaimed; construction of a new haul road; etc.) or permanent (e.g., construction of a dam and its appurtenant structures, relocation of an existing road or construction of a permanent new road). Usually privately owned lands that will be rendered permanently unavailable (such as the dam and reservoir footprint of a storage project) would be purchased unless the owner desired (and the sponsoring entity agreed) to a permanent easement. Permanent use of BLM lands (if required) would most likely be administered under a grant with an appropriate term issued under their ROW process. The specific requirements for rights-of-way, special use permits and easements vary widely and should be determined as part of the early stages of planning for a specific proposed project. This will help to avoid the potential for significant project delay, higher costs, or required changes in location/alignment or design during project development and implementation.

**Other.** In addition to the above, there may be other permits and clearances required for a given dam and reservoir project. These might include permits typically required to be provided by the construction contractor (e.g., air quality permit; trash/slash burning permit; etc.).
7.2.3 Mitigation

Based on prior experience, mitigation will be required at any of the identified preferred alternative dam and reservoir sites to address impacts to wetlands, riparian vegetation, stream channel habitat, big game resources, and possibly threatened, endangered or experimental status species. As noted previously, it is preferred to avoid the need for mitigation of a potentially significant impact by relocation and/or “self-mitigating” design if technically and economically feasible, but this not likely possible for these projects.

Detailed mitigation plans would need to be prepared and approved to replace any lost wetlands identified and quantified by formal wetlands delineation, and riparian vegetation communities. It is anticipated that mitigation of this resource will be possible, albeit costly, at any of the sites by constructing additional wetlands nearby, ideally in a comparable environment as the area impacted. Reconnaissance-level review of available color infrared (CIR) aerial imagery of the study area indicates that there are overbank and low terrace areas along most of the major tributary valleys that are not mapped as NWI wetlands. These areas should be further evaluated for potential development as mitigation wetlands should one or more of the preferred projects advance to the next level of study.

Mitigation of potential raptor impacts would generally involve control of certain construction activities during sensitive time periods, and avoidance of direct disturbance of the subject species. Mitigation of potential sage grouse lek impacts and big game crucial habitat will be given special consideration as discussed previously. If any T&E species were encountered at a given site special consultation with FWS would be required to determine if appropriate mitigation could be implemented. In general, any such impacts would be avoided to the greatest extent possible by relocation of site facilities.

Other potential mitigation related to fisheries may involve fish screens on supply and delivery canals, fish ladders to provide passage around dams, and instream habitat improvements on tributary reaches upstream of reservoirs to mitigate loss of spawning and rearing habitat.

Mitigation may also be required if construction of reservoirs and supply and/or delivery canals impact big game migration routes and/or livestock access to and use of grazing lands. This may include replacement or relocation of fences to retain appropriate livestock grazing management practices.

Mitigation will also include the need to relocate existing public access disrupted by project facilities (e.g., access to the Bridger-Teton National Forest via the South Piney Creek Road through the Alternative 4 Fish Creek Dam and Reservoir site). Access to existing minerals and oil and gas resources will also have to be negotiated with the owners or lease holders where impacted by project facilities.

Additional cultural and historic resource fieldwork would need to be completed to identify and document any such resources that would be inundated or otherwise impacted as a result of constructing any one of the alternative dams and reservoirs studied herein. This would involve a Class III (intensive inventory) survey. Ultimately, a mitigation plan for cultural resources would be developed which would culminate in a Memorandum of Agreement (MOA) between the Wyoming SHPO and the lead federal agency with concurrence by the project sponsor(s), and any
affected Native American tribes (if any). The agreement would ultimately require approval from the Advisory Council on Historic Preservation. See related discussion of cultural resources mitigation in Section 8.0.

8.0 Archaeological Investigation

The scope of Task 8 – Archaeological Investigation was modified during the course of the study with the concurrence of the WWDO Project Manager to eliminate Class I surveys of the preferred water supply alternatives. The assessment of cultural resources during site screening and the characterization of potential cultural resources issues at the preferred alternative sites are instead based on existing information from previous studies including ARIX (1983), Kleinfelder (2007), and input from staff of the BLM Pinedale Office (BLM, 2008). It is recognized that prior Class I surveys in the study area cannot be used as a reliable basis to assess the presence of cultural resources at a given alternative dam and reservoir site or along the alignments of associated canals, pipelines or access roads. Furthermore, the absence of sites identified as part of a Class I survey is no guarantee that they are not in fact present (only that they have not yet been identified). Based on very extensive experience in the region, staff of the Pinedale Field Office of BLM indicate that “All proposals [i.e., Alternatives 1-4] are high in known or suspected cultural resources, including sites considered sacred, sensitive or of importance to known Native American groups” (clarification added; BLM, 2008).

Cultural resources in the context of the proposed alternative dam and reservoir sites being evaluated include prehistoric and historic cultural resources, paleontologic resources, and natural history resources. Specific cultural resources features, sites and issues known or suspected within the study area include, but are not limited to, the following:

- Lander’s Cut Off Trail (see additional discussion below)
- Several known or suspected Emigrant graves, a CCC camp and other known cultural resources at the Alternative 4 Fish Creek Dam and Reservoir site at the confluence of South Piney Creek and Fish Creek
- A known Native American burial at or near the Alternative 3 Whiskey Creek Dam and Reservoir site on North Piney Creek
- Various Indian trails
- Various prehistoric open camps/lithic scatters, stone circles, burn sites
- An historic ranch/homestead at the Alternative 2 Mickelson Creek Dam and Reservoir site on South Cottonwood Creek
- The site of historic Fort Bonneville
- The site of Father DeSmet’s “prairie mass”
- The Upper Green River Rendezvous site

The locations of the last three sites above are shown on Figure 8.1-1 – Historical Sites and Trails. The specific locations of the other sites and features noted above have not yet been identified during this study with sufficient certainty to include on Figure 8.1-1. An acknowledgment of the lack of site specific cultural resources information together with the potential for some cultural resources at any of the water supply alternative sites evaluated in this study is provided in Tables 4.3-1 and 4.5-1.
by designating all sites as marginal in terms of Other Archeological or Historic Resources. The Lander Cut-Off Trail is discussed separately in more detail below.

If any of the preferred alternatives identified in this study are further considered, it will be necessary to conduct detailed Class III surveys consistent with 48CFR 44716 (Standards and Guidelines for Archaeology and Historic Preservation), and otherwise fully comply with the requirements of Section 106 of the National Historic Preservation Act (NHPA) and all other relevant and applicable laws and regulations. Any sites identified during the Class III surveys will need to be evaluated for eligibility for nomination to the National Register of Historic Places.

Mitigation of cultural resources impacts will need to be identified, characterized and costs estimated for any significant impacts that cannot be avoided. Mitigation can range from reporting associated with the Class III surveys to extensive documentation and protection of especially important resources. In some rare cases it may be necessary to relocate or realign facilities and/or avoid certain operations if other mitigation is found not sufficient.

The Lander Cut-Off Trail has been identified as an especially important cultural resource in part by virtue of its Congressional designation as a National Historic Trail (NHT). The location of the NHT and its associated rated viewshed are shown on Figure 8.1-1, and the potential unfavorable impact of this feature on preferred Alternative 4 Fish Creek Dam and Reservoir is indicated on Table 4.5-1. Detailed studies would be required for any alternative with features or operations that would cross, inundate or otherwise impact any portion of this NHT within the study area. This would include impacts from construction and/or operation of the preferred Alternative 4 dam, reservoir and delivery canal (burial by the dam footprint, inundation by the reservoir, disturbance or burial at the delivery canal crossing, etc.). Evaluation of potential impacts would include (but would not be limited to) assessment of the trails themselves (e.g., the presence of original, undisturbed ruts) and the setting within which the subject reach of the trail exists (including current vistas and nearby development and land uses as compared to those at the time of historical use of the trail). Any such studies should be conducted in close consultation with the State Historic Preservation Officer (SHPO) and State Archaeologist. The studies should be phased and begun early (if a project advances to further Level II evaluation) to determine if the known and/or potential impacts of a given alternative can be mitigated by means other than complete avoidance, and what the estimated nature and cost of such mitigation would be.

9.0 Conceptual Level Designs

9.1 Key Design Considerations

Conceptual designs were prepared for each of the alternative dam and reservoir sites identified in Sections 4.5 and 5.2 as discussed previously. These conceptual designs are based on information developed throughout the project under various work tasks and significant prior experience in the planning, design and/or construction oversight of numerous dam and reservoir projects in Wyoming over the past 25 years.

9.1.1 Anticipated Geologic Conditions

Anticipated geologic conditions at all of the preferred alternative water supply sites were discussed previously in Section 6.3.
9.1.2 Flood Hydrology and Spillway Sizing

**Dam Safety Classification and Inflow Design Flood Requirements.** Requirements for dam safety, including inflow design flood (IDF) size, for any jurisdictional dam and reservoir project are promulgated and administered by the Safety of Dams Program, Surface Water Division of the Wyoming State Engineer’s Office. The size of the IDF required for any new storage reservoir is determined by the hazard classification of the dam. There are four classifications (I through IV) based on the potential for loss of life and/or significant property damage in the event of dam failure. For the purposes of hazard classification, an assumption is made that the dam under review fails in a clear weather breach. The likely consequences of that failure are then evaluated to arrive at the dam’s classification. The definitions for each of the four classes are as follows:

- A “Class I” dam is a dam for which loss of human life is expected in the event of the failure of the dam.
- A “Class II” dam is a dam for which significant damage is expected to occur, but no loss of human life is expected in the event of failure of the dam. Significant damage is defined as damage to structures where people generally live, work, or recreate, or public or private facilities exclusive of non-primary roads and picnic areas. Damage means rendering the structures uninhabitable or inoperable.
- A “Class III” dam is a dam for which loss of human life is not expected, and damage to structures and public facilities as defined for a “Class II” dam is not expected in the event of failure of the dam.
- A “Class IV” dam is a dam for which no loss of human life is expected, and for which damage will occur only to the dam owner’s property in the event of failure of the dam.

**Conceptual-Level Hazard Classification.** Hazard classification requires determination of the potential for inundation of existing structures, recreational areas or primary roads. Completing such a classification rigorously requires dam break analysis and routing of flood waters and is beyond the scope of this study. Accordingly, judgment has been used to “select” an appropriate hazard classification and provide an initial basis for sizing the IDF and thereby the conceptual spillway types and sizes. In general, sparsely populated areas with structures well out of the flood plain and/or significantly downstream from the reservoir (enabling dissipation of a flood wave), and/or small reservoirs which would provide minimal impacts on failure offer a reduced threat to property and human life. Based on this concept, the size of the reservoirs, a review of topographic mapping and potentially impacted infrastructure and/or residences downstream from Alternatives 1, 2, 3 and 4, a conservative classification of Class I is assumed for each alternative.

**Inflow Design Flood Determination.** The required IDF for both Class I and II dams is the Probable Maximum Flood (PMF), unless an incremental damage/loss of life analysis (IDA) demonstrates that a lesser IDF is applicable. At this level of study it is not practicable to perform a detailed and fully defensible IDA. Accordingly, the IDF was conservatively assumed to be the PMF for the assumed Class I dams. Because the consequences of the potentially significant conservatism inherent in this assumption can be significant in terms of the cost of the spillway capacity required, it would be appropriate to evaluate the IDF further in a subsequent study if any of the preferred alternatives continue to be found favorable.
Probable Maximum Flood Estimation. At this level of study it is not warranted to perform the extensive and detailed analyses necessary to most accurately determine the characteristics of a PMF at the preferred alternative sites. Instead, estimates of PMF peak flows were made from correlations of peak flow versus drainage area based on past studies of other sites in Wyoming. Initially, data on a total of 27 dam sites for which previous estimates of PMF peak flow had been made by others were compiled and evaluated. The source of the data for these previous PMF study results was the U.S. Bureau of Reclamation and other projects completed for WWDC. Correlations of peak flow versus drainage area were investigated using this complete data set and various subsets of the data to determine if a reasonably reliable correlation could be derived.

Reasonable correlations (i.e., with relatively high $R^2$ values) were found once obvious outliers were excluded from the data set, leaving 23 data points with areas ranging from 1.3 sq miles to nearly 20,000 sq miles. Because the majority of sites on this project have quite small drainage basins, the analysis was limited to sites with smaller areas, leaving 14 data points for which the following regression equation was determined:

$$Q_{PMF} = 5755(A^{0.58}),$$

where $Q$ is peak PMF discharge in cfs and $A$ is drainage area in mi$^2$.

The estimated peak PMF discharge utilizing this methodology is as follows:

- Alternative 1: 44,000 cfs
- Alternative 2: 52,000 cfs
- Alternative 3: 65,000 cfs
- Alternative 4: 74,000 cfs

A more detailed evaluation of PMF peak discharge is recommended should any of the preferred alternative projects advance to the next level of study.

100-Year Flood Estimation. Peak 100-year flood discharges were estimated for the alternative sites as a basis for sizing a service spillway. These estimates were made using the methodology of Lowham (1988). This methodology is based on regression equations using data from numerous gaged sites in hydrologically similar regions of Wyoming as applicable to these sites. The regression equations used for this study were those requiring input of the drainage area above the site of interest and the average annual precipitation over the drainage area. The resulting estimated peak flows for each alternative are as follows:

- Alternative 1: 931 cfs
- Alternative 2: 3,489 cfs
- Alternative 3: 1,593 cfs
- Alternative 4: 1,762 cfs

9.2 Conceptual Design Methodology

The bases for establishing conceptual-level dam and reservoir size and spillway capacity for all of the dam and reservoir site alternatives has been described
previously in Section 9.1.2. These parameters and others relevant to the conceptual design and cost estimating of the preferred alternatives (dealt with in more detail in Section 9.3) are among the key information summarized on Table 4.5-1 that will have to be appropriately modified should further studies regarding needs, reservoir operations, and site-specific hydrologic and geologic/geotechnical conditions be undertaken.

In particular, final storage capacity should be tied to the desired reservoir yield and operations, and spillway capacity should reflect appropriate project-, site- and/or region-specific analyses to account for factors such as IDF determination, reservoir routing and attenuation (i.e., flood storage), incremental downstream damage/loss of life potential, and practicality of downstream warning/evacuation. Finally, note that the storage capacities reported for each alternative site include normal storage and carry-over storage. At this level of study the reservoir operations simulations discussed in Section 5.2 assumed that the total reported storage capacity was available to the degree needed to meet demands. A minimum pool to accommodate sedimentation, recreation, fishery maintenance, and perhaps other operational or environmental factors was not included at this conceptual level of study. More detailed evaluation of the need and required capacity for each of these storage components should be carried out if this project is advanced to the next level of study.

**Earth Dam/Abutment Spillway Concept.** The approach to the conceptual design of the dams, spillways and outlet works for the alternatives characterization stage of this study involved first establishing a “typical design” representative of an assumed concept involving a zoned earth dam with abutment spillways and an upstream controlled outlet works. The typical design was then applied to each alternative site as appropriate utilizing the conceptual design algorithms in the spreadsheet model behind Table 4.5-1. This concept was then developed in more detail for the preferred alternatives as described in the next section still utilizing the spreadsheet model as appropriate as the primary conceptual-level design tool.

**9.3 Alternative 1 – Horse Creek/Cottonwood Creek Storage**

**9.3.1 Overview**

The overall design concept and layout of features and facilities is shown in plan view on Figure 9.3-1 – Alternative 1 – Horse Creek/Cottonwood Creek Storage Facilities Layout. As shown, the major components of this design include:

- Haines Flat Reservoir
- Haines Flat North Dam and South Dam
- Service and emergency spillways
- Outlet works (one at each dam)
- Delivery and Supply Canals
- Miscellaneous appurtenances
- Access Roads

Each of these major components is described below together with the bases for key elements of their design.
9.3.2 Reservoir
The reservoir at Haines Flat, illustrated in Figure 9.3-2 - Alternative 1 – Haines Flat Reservoir, Dam and Appurtenances Layout, is sized at approximately 40,000 ac-ft at a normal high water level (NHWL) of 7,659 feet elevation. This NHWL will allow capture of legally and physically available flows from North Horse Creek, South Horse Creek, and North Cottonwood Creek either directly or by supply canal/infrastructure described in Section 9.3.3. At NHWL the maximum water depth will be approximately 84 feet in the north arm and 59 feet in the south arm of the reservoir, and the overall average depth of the reservoir will be about 29 feet. The surface area at NHWL is approximately 1,393 acres. The reservoir is situated to supply storage to South Horse Creek, North Horse Creek, North Cottonwood Creek, South Cottonwood Creek and subsidiary drainages either directly or via delivery canal/infrastructure described in Section 9.3.4.

9.3.3 Supply Canals
As illustrated in Figure 9.3-1, in addition to receiving drainage directly from South Horse Creek, the reservoir is situated topographically to receive available flow from North Horse Creek and North Cottonwood Creek via gravity-fed canal. The supply canals/infrastructure consist of a 5.6 mile long, 241 cfs capacity canal from North Horse Creek, and a 6.1 mile long, 165 cfs capacity canal from North Cottonwood Creek as well as an appropriately sized stream diversion structure and miscellaneous appurtenances where necessary such as wasteways and existing infrastructure crossings. Supply canals are designed as conventional open channel, unlined earth cut/fill, except as described below. Table 4.5-1 provides additional details of the canals not provided herein.

As indicated in Section 6.3.1, the canals cross a variety of geologic conditions and terrain and may be locally impacted by existing landsliding and/or future slope instability. Where canals cross alluvial and terrace deposits, regardless of terrain, it has been conservatively assumed that these deposits are subject to significant seepage loss from the canal. A similar assumption has been made where canals cross relatively steep or potentially unstable terrain, where excessive seepage could potentially lead to slope instability. While Polyacrylamide (PAM) technologies could result in a low-cost solution to potential seepage, it has been conservatively assumed at this level of study that a geosynthetic liner technology is required to provide a more robust solution due to its typically superior effectiveness. Additionally, a portion of the supply canal from North Cottonwood Creek crosses very difficult terrain, and it is assumed that approximately 0.8 miles is constructed utilizing 84-inch concrete pipe rather than open channel.

9.3.4 Delivery Canals
As illustrated in Figure 9.3-1, in addition to providing storage releases directly to South Horse Creek and North Cottonwood Creek (via an unnamed tributary), the reservoir is situated topographically to provide storage release to a portion of North Horse Creek via gravity-fed canal and to a portion of South Cottonwood Creek via pumping station/pipeline and canal (after gravity release to North Cottonwood Creek). The delivery canals/infrastructure consist of a 6.1 mile long, 112 cfs capacity canal to North Horse Creek, and a 158 cfs pump station/pipeline on North Cottonwood Creek (receiving flows from the reservoir via gravity drainage in existing intermittent and perennial tributaries) delivering flow via a 4.3 mile long, 158 cfs capacity canal to South Cottonwood Creek. Supply canals are designed as
conventional, unlined open channel earth cut/fills, with miscellaneous appurtenances such as wasteways and existing infrastructure crossings where necessary. Table 4.5-1 provides additional details of the delivery canals/infrastructure not provided herein.

As indicated in Section 6.3.1, the canals cross a variety of geologic conditions and terrain. Similar assumptions with regard to canal design (including canal lining) to the supply canals described in Section 9.3.3 have been made in the conceptual design of the delivery canals described herein.

9.3.5 Dams
As shown on Figure 9.3-2, two dams form the reservoir; the north dam is located onstream on South Horse Creek, and the south dam is located in an unnamed gulch south of Haines Flat tributary to North Cottonwood Creek. The north dam is the smaller of the two, having a crest length of 3,229 feet and a height of 69 feet. The south dam has a crest length of 3,542 feet and a height of 94 feet. Together, the dams require approximately 4.0 million cubic yards of earthwork to construct.

Given the currently anticipated geologic and seismotectonic conditions at the site a zoned earthfill dam is proposed, and the remainder of this section is based on this assumption.

Foundation Treatment. It is conservatively assumed that all unconsolidated alluvial and colluvial materials will first be excavated from beneath the dam core to construct a cutoff trench extending to unweathered bedrock (see Figure 9.3-3A and 3B – Alternative 1 – Haines Flat Dam Profiles and Maximum Sections). The core trench provides for seepage reduction to minimize storage loss. Additionally, a significant amount (10 feet) of unconsolidated deposits beneath the dam shells are excavated to remove the loose, upper portion of the unconsolidated deposits. This is to provide for the potential that these deposits would lose significant strength (if not liquefy) under the very strong potential future ground shaking discussed in Section 6.2 if they were left in place beneath the dam. Strong ground motion is presumed to weaken, but not liquefy the remaining deposits, which is considered a reasonable assumption given the ground motion estimates and the nature of the foundation materials. A stability berm, described later, is included in the embankment design to counteract this strength reduction.

The technical and cost feasibility of this type of foundation treatment cannot be confirmed without adequate subsurface exploration to evaluate the potential for liquefaction during the design earthquake of the remaining unconsolidated deposits beneath the dam footprint. If this project advances to the next level of study, subsurface exploration may indicate that additional or alternative foundation treatment measures are necessary to provide adequate post-earthquake stability. Additional or alternative measures that could be required include dynamic compaction, compaction grouting or removal of all unconsolidated, liquefiable materials from the foundation.

Upon completion of the foundation excavation a grout curtain would be constructed beneath the upstream portion of what will be the overlying central core of the dam. The grout curtain is assumed for purposes of this conceptual design to extend into the exposed rock foundation a depth approximately equal to the full height of the dam, tapering to proportionally shallower depths in the dam abutments. The deep curtain is assumed to be formed by grout holes at 10-foot centers. This grouting is intended
to mitigate the potential for seepage through potentially moderate fracturing to at least tens of feet depth associated with the bedrock structure previously described at the site.

Upon completion of, or contemporaneous with, construction of the grout curtain, slush grout and dental concrete will be applied to any open joints, fractures, fault zones or other openings found in the exposed bedrock at foundation excavation grade within the core trench.

**Embankment Dams.** As shown on Figure 9.3-3, the maximum total structural height of the dams (including the portion below original grade) will be approximately 100 feet and 120 feet for the north and south dams, respectively. The dam heights above original ground are about 69 and 94 feet for the north and south dams, respectively. Outside slopes of 2H:1V downstream (with a supplemental stability berm) and 3H:1V upstream are judged adequately stable given the nature of construction and foundation materials available and present. Crest widths of 24 and 29 feet are provided to allow the crest to be used for access onto and across the dam for the north and south dams, respectively.

As described previously in Section 6.3.1, relatively abundant alluvial and terrace deposits exist in the vicinity of the site, and these materials would be processed and separated into various components to construct the dams or selectively utilized in unprocessed form. Subsurface investigation will be required if the project advances to the next level to confirm the feasibility of utilizing a processing operation to obtain various components. In the event that processing is uneconomic or not possible for other reasons, the dam zoning could be altered to reduce the amount of processed materials (which would then have to be imported from remote suppliers) while increasing the use of unprocessed materials (for example, utilizing shallower dam slopes). Additionally, deposits of weathered bedrock as described in Section 6.3.1 would be utilized for low permeability core. The proposed internal zoning and its rationale are summarized as follows:

- **Downstream slope stability shell** – coarse, strong, erosion resistant soil/rock fill to minimize raveling and shallow slope failures and protect heterogeneous, potentially weaker, more erodible soil and/or rock to be used in shell. Borrow for this zone would likely be derived from select, coarse grain alluvial/terrace deposits and/or select excavated bedrock.

- **Shells** – common soil and/or rock fill as derived from required excavations (service and emergency spillways, dam foundation, etc.); well compacted to prevent loss of significant shear strength and potential settling or slope failure under earthquake shaking. Supplemental borrow for this zone would likely be derived from nearby alluvial/terrace deposits.

- **Upstream slope protection** – riprap (or soil cement) erosion protection on mid to upper slope to prevent wave erosion, underlain by drain rock and earth filter to prevent potential for rapid drawdown or earthquake-induced shallow to moderate depth failure of erosion protection layer or upstream slope. Riprap would likely be obtained from local suppliers, if available. It is unlikely that the borrow processing operation would produce riprap of sufficient size and/or quantity, and permitting a quarry in suitable locales in the vicinity is likely to be cost-prohibitive. An alternative to this zone, if local sources of riprap are insufficient
or too expensive, would be to use an alternate upstream slope protection method of soil cement.

- **Upstream slope drain and filter** – specially designed gradation of highly permeable coarse aggregate to cobbles to provide for positive relief of excess pore pressures that may form in the upstream slope during rapid drawdown, and to serve as bedding for the riprap layer; protected on the bottom by filter/drain material (similar to chimney/filter/drain material described below) to prevent piping of adjacent shell material into drain zone. This material is assumed to derive from the coarse-grained reject of the chimney filter/drain and upstream filter zone processing operations.

- **Upstream slope stability shell** – same as for downstream slope stability shell (except specifically selected for higher permeability characteristics) on portion of upstream slope not otherwise protected as described above; also provides strong foundation for overlying slope protection zones, as well as lower slope drainage during rapid drawdown events.

- **Core** – A central zone core constructed of well-compacted, relatively fine-grained soils of sufficiently low permeability to serve as the primary waterstop for the dam; carried down to positive connection with sound, seepage-resistant bedrock (improved as necessary with slush grout and dental concrete). Borrow for this zone would likely be derived from select weathered bedrock in the vicinity with suitable seepage-resistance, strength, and other engineering characteristics.

- **Downstream chimney filter/drain** – specially designed gradation of hard, durable aggregate to prevent piping (internal erosion) of core material into the downstream shell under normal seepage or at any local cracks that may occur in the core; with adequate drainage capacity to convey seepage or crack flow to a safe exit at the toe of the dam via the blanket drain without allowing saturation of the overlying downstream shell. Borrow for this zone would likely be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel.

- **Upstream filter** – specially designed gradation of hard, durable fine aggregate (with similar or potentially identical specifications as the chimney filter) sized to clog any cracks that may form in the core as a result of earthquake shaking, non-uniform settling of, or some other unanticipated defect in the core zone; also known as a crack stopper. Borrow for this zone would likely be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel.

- **Blanket drain** – horizontal layer of highly permeable coarse aggregate to cobbles to provide for positive relief of excess pore pressures that may form in the foundation, and conduit for seepage water collected in the chimney filter/drain zone; protected top and bottom by filter/drain material to prevent piping of adjacent shell material into drain zone. Borrow for this zone would likely be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel. This material is assumed to derive from the coarse-grained reject of the chimney filter/drain and upstream filter zones.
9.3.6 Service and Emergency Spillways
As shown on Figure 9.3-2, service and emergency spillways are combined and located to take advantage of a topographic saddle located approximately one mile northwest of the south dam.

Service Spillway. The service spillway is sized to accommodate an estimated 100-year peak inflow of 931 cfs. At this level of study, no credit in the conceptual design has been taken for attenuation of this peak flow in the reservoir. The approximate spillway width is 22 feet, and a maximum head of five (5) feet is required to pass the 100-year peak flow. The total head available at the service spillway is 10 feet to provide for a portion of the discharge flow during a PMF event (see related discussion below under Emergency Spillway). A fully concrete lined structure with a horizontal controlled crest section (likely an ogee section) incised within the emergency spillway described below and downstream energy dissipation at the discharge end is envisioned. The area below the discharge end of the emergency spillway will be graded if/as necessary to ensure that peak discharges from the spillway do not present any greater risk of damage to the existing drainage downstream than a natural flood of comparable peak flow at this location would. Grade control structures to mitigate erosion in the receiving channel would be utilized as needed. At this level of study, it is unknown without further subsurface exploration whether the foundation in this area would support the type of spillway envisioned. For purposes of costing described later in Section 10.0, a similarly formed service spillway, but located on the right abutment of the North Dam where conditions may be more favorable is conservatively assumed, and is expected to result in a higher cost.

Emergency Spillway. The emergency spillway is planned as a broad crest overflow channel constructed as an earth cut through the ridge/saddle approximately one (1) mile northwest of the south dam. A channel width of approximately 970 feet and a maximum flow depth of 5 feet were chosen to safely pass the estimated peak PMF discharge flow of 41,000 cfs. The additional approximately 3,000 cfs of the PMF inflow is discharged by the service spillway operating at 10 feet of head. Given the relatively low adverse grade of the approach channel from the reservoir pool to the control section at the crest of the saddle, velocities will be low even at maximum discharge and major erosion protection or lining is not anticipated as necessary even where alluvium will be encountered near the reservoir (see Figure 6.3-1B). Most of the spillway channel excavation foundation is anticipated to be in alluvium once surficial materials are removed. The spillway crest will be shaped to provide relatively uniform flow into the chute section on the west slope of the ridge, and will be protected from any possibility of back-cutting erosion by grouting or installation of a concrete cut-off wall if necessary (depending on the nature of the materials encountered). The chute section is also anticipated to be founded in alluvium at relatively shallow grade. If necessary, the cut slope would be laid back to a stable angle and the lower portion of the slope subject to flow at maximum discharge would be armored as necessary (e.g., with riprap, grouted riprap, shotcrete or some other suitable material).

9.3.7 Outlet Works
The outlet works is assumed to be a conventional low-level structure comprised of an upstream trashrack-protected gated inlet, a horizontal steel pipe, a downstream energy dissipation structure, and a flow measurement weir to track reservoir releases.
At this level of study, it is assumed the outlet pipe will be founded on compacted alluvium utilizing ductile steel to accommodate settlement of the embankment. Both north and south dams will have a similar outlet works to provide supply to South Horse and North Cottonwood Creeks, respectively. If the foundation is discovered to have excessive settlement, the outlet works could be relocated to be founded on rock in either abutment at somewhat higher cost, with suitably constructed inlet and outlet channels to provide for complete evacuation of the reservoir. Hydraulic control of a single slide gate is assumed, with the operator stem mounted on the upstream slope of the dam and operated from the dam crest. Manual control is assumed given the relative easy access to the site, although automated remote control could be provided if necessary or desirable. The outlet will be sized to meet WSEO requirements for emergency lowering of the reservoir and to provide for maximum anticipated irrigation releases. Evaluation of the need for a multiple level outlet structure to provide some control of the temperature of released water may be required at the next level of study depending on the results of further environmental studies. Such an evaluation will need to assess the anticipated daily and seasonal variations in water temperature with depth in the reservoir.

9.3.8 Miscellaneous Appurtenances

The reservoir bottom includes an excavated channel feature to maximize the storage efficiency of the reservoir. Because the reservoir is formed by the topographic combination of two drainages (South Horse Creek and a tributary to North Cottonwood), when the reservoir is partially depleted, storage remaining in the reservoir separates into two pools and can only be delivered to the respective drainage. A channel cut between the two drainages allows for additional transfer of water to either delivery basin at lower pool levels, allowing more flexibility to address existing shortage in either Horse or Cottonwood Creek. Borrow excavated from this channel would be utilized in construction of the dams.

9.3.9 Access Road(s)

Access to the site is provided by existing mapped roads serving both the north and south dam sites as well as service and emergency spillways as shown on Figure 9.3-2. At this level of study, suitability of existing roads for construction and permanent access is assumed to be adequate (except as described below), although grading/resurfacing is likely to be required during construction and during the operation and maintenance phase of the project. Small spur (less than 0.25 mile) roads are required to access the crests of either dam from existing roads. As described previously, access roads would be provided on each crest to provide access to each dam. Two sections of existing road, less than approximately 0.5 mile total require relocation due to inundation by the proposed reservoir pool as shown on Figure 9.3-2. This road would be rerouted approximately 0.5 miles or less outward from the perimeter of the reservoir.

9.4 Alternative 2 – South Cottonwood Creek Storage

9.4.1 Overview

The overall design concept and layout of features and facilities is shown in plan view on Figure 9.4-1 – Alternative 2 – South Cottonwood Creek Storage Facilities Layout. As shown, the major components of this design include:

- Mickelson Reservoir
- Mickelson North Dam and South Dam
- Service and emergency spillways
- Outlet works
- Supply Canal
- Access Roads

Each of these major components is described below together with the bases for key elements of their design.

### 9.4.2 Reservoir

The reservoir at Mickelson Creek, illustrated in Figure 9.4-2 - Alternative 2 – Mickelson Creek Reservoir, Dam and Appurtenances Layout, is sized at approximately 15,000 ac-ft at normal high water level (NHWL) of 7,740 feet elevation. This reservoir location will allow capture of legally available flows from South Horse Creek, and its local tributary, Mickelson Creek directly. At NHWL the maximum water depth will be approximately 70 feet, and the average depth of the reservoir will be about 25 feet. The surface area at NHWL is approximately 598 acres. The reservoir is situated to supply storage to South Cottonwood Creek and subsidiary drainages either directly or via delivery canal/infrastructure described in Section 9.4.3.

### 9.4.3 Delivery Canal

As illustrated in Figure 9.4-1, in addition to providing storage releases directly to South Cottonwood Creek, the reservoir is situated topographically to provide storage release to a portion of additional South Cottonwood Creek irrigation via gravity-fed canal. The delivery canal/infrastructure consists of a 6.0 mile long, 100 cfs capacity canal. Supply canals are designed as conventional, unlined open channel earth cut/fills, with miscellaneous appurtenances such as wasteways and existing infrastructure crossings where necessary, except as described below. Table 4.5-1 provides additional details of the delivery canals/infrastructure not provided herein.

As indicated in Section 6.3.2, the canals cross a variety of geologic conditions and terrain. Where canals cross alluvial and terrace deposits, regardless of terrain, it has been conservatively assumed that these deposits are subject to significant seepage loss from the canal. A similar assumption has been made where canals cross relatively steep or potentially unstable terrain, where excessive seepage could potentially lead to slope instability. While Polyacrylamide (PAM) technologies could result in a low-cost solution to potential seepage, it has been conservatively assumed at this level of study that a geosynthetic liner technology is required to provide a more robust solution due to it's typically superior effectiveness. Additionally, a portion of the delivery canal crosses very difficult terrain, and it is assumed that approximately 1.1 miles is constructed utilizing 60-inch concrete pipe rather than open channel.

### 9.4.4 Dams

As shown on Figure 9.4-2, two dams form the reservoir; the north dam is located in a small saddle north of the South Cottonwood Creek floodplain, and the south dam spans the valley just upstream of the confluence of South Cottonwood and Mickelson Creeks. The north dam is the significantly smaller of the two, having a crest length of 418 feet and a height of 20 feet. The south dam has a crest length of 3,739 feet and a height of 80 feet. Together, the dams require approximately 1.5 million cubic yards of earthwork to construct.
Given the currently anticipated geologic and seismotectonic conditions at the site presented in Sections 6.2 and 6.3.2, a zoned earthfill dam is proposed, and the design presented in the remainder of this section is based on this assumption.

**Foundation Treatment.** It is conservatively assumed that all unconsolidated alluvial and colluvial materials will first be excavated from beneath the dam core to construct a cutoff trench extending to unweathered bedrock (see Figure 9.4-3 – Alternative 2 – Mickelson Creek Dam Profile and Maximum Section). The core trench provides for seepage reduction to minimize storage loss. Additionally, a significant amount (10 feet) of unconsolidated deposits beneath the dam shells is excavated to remove the loose, upper portion of the unconsolidated deposits. This is to provide for the potential that these deposits would lose significant strength (if not liquefy) under the very strong potential future ground shaking identified in Section 6.2 if they were left in place beneath the dam. Strong ground motion is presumed to weaken, but not liquefy the remaining deposits, which is considered a reasonable assumption at this level of study given the ground motion estimates and the nature of the foundation materials. A stability berm, described later, is included in the embankment design to counteract this strength reduction.

The technical and cost feasibility of this type of foundation treatment cannot be confirmed without adequate subsurface exploration to evaluate the potential for liquefaction during the design earthquake of the remaining unconsolidated deposits beneath the dam footprint. If this project advances to the next level of study, subsurface exploration may indicate that additional or alternative foundation treatment measures are necessary to provide adequate post-earthquake stability. Additional or alternative measures that could be required include dynamic compaction, compaction grouting or removal of all unconsolidated, liquefiable materials from the foundation.

Upon completion of the foundation excavation a grout curtain would be constructed beneath the upstream portion of what will be the overlying central core of the dam. The grout curtain is assumed for purposes of this conceptual design to extend into the exposed rock foundation a depth approximately equal to the full height of the dam, tapering to proportionally shallower depths in the dam abutments. The deep curtain is assumed to be formed by grout holes at 10-foot centers. This grouting is intended to mitigate the potential for seepage through potentially moderate fracturing to at least tens of feet depth associated with the bedrock structure previously described at the site.

Upon completion of, or contemporaneous with, construction of the grout curtain, slush grout and dental concrete will be applied to any open joints, fractures, fault zones or other openings found in the exposed bedrock at foundation excavation grade within the core trench.

**Embankment Dam.** As shown on Figure 9.4-3, the maximum total structural height of the main dam (including the portion below original grade) will be approximately 130 feet. The maximum dam height of the north and south dams above original ground is about 20 and 80 feet, respectively. Outside slopes of 2H:1V downstream (with an supplemental stability berm) and 3H:1V upstream are judged adequately stable given the nature of the construction and foundation materials available and present. A crest width of 20 feet for the north dam and 26 feet for the south dam feet is provided to allow the crest to be used for access onto and across the dam.
As described previously in Section 6.3.2, relatively abundant alluvial and terrace deposits exist in the vicinity of the site, and these materials would be processed and separated into various components to construct the dam or selectively utilized in unprocessed form. Subsurface investigation will be required if the project advances to the next level to confirm the feasibility of utilizing a processing operation to obtain various components. In the event that processing is uneconomic or not possible for other reasons, the dam zoning could be altered to reduce the amount of processed materials (which would then have to be imported from external suppliers) while increasing the use of unprocessed materials (for example, utilizing shallower dam slopes). Additionally, deposits of weathered bedrock would be utilized for low permeability core. The proposed internal zoning and its rationale are summarized as follows:

- **Downstream slope stability shell** – coarse, strong, erosion resistant soil/rock fill to minimize raveling and shallow slope failures and protect heterogeneous, potentially weaker, more erodible soil and/or rock to be used in shell. Borrow for this zone would likely be derived from select, coarse grain alluvial/terrace deposits and/or select excavated bedrock.

- **Shells** – common soil and/or rock fill as derived from required excavations (service and emergency spillways, dam foundation, etc.); well compacted to prevent loss of significant shear strength and potential settling or slope failure under earthquake shaking. Supplemental borrow for this zone would likely be derived from nearby alluvial/terrace deposits.

- **Upstream slope protection** – riprap (or soil cement) erosion protection on mid to upper slope to prevent wave erosion, underlain by drain rock and earth filter to prevent potential for rapid drawdown or earthquake-induced shallow to moderate depth failure of erosion protection layer or upstream slope. Riprap would likely be obtained from local suppliers, if available. It is unlikely that the borrow processing operation would produce riprap of sufficient size and/or quantity, and permitting a quarry in suitable locales in the vicinity is likely to be cost-prohibitive. An alternative to this zone, if local sources of riprap are insufficient or too expensive, would be to use an alternate upstream slope protection method such as soil cement.

- **Upstream slope drain and filter** – specially designed gradation of highly permeable coarse aggregate to cobbles to provide for positive relief of excess pore pressures that may form in the upstream slope during rapid drawdown, and to serve as bedding for the riprap layer; protected on the bottom by filter/drain material (similar to chimney/filter/drain material described below) to prevent piping of adjacent shell material into drain zone. This material is assumed to derive from the coarse-grained reject of the chimney filter/drain and upstream filter zone processing operations.

- **Upstream slope stability shell** – same as for downstream slope stability shell (except specifically selected for higher permeability characteristics) on portion of upstream slope not otherwise protected as described above; also provides strong foundation for overlying slope protection zones, as well as lower slope drainage during rapid drawdown events.

- **Core** – A central zone core constructed of well-compacted, relatively fine-grained soils of sufficiently low permeability to serve as the primary waterstop for the dam; carried down to positive connection with sound, seepage-resistant
bedrock (improved as necessary with slush grout and dental concrete). Borrow for this zone is assumed to be derived from select weathered bedrock in the vicinity with suitable seepage-resistance, strength, and other engineering characteristics.

- **Downstream chimney filter/drain** – specially designed gradation of hard, durable aggregate to prevent piping (internal erosion) of core material into the downstream shell under normal seepage or at any local cracks that may occur in the core; with adequate drainage capacity to convey seepage or crack flow to a safe exit at the toe of the dam via the blanket drain without allowing saturation of the overlying downstream shell. Borrow for this zone would be assumed to be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel.

- **Upstream filter** – specially designed gradation of hard, durable fine aggregate (with similar or potentially identical specifications as the chimney filter) sized to clog any cracks that may form in the core as a result of earthquake shaking, non-uniform settling of, or some other unanticipated defect in the core zone; also known as a crack stopper. Borrow for this zone is assumed to be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel.

- **Blanket drain** – horizontal layer of highly permeable coarse aggregate to cobbles to provide for positive relief of excess pore pressures that may form in the foundation, and conduit for seepage water collected in the chimney filter/drain zone; protected top and bottom by filter/drain material to prevent piping of adjacent shell material into drain zone. Borrow for this zone is assumed to be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel. This material is assumed to be produced as a coarse-grained byproduct of the coarse chimney filter/drain and upstream filter zone processing operation.

9.4.5 **Service and Emergency Spillways**

As shown on Figure 9.4-2, the emergency spillway is located to take advantage of a topographic ridge located less than one mile southwest of the south dam. The service spillway is located adjacent to the right abutment of the north dam and flows to a gulch tributary to South Cottonwood Creek.

**Service Spillway.** The service spillway is sized to accommodate an estimated 100-year peak inflow of 3,489 cfs. At this level of study, no credit in the conceptual design has been taken for attenuation of this peak flow in the reservoir. The spillway has approximate dimensions of 82 feet wide and 300 feet long, with a maximum head of five (5) feet provided to pass the peak 100-year flow and an additional five (5) feet of head provided to accommodate PMF flows described below. A fully concrete lined structure with a horizontal controlled crest section (likely an ogee section) and downstream energy dissipation at the discharge end is envisioned. The area below the discharge end of the spillway will be graded if/as necessary to ensure that peak discharges from the spillway do not present any greater risk of damage to the existing drainage downstream than a natural flood of comparable peak flow at this location would. Grade control structures to mitigate erosion in the receiving channel would also be utilized.
Emergency Spillway. The emergency spillway is planned as a broad crest overflow channel constructed as an earth/rock cut through the ridge less than one mile southwest of the south dam. A channel width of approximately 990 feet and a maximum flow depth of 5 feet were chosen to safely pass the estimated peak PMF discharge flow of 42,000 cfs. The additional approximately 10,000 cfs of the PMF inflow is discharged by the service spillway operating at 10 feet of head. Without subsurface exploration of the area, it is unknown whether the spillway channel excavation foundation will be in rock once surficial materials are removed. However, given the relatively low adverse grade of the approach channel from the reservoir pool to the control section at the crest of the saddle, velocities will be low even at maximum discharge and major erosion protection or lining is not anticipated as necessary even where alluvium will be encountered. The spillway crest will be shaped to provide relatively uniform flow into the chute section on the south slope of the ridge, and will be protected from any possibility of back-cutting erosion by grouting or installation of a concrete cut-off wall if necessary (depending on the nature of the excavated materials encountered). The chute section is also anticipated to be founded in alluvium at relatively shallow grade. If necessary, the cut slope would be laid back to a stable angle and the lower portion of the slope subject to flow at maximum discharge would be armored as necessary (e.g., with riprap, grouted riprap, shotcrete or some other suitable material).

9.4.6 Outlet Works

The outlet works, located in the south dam adjacent to the existing alignment of South Cottonwood Creek, is assumed to be a conventional low-level structure comprised of an upstream trashrack-protected gated inlet, a horizontal steel pipe, a downstream energy dissipation structure, and a flow measurement weir to track reservoir releases. At this level of study, it is assumed the outlet pipe will be founded on compacted alluvium utilizing ductile steel to accommodate settlement of the embankment. If the foundation is discovered to have excessive settlement once subsurface investigation is conducted in later studies, the outlet works could be relocated to be founded on rock in either abutment at the design minimum pool invert elevation at somewhat higher cost, with suitably constructed inlet and outlet channels to provide for complete evacuation of the reservoir. Hydraulic control of a single slide gate is assumed, with the operator stem mounted on the upstream slope of the dam and operated from the dam crest. Manual control is assumed given the relative easy access to the site, although automated remote control could be provided if necessary or desirable. The outlet will be sized to meet WSEO requirements for emergency lowering of the reservoir and to provide for maximum anticipated irrigation releases. Evaluation of the need for a multiple level outlet structure to provide some control of the temperature of released water may be required at the next level of study depending on the results of further environmental studies. Such an evaluation will need to assess the anticipated daily and seasonal variations in water temperature with depth in the reservoir.

9.4.7 Access Road(s)

Access to the site is provided by existing mapped roads serving both the north and south dam sites and service spillway as shown on Figure 9.4-2. At this level of study, suitability of existing roads for construction and permanent access is assumed to be adequate (except as described below), although grading/resurfacing is likely to be required during construction and the operations and maintenance phases of the project. Only small spur (less than 0.5 mile) roads are required to access the crests of
either dam from existing roads. As described previously, access roads would be provided on each crest to provide access to each dam as well as the service spillway on the north dam and the emergency spillway southwest of the main (south) dam. A section of road approximately 1.0 mile long will require relocation due to inundation by the proposed reservoir pool. This road would be rerouted to the north to connect with the existing road running adjacent to the perimeter of the reservoir.

9.5 Alternative 3 – North Piney Creek Storage

9.5.1 Overview
The overall design concept and layout of features and facilities is shown in plan view on Figure 9.5-1 – Alternative 3 – North Piney Creek Storage Facilities Layout. As shown, the major components of this design include:

- Whiskey Creek Reservoir
- Whiskey Creek Dam
- Service and emergency spillways
- Outlet works
- Access Roads

Each of these major components is described below together with the bases for key elements of their design.

9.5.2 Reservoir
The reservoir at Whiskey Creek, illustrated in Figure 9.5-2 - Alternative 3 – Whiskey Creek Reservoir, Dam and Appurtenances Layout, is sized at approximately 20,000 ac-ft at normal high water level (NHWL) of 7,539 feet elevation. This reservoir location will allow capture of legally available flows from North Piney Creek directly. At NHWL the maximum water depth will be approximately 89 feet, and the average depth of the reservoir will be about 32 feet. The surface area at NHWL is approximately 621 acres. The reservoir is situated to supply storage to North Piney Creek and subsidiary drainages either directly or via delivery by existing canal/infrastructure.

9.5.3 Dam
As shown on Figure 9.5-2, a single dam located onstream on North Piney Creek forms the reservoir. The dam has a crest length of 3,374 feet and a height of 102 feet and requires approximately 3.2 million cubic yards of earthwork to construct.

Given the currently anticipated geologic and seismotectonic conditions at the site presented in Sections 6.2 and 6.3.3, a zoned earthfill dam is proposed, and the design presented in the remainder of this section is based on this assumption.

Foundation Treatment. It is conservatively assumed that all unconsolidated alluvial and colluvial materials will first be excavated from beneath the dam core to construct a cutoff trench extending to unweathered bedrock (see Figure 9.5-3 – Alternative 3 – Whiskey Creek Dam Profile and Maximum Section). The core trench provides for seepage reduction to minimize storage loss. Additionally, a significant amount (10 feet) of unconsolidated deposits beneath the dam shells is excavated to remove the loose, upper portion of the unconsolidated deposits. This is to provide for the potential that these deposits would lose significant strength (if not liquefy) under the very strong potential future ground shaking identified in Section 6.2 if they were left
in place beneath the dam. Strong ground motion is presumed to weaken, but not liquefy the remaining deposits, which is considered a reasonable assumption at this level of study given the ground motion estimates and the nature of the foundation materials. A stability berm, described later, is included in the embankment design to counteract this strength reduction.

The technical and cost feasibility of this type of foundation treatment cannot be confirmed without adequate subsurface exploration to evaluate the potential for liquefaction during the design earthquake of the remaining unconsolidated deposits beneath the dam footprint. If this project advances to the next level of study, subsurface exploration may indicate that additional or alternative foundation treatment measures are necessary to provide adequate post-earthquake stability. Additional or alternative measures that could be required include dynamic compaction, compaction grouting or removal of all unconsolidated, liquefiable materials from the foundation.

Upon completion of the foundation excavation a grout curtain would be constructed beneath the upstream portion of what will be the overlying central core of the dam. The grout curtain is assumed for purposes of this conceptual design to extend into the exposed rock foundation a depth approximately equal to the full height of the dam, tapering to proportionally shallower depths in the dam abutments. The deep curtain is assumed to be formed by grout holes at 10-foot centers. This grouting is intended to mitigate the potential for seepage through potentially moderate fracturing to at least tens of feet depth associated with the bedrock structure previously described at the site.

Upon completion of, or contemporaneous with, construction of the grout curtain, slush grout and dental concrete will be applied to any open joints, fractures, fault zones or other openings found in the exposed bedrock at foundation excavation grade within the core trench.

**Embankment Dam.** As shown on Figure 9.5-3, the maximum total structural height of the dam (including the portion below original grade) will be approximately 140 feet. The maximum dam height of the dam above original ground is about 102 feet. Outside slopes of 2H:1V downstream (with a supplemental stability berm) and 3H:1V upstream are judged adequately stable given the nature of the construction and foundation materials available and present. A crest width of 30 feet for the dam is provided to allow the crest to be used for access onto and across the dam.

As described previously in Section 6.3.3, relatively abundant alluvial and terrace deposits exist in the vicinity of the site, and these materials would be processed and separated into various components to construct the dam or selectively utilized in unprocessed form. Subsurface investigation will be required if the project advances to the next level to confirm the feasibility of utilizing a processing operation to obtain various components. In the event that processing is uneconomic or not possible for other reasons, the dam zoning could be altered to reduce the amount of processed materials (which would then have to be imported from external suppliers) while increasing the use of unprocessed materials (for example, utilizing shallower dam slopes). Additionally, deposits of weathered bedrock would be utilized for low permeability core. The proposed internal zoning and its rationale are summarized as follows:
- **Downstream slope stability shell** – coarse, strong, erosion resistant soil/rock fill to minimize raveling and shallow slope failures and protect heterogeneous, potentially weaker, more erodible soil and/or rock to be used in shell. Borrow for this zone would likely be derived from select, coarse grain alluvial/terrace deposits and/or select excavated bedrock.

- **Shells** – common soil and/or rock fill as derived from required excavations (service and emergency spillways, dam foundation, etc.); well compacted to prevent loss of significant shear strength and potential settling or slope failure under earthquake shaking. Supplemental borrow for this zone would likely be derived from nearby alluvial/terrace deposits.

- **Upstream slope protection** – riprap (or soil cement) erosion protection on mid to upper slope to prevent wave erosion, underlain by drain rock and earth filter to prevent potential for rapid drawdown or earthquake-induced shallow to moderate depth failure of erosion protection layer or upstream slope. Riprap would likely be obtained from local suppliers, if available. It is unlikely that the borrow processing operation would produce riprap of sufficient size and/or quantity, and permitting a quarry in suitable locales in the vicinity is likely to be cost-prohibitive. An alternative to this zone, if local sources of riprap are insufficient or too expensive, would be to use an alternate upstream slope protection method such as soil cement.

- **Upstream slope drain and filter** – specially designed gradation of highly permeable coarse aggregate to cobbles to provide for positive relief of excess pore pressures that may form in the upstream slope during rapid drawdown, and to serve as bedding for the riprap layer; protected on the bottom by filter/drain material (similar to chimney/filter/drain material described below) to prevent piping of adjacent shell material into drain zone. This material is assumed to derive from the coarse-grained reject of the chimney filter/drain and upstream filter zone processing operations.

- **Upstream slope stability shell** – same as for downstream slope stability shell (except specifically selected for higher permeability characteristics) on portion of upstream slope not otherwise protected as described above; also provides strong foundation for overlying slope protection zones, as well as lower slope drainage during rapid drawdown events.

- **Core** – A central zone core constructed of well-compacted, relatively fine-grained soils of sufficiently low permeability to serve as the primary waterstop for the dam; carried down to positive connection with sound, seepage-resistant bedrock (improved as necessary with slush grout and dental concrete). Borrow for this zone is assumed to be derived from select weathered bedrock in the vicinity with suitable seepage-resistance, strength, plasticity and other engineering characteristics.

- **Downstream chimney filter/drain** – specially designed gradation of hard, durable aggregate to prevent piping (internal erosion) of core material into the downstream shell under normal seepage or at any local cracks that may occur in the core; with adequate drainage capacity to convey seepage or crack flow to a safe exit at the toe of the dam via the blanket drain without allowing saturation of the overlying downstream shell. Borrow for this zone would be assumed to be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel.
- **Upstream filter** – specially designed gradation of hard, durable fine aggregate (with similar or potentially identical specifications as the chimney filter) sized to clog any cracks that may form in the core as a result of earthquake shaking, non-uniform settling of, or some other unanticipated defect in the core zone; also known as a crack stopper. Borrow for this zone is assumed to be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel.

- **Blanket drain** – horizontal layer of highly permeable coarse aggregate to cobbles to provide for positive relief of excess pore pressures that may form in the foundation, and conduit for seepage water collected in the chimney filter/drain zone; protected top and bottom by filter/drain material to prevent piping of adjacent shell material into drain zone. Borrow for this zone is assumed to be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel. This material is assumed to be produced as a coarse-grained byproduct of the coarse the chimney filter/drain and upstream filter zone processing operation.

### 9.5.4 Service and Emergency Spillways

As shown on Figure 9.5-2, the emergency spillway is located to take advantage of a topographic feature located less than one-quarter mile south of the dam. The service spillway is located adjacent to the right abutment of the dam where a bedrock foundation is presumed to be present after sufficient excavation of overburden. Both spillways discharge to North Piney Creek.

**Service Spillway.** The service spillway is sized to accommodate an estimated 100-year peak inflow of 1,593 cfs from a 66 square mile contributing drainage area. At this level of study, no credit in the conceptual design has been taken for attenuation of this peak flow in the reservoir. The spillway has approximate dimensions of 37 feet wide and 350 feet long, with a maximum head of five (5) feet provided to pass the peak 100-year flow and an additional eight (8) feet of head provided to accommodate PMF flows described below. A fully concrete lined structure with a horizontal controlled crest section (likely an ogee section) and downstream energy dissipation at the discharge end is envisioned. The area below the discharge end of the spillway will be graded if/as necessary to ensure that peak discharges from the spillway do not present any greater risk of damage to the existing drainage downstream than a natural flood of comparable peak flow at this location would. Grade control structures to mitigate erosion in the receiving channel would also be utilized as appropriate.

**Emergency Spillway.** The emergency spillway is planned as a broad crest overflow channel constructed as an earth cut through the ridge less than one quarter mile south of the dam. A channel width of approximately 670 feet and a maximum flow depth of 5 feet were chosen to safely pass the estimated peak PMF discharge flow of 58,000 cfs. The additional approximately 7,000 cfs of the PMF inflow is discharged by the service spillway operating at 13 feet of head. Without subsurface exploration of the area, it is unknown whether the spillway channel excavation foundation will be in rock once surficial materials are removed. However, given the relatively low adverse grade of the approach channel from the reservoir pool to the control section at the crest of the saddle, velocities will be low even at maximum discharge and major erosion protection or lining is not anticipated as necessary even where alluvium will be encountered. The spillway crest will be shaped to provide relatively
uniform flow into the chute section, and will be protected from any possibility of back-cutting erosion by grouting or installation of a concrete cut-off wall if necessary (depending on the nature of the excavated materials encountered). The chute section is also anticipated to be founded in alluvium at relatively shallow grade. If necessary, the cut slope would be laid back to a stable angle and the lower portion of the slope subject to flow at maximum discharge would be armored as necessary (e.g., with riprap, grouted riprap, shotcrete or some other suitable material).

9.5.5 Outlet Works

The outlet works, located in the south dam adjacent to the existing alignment of North Piney Creek, is assumed to be a conventional low-level structure comprised of an upstream trashrack-protected gated inlet, a horizontal steel pipe, a downstream energy dissipation structure, and a flow measurement weir to track reservoir releases. At this level of study, it is assumed the outlet pipe will be founded on compacted alluvium utilizing ductile steel to accommodate settlement of the embankment. If the foundation is discovered to have excessive settlement once subsurface investigation is conducted in later studies, the outlet works could be relocated to be founded on rock in either abutment at the design minimum pool invert elevation at somewhat higher cost, with suitably constructed inlet and outlet channels to provide for complete evacuation of the reservoir. Hydraulic control of a single slide gate is assumed, with the operator stem mounted on the upstream slope of the dam and operated from the dam crest. Manual control is assumed given the relative easy access to the site, although automated remote control could be provided if necessary or desirable. The outlet will be sized to meet WSEO requirements for emergency lowering of the reservoir and to provide for maximum anticipated irrigation releases. Evaluation of the need for a multiple level outlet structure to provide some control of the temperature of released water may be required at the next level of study depending on the results of further environmental studies. Such an evaluation will need to assess the anticipated daily and seasonal variations in water temperature in the reservoir.

9.5.6 Access Road(s)

Access to the site is provided by existing mapped roads serving the area as shown on Figure 9.5-2. At this level of study, suitability of existing roads for construction and permanent access is assumed to be adequate (except as described below), although grading/resurfacing is likely to be required during construction and the operations and maintenance phases of the project. Only small spur (less than 0.5 mile) roads are required to access the crest of the dam from existing roads. As described previously, access roads would be provided on each crest to provide access to each dam as well as the service spillway. Two sections of road approximately 0.75 mile long each require relocation due to inundation by the proposed reservoir pool and overlay of the emergency spillway footprint. This road would be rerouted to the south slightly to avoid the reservoir and emergency spillway.

9.6 Alternative 4 – South/Middle Piney Creek Storage

9.6.1 Overview

The overall design concept and layout of features and facilities is shown in plan view on Figure 9.6-1 – Alternative 4 – South/Middle Piney Creek Storage Facilities Layout. As shown, the major components of this design include:

- Fish Creek Reservoir
Each of these major components is described below together with the bases for key elements of their design.

9.6.2 Reservoir

The reservoir at Fish Creek, illustrated in Figure 9.6-2 - Alternative 4 – Fish Creek Dam, Reservoir and Appurtenances Layout, is sized at approximately 20,000 ac-ft at normal high water level (NHWL) of 7,564 feet elevation. This reservoir location will allow capture of legally available flows from South Piney Creek and its tributary Fish Creek directly. At NHWL the maximum water depth will be approximately 84 feet, and the average depth of the reservoir will be about 37 feet. The surface area at NHWL is approximately 542 acres. The reservoir is situated to supply storage to South and Middle Piney Creeks either directly or via delivery by delivery canal/infrastructure described in Section 9.6.3.

9.6.3 Delivery Canal

As illustrated in Figure 9.6-1, in addition to providing storage releases directly to South Piney Creek, the reservoir is situated topographically to provide storage release to Middle Piney Creek irrigation via gravity-fed canal. The delivery canal/infrastructure consists of a 4.5 mile long, 150 cfs capacity canal. Supply canals are designed as conventional, unlined open channel earth cut/fills, with miscellaneous appurtenances such as wasteways and existing infrastructure crossings where necessary, except as described below. Table 4.5-1 provides additional details of the delivery canals/infrastructure not provided herein.

As indicated in Section 6.1, the canals cross a variety of geologic conditions and terrain. Where canals cross alluvial and terrace deposits, regardless of terrain, it has been conservatively assumed that these deposits are subject to significant seepage loss from the canal. While Polyacrylamide (PAM) technologies could result in a low-cost solution to potential seepage, it has been conservatively assumed at this level of study that a geosynthetic liner technology is required to provide a more robust solution due to it's typically superior effectiveness.

9.6.4 Dam

As shown on Figure 9.6-2, a single dam located onstream spanning South Piney and Fish Creeks forms the reservoir. The dam has a crest length of 3,639 feet, a height of 99 feet and requires approximately 3.3 million cubic yards of earthwork to construct.

Given the currently anticipated geologic and seismotectonic conditions at the site presented in Sections 6.2 and 6.3.4, a zoned earthfill dam is proposed, and the design presented in the remainder of this section is based on this assumption.

**Foundation Treatment.** It is conservatively assumed that all unconsolidated alluvial and colluvial materials will first be excavated from beneath the dam core to construct a cutoff trench extending to unweathered bedrock (see Figure 9.6-3 – Alternative 3 – Fish Creek Dam Profile and Maximum Section). The core trench provides for
seepage reduction to minimize storage loss. Additionally, a significant amount (10 feet) of unconsolidated deposits beneath the dam shells is excavated to remove the loose, upper portion of the unconsolidated deposits. This is to provide for the potential that these deposits would lose significant strength (if not liquefy) under the very strong potential future ground shaking identified in Section 6.2 if they were left in place beneath the dam. Strong ground motion is presumed to weaken, but not liquefy the remaining deposits, which is considered a reasonable assumption at this level of study given the ground motion estimates and the nature of the foundation materials. A stability berm, described later, is included in the embankment design to counteract this strength reduction.

The technical and cost feasibility of this type of foundation treatment cannot be confirmed without adequate subsurface exploration to evaluate the potential for liquefaction during the design earthquake of the remaining unconsolidated deposits beneath the dam footprint. If this project advances to the next level of study, subsurface exploration may indicate that additional or alternative foundation treatment measures are necessary to provide adequate post-earthquake stability. Additional or alternative measures that could be required include dynamic compaction, compaction grouting or removal of all unconsolidated, liquefiable materials from the foundation.

Upon completion of the foundation excavation a grout curtain would be constructed beneath the upstream portion of what will be the overlying central core of the dam. The grout curtain is assumed for purposes of this conceptual design to extend into the exposed rock foundation a depth approximately equal to the full height of the dam, tapering to proportionally shallower depths in the dam abutments. The deep curtain is assumed to be formed by grout holes at 10-foot centers. This grouting is intended to mitigate the potential for seepage through potentially moderate fracturing to at least tens of feet depth associated with the bedrock structure previously described at the site.

Upon completion of, or contemporaneous with, construction of the grout curtain, slush grout and dental concrete will be applied to any open joints, fractures, fault zones or other openings found in the exposed bedrock at foundation excavation grade within the core trench.

**Embankment Dam.** As shown on Figure 9.6-3, the maximum total structural height of the dam (including the portion below original grade) will be approximately 150 feet. The maximum dam height of the dam above original ground is about 99 feet. Outside slopes of 2H:1V downstream (with a supplemental stability berm) and 3H:1V upstream are judged adequately stable given the nature of the construction and foundation materials available and present. A crest width of 30 feet for the dam is provided to allow the crest to be used for access onto and across the dam.

As described previously in Section 6.3.4, relatively abundant alluvial and terrace deposits exist in the vicinity of the site, and these materials would be processed and separated into various components to construct the dam or selectively utilized in unprocessed form. Subsurface investigation will be required if the project advances to the next level to confirm the feasibility of utilizing a processing operation to obtain various components. In the event that processing is uneconomic or not possible for other reasons, the dam zoning could be altered to reduce the amount of processed materials (which would then have to be imported from external suppliers) while
increasing the use of unprocessed materials (for example, utilizing shallower dam slopes). Additionally, deposits of weathered bedrock would be utilized for low permeability core. The proposed internal zoning and its rationale are summarized as follows:

- **Downstream slope stability shell** – coarse, strong, erosion resistant soil/rock fill to minimize raveling and shallow slope failures and protect heterogeneous, potentially weaker, more erodible soil and/or rock to be used in shell. Borrow for this zone would likely be derived from select, coarse grain alluvial/terrace deposits and/or select excavated bedrock.

- **Shells** – common soil and/or rock fill as derived from required excavations (service and emergency spillways, dam foundation, etc.); well compacted to prevent loss of significant shear strength and potential settling or slope failure under earthquake shaking. Supplemental borrow for this zone would likely be derived from nearby alluvial/terrace deposits.

- **Upstream slope protection** – riprap (or soil cement) erosion protection on mid to upper slope to prevent wave erosion, underlain by drain rock and earth filter to prevent potential for rapid drawdown or earthquake-induced shallow to moderate depth failure of erosion protection layer or upstream slope. Riprap would likely be obtained from local suppliers, if available. It is unlikely that the borrow processing operation would produce riprap of sufficient size and/or quantity, and permitting a quarry in suitable locales in the vicinity is likely to be cost-prohibitive. An alternative to this zone, if local sources of riprap are insufficient or too expensive, would be to use an alternate upstream slope protection method such as soil cement.

- **Upstream slope drain and filter** – specially designed gradation of highly permeable coarse aggregate to cobbles to provide for positive relief of excess pore pressures that may form in the upstream slope during rapid drawdown, and to serve as bedding for the riprap layer; protected on the bottom by filter/drain material (similar to chimney/filter/drain material described below) to prevent piping of adjacent shell material into drain zone. This material is assumed to derive from the coarse-grained reject of the chimney filter/drain and upstream filter zone processing operations.

- **Upstream slope stability shell** – same as for downstream slope stability shell (except specifically selected for higher permeability characteristics) on portion of upstream slope not otherwise protected as described above; also provides strong foundation for overlying slope protection zones, as well as lower slope drainage during rapid drawdown events.

- **Core** – A central zone core constructed of well-compacted, relatively fine-grained soils of sufficiently low permeability to serve as the primary waterstop for the dam; carried down to positive connection with sound, seepage-resistant bedrock (improved as necessary with slush grout and dental concrete). Borrow for this zone is assumed to be derived from select weathered bedrock in the vicinity with suitable seepage-resistance, strength, and other engineering characteristics.

- **Downstream chimney filter/drain** – specially designed gradation of hard, durable aggregate to prevent piping (internal erosion) of core material into the downstream shell under normal seepage or at any local cracks that may occur in
the core; with adequate drainage capacity to convey seepage or crack flow to a safe exit at the toe of the dam via the blanket drain without allowing saturation of the overlying downstream shell. Borrow for this zone would be assumed to be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel.

- **Upstream filter** – specially designed gradation of hard, durable fine aggregate (with similar or potentially identical specifications as the chimney filter) sized to clog any cracks that may form in the core as a result of earthquake shaking, non-uniform settling of, or some other unanticipated defect in the core zone; also known as a crack stopper. Borrow for this zone is assumed to be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel.

- **Blanket drain** – horizontal layer of highly permeable coarse aggregate to cobbles to provide for positive relief of excess pore pressures that may form in the foundation, and conduit for seepage water collected in the chimney filter/drain zone; protected top and bottom by filter/drain material to prevent piping of adjacent shell material into drain zone. Borrow for this zone is assumed to be derived from the processing of select local alluvial and/or terrace deposits containing sufficient portions of sand and gravel. This material is assumed to be produced as a coarse-grained byproduct of the coarse chimney filter/drain and upstream filter zone processing operation.

### 9.6.5 Service and Emergency Spillways

As shown on Figure 9.6-2, the emergency spillway is located adjacent to the left abutment the dam. The service spillway is incised within the emergency spillway where a bedrock foundation is presumed to be present after sufficient excavation of overburden. Both spillways discharge to Fish Creek.

**Service Spillway.** The service spillway is sized to accommodate an estimated 100-year peak inflow of 1,762 cfs from an 81 square mile contributing drainage area. At this level of study, no credit in the conceptual design has been taken for attenuation of this peak flow in the reservoir. The spillway has approximate dimensions of 35 feet wide and 550 feet long, with a maximum head of five (5) feet provided to pass the peak 100-year flow and an additional ten (10) feet of head provided to accommodate PMF flows described below. A fully concrete lined structure with a horizontal controlled crest section (likely an ogee section) and downstream energy dissipation at the discharge end is envisioned. The area below the discharge end of the spillway will be graded if/as necessary to ensure that peak discharges from the spillway do not present any greater risk of damage to the existing drainage downstream than a natural flood of comparable peak flow at this location would. Grade control structures to mitigate erosion in the receiving channel would also be utilized as appropriate.

**Emergency Spillway.** The emergency spillway is planned as a broad crest overflow channel constructed as an earth/rock cut through the ridge less than one quarter mile south of the dam. A channel width of approximately 550 feet and a maximum flow depth of 10 feet were chosen to safely pass the estimated peak PMF discharge flow of 66,000 cfs. The additional approximately 8,000 cfs of the PMF inflow is discharged by the service spillway operating at 15 feet of head. Without subsurface exploration of the area, it is unknown whether the spillway channel excavation foundation will be in rock once surficial materials are removed, however, given the relatively low
adverse grade of the approach channel from the reservoir pool to the control section at the crest of the saddle, velocities will be low even at maximum discharge and major erosion protection or lining is not anticipated as necessary even where alluvium will be encountered. The spillway crest will be shaped to provide relatively uniform flow into the chute section, and will be protected from any possibility of back-cutting erosion by grouting or installation of a concrete cut-off wall if necessary (depending on the nature of the excavated materials encountered). The chute section is anticipated to be founded in alluvium at relatively shallow grade. If necessary, the cut slope would be laid back to a stable angle and the lower portion of the slope subject to flow at maximum discharge would be armored as necessary (e.g., with riprap, grouted riprap, shotcrete or some other suitable material).

9.6.6 Outlet Works
The outlet works, located adjacent to the existing alignment of South Piney Creek, is assumed to be a conventional low-level structure comprised of an upstream trashrack-protected gated inlet, a horizontal steel pipe, a downstream energy dissipation structure, and a flow measurement weir to track reservoir releases. At this level of study, it is assumed the outlet pipe will be founded on compacted alluvium utilizing ductile steel to accommodate settlement of the embankment. If the foundation is discovered to have excessive settlement once subsurface investigation is conducted in later studies, the outlet works could be relocated to be founded on rock in either abutment at the design minimum pool invert elevation at somewhat higher cost, with suitably constructed inlet and outlet channels to provide for complete evacuation of the reservoir. Hydraulic control of a single slide gate is assumed, with the operator stem mounted on the upstream slope of the dam and operated from the dam crest. Manual control is assumed given the relative easy access to the site, although automated remote control could be provided if necessary or desirable. The outlet will be sized to meet WSEO requirements for emergency lowering of the reservoir and to provide for maximum anticipated irrigation releases. Evaluation of the need for a multiple level outlet structure to provide some control of the temperature of released water may be required at the next level of study depending on the results of further environmental studies. Such an evaluation will need to assess the anticipated daily and seasonal variations in water temperature in the reservoir.

9.6.7 Access Road(s)
Access to the site is provided by existing mapped roads serving the area as shown on Figure 9.6-2. At this level of study, suitability of existing roads for construction and permanent access is assumed to be adequate (except as described below), although grading/resurfacing is likely to be required during construction and the operations and maintenance phases of the project. A small spur (less than 1.0 mile) road is required to access the crest of the dam from existing roads. As described previously, access roads would be provided on the crest to provide access to the dam crest from the northeast. The same road would cross/serve the emergency and service spillways as well. A section of road approximately 2.5 miles long would require relocation due to inundation by the proposed reservoir pool and the overlay of the dam. This road would be rerouted to the north of the reservoir, across Fish Creek, along the northern perimeter of the reservoir and eventually connected with the existing alignment near the west end of the South Piney Creek arm of the reservoir.
9.7 Alternative 5 – Pumping to Lower Piney Creek Subbasins from Green River

9.7.1 Overview
The overall design concept and layout of features and facilities is shown in plan view on Figure 9.7-1A – Alternative 5 – Green River Pumping Station, Pipeline and Canal Layout (Aerial Photo Base) and Figure 9.7-1B – Alternative 5 – Green River Pumping Station, Pipeline and Canal Layout (Topographic Photo Base). As shown, the major components of this design include:

- Green River Diversion
- Pumping Station
- Pressure Pipeline
- Delivery Canal
- Access Roads

Each of these major components is described below together with the bases for key elements of their design.

9.7.2 Green River Diversion
A diversion facility, consisting of a sheetpile cutoff wall and grade control structure, concrete headwall, debris removal trashrack, fish screen, sediment removal pool (as necessary), and a pumping station intake channel would be installed in the west bank of the Green River stream channel to divert incoming, available flows to the pumping station described in the next section. At this level of study, it is assumed that sufficient flow is available within the Green River and that favorable stream channel geometry is present to allow this relatively low-impact side channel type of stream diversion as opposed to a full cross-channel diversion dam. Exact location of the diversion facility will depend on the results of further study (subsurface foundation investigation, stream channel geomorphic and hydraulic analyses, existing utility corridor location, if present, and other studies as appropriate).

9.7.3 Pumping Station
The proposed pumping station has a design capacity of 75 cfs and a static lift of 180 feet, not including losses in the receiving pressure pipeline described in the next section. The pump station would be sized to deliver a mean annual volume of approximately 5,000 acre-feet.

9.7.4 Pressure Pipeline
A pressurized steel pipeline would receive the pumping station discharge and convey pumped flows to a distribution canal system described in the next section. The proposed pipe diameter is 48-inches. The pipeline alignment is along a relatively smoothly sloping grade as illustrated in Figure 9.7-1B.

Exact alignment of the pipeline would be determined upon further study to minimize any potential conflicts with existing utility corridors, other existing infrastructure or existing rights-of-way. It is recognized that the conceptual alignment shown passes through neighborhoods in east Marbleton that were not present when the available topographic mapping was developed. In fact, even more development has occurred in northeast Marbleton since the CIR-DOQQ photos used for the base of Figure 9.7.1A were flown.
9.7.5 Delivery Canal
Pumped discharge from the pressure pipeline described in the previous section would be released into a distribution canal for delivery to existing irrigation water distribution systems. The delivery canal crosses the lower Piney Creek basins transversely to intersect existing canals, ditches and other infrastructure. Turnouts would be provided to route water to existing facilities to replace water exchanged upstream as described in Section 5.0. Culverts would be provided as necessary where the canal crosses other infrastructure visible in Figures 9.7-1A and B and otherwise present at the time of design and construction.

9.7.6 Access Road(s)
Access to most of the Alternative 5 facilities can be made directly from existing paved and unpaved roads, or from relatively short spurs/extensions that would be made for construction and then maintained as necessary for operational and maintenance access.

9.8 Alternative 6 – Combined Alternative
This alternative consists of a combination of each of the Alternatives 1 through 5 components operating in tandem if/as appropriate. Conceptual designs for each component alternative are identical to their stand-alone counterparts described in the previous Sections 9.3 through 9.7.

10.0 Cost Estimates
Conceptual level cost estimates for each of the preferred water supply alternatives described in Sections 4.5 and 5.2 were prepared based on the conceptual-level designs and assumptions presented in Section 9.0 as well as other assumptions and factors described herein. This approach first involved estimation of construction costs for each of the major project components (i.e., dam, spillway and outlet works, conveyance canals/pipelines, etc.), appurtenant and miscellaneous items (e.g., access roads, mobilization/demobilization, etc.), and known interferences from existing infrastructure such as road relocation. Indirect costs (i.e., construction engineering and contingency) were then added as a percentage of the construction cost estimate following WWDC guidelines. Other costs, such as permitting, legal fees, access, land acquisition and right-of-way were added either as a percentage of construction cost or based on acreage or other estimates as noted herein.

10.1 Methodology
The construction cost estimating approach included preparation of a conceptual layout/design and quantity takeoffs as described in Section 9.0 for all alternatives. It is important to note that all of the conceptual designs were based on the available USGS topographic mapping (at either 20 ft or 40 ft contour interval depending on the site). Volumes of earthwork and storage capacity were calculated at the selected dam heights (using multiple sections) to provide an approximate curve of dam height versus storage capacity and excavation/fill requirements. The overall dam volume was apportioned based on dam geometry (i.e., average dam height and length) to estimate various materials requirements such as riprap, core, shell, drain, etc. In each case, borrow area location and haul distances were accounted for, in addition to processing costs (if required as described in Section 9.0).

The estimated construction cost for the service spillway was based on a formula used to estimate the approximate concrete volume considering dam height, head on the
spillway, slope of abutment, and spillway width. The derived formula was then checked against prior dam construction projects. The emergency spillway cost was based on construction of a concrete crest (cutoff wall) and open cut rock/earth spillway in one of the abutments. If estimated earthwork cut volumes for the spillway exceeded that required for construction of the dam embankment, an additional cost was added to cover hauling this material to a local waste fill assumed to be within the reservoir area or immediate vicinity of the dam and reservoir.

The outlet works estimate for new reservoirs was based on a formula which related outlet works size to storage volume (and associated dam safety drawdown requirements) and height of dam (which is related to conduit diameter and length). The generalized formula was then checked for reasonableness against costs from prior projects.

Costs were also included on a case by case basis to provide an allowance for other items such as site access, wetlands mitigation, and other items as appropriate. Costs for the non-project component items were estimated as follows:

- Preparation of final design and specifications - 12% of construction cost;
- Construction engineering - 10% of construction cost per WWDC guidelines;
- Contingency - 15% of construction cost per WWDC guidelines;
- Legal fees - 0.5% of construction cost;
- Acquisition of access and rights of way - based on estimated acreage and type of impacted lands estimated from topographic maps and irrigated lands data;
- Environmental permitting and mitigation - based on estimated acreage/quantities and type of impacted wetlands, riparian and cultural resources discussed in Section 7.0 and Section 8.0.

10.2 Results

The conceptual-level estimated project costs for each of the preferred alternatives are included in Table 4.5-1. Costs per cubic yard of fill and per ac-ft of storage are also provided on Table 4.5-1 for relative comparison to other WWDC projects. The total project costs are also summarized on Table 10.2-1 – Summary of Estimated Costs of Alternatives.

More detailed breakout estimates for each alternative are presented in Tables 10.2-2 – Alternative 1 – Horse Creek/Cottonwood Creek Storage, Conceptual Level Cost Estimate through Table 10.2-7 – Alternative 6 – Combination of Alternatives 1-5, Conceptual Level Cost Estimate in the contract-required WWDC format. Additional detailed breakdown of all costs is included in Table 10.2-8 – Cost Estimate Detail. All cost estimates are based on 2008 dollars. Note that the costs for final design, specifications, contract documents and permitting eligible for inclusion as Phase III of Level II are deducted from the Project Cost Total to arrive at the Level III Project Cost Total. This is the amount that would then be subject to a grant/loan mix under WWDC funding as described in Section 11.3.

It is important to understand that these opinions of cost are very preliminary, and that a number of potentially significant factors must be further investigated to support refinement of these costs. At this level of study, the opinions of cost are estimated to be within +50 to –30 percent of the actual costs.
11.0 Economic Analysis

This section analyzes the order-of-magnitude economics of and considers potential funding scenarios for the selected surface water storage project alternatives identified in Sections 4.5 and 5.2 above. The economic analyses are based on the direct and indirect benefits of using stored water for supplemental irrigation of existing irrigated lands. The funding scenarios assume WWDC grant/loan funding of an eligible local project sponsor in accordance with the contract scope of work. The economic and financing analyses address the following key elements:

- Benefits associated with the alternative projects;
- The ability-to-pay of local irrigators;
- The minimum cost of water to irrigators under current WWDC guidelines; and
- The sponsor’s ability-to-pay under different grant/loan scenarios.

In regard to funding of surface water storage projects, other potential funding sources than just WWDC may be identified and quantified if more detailed study proceeds with one or more project alternatives. Given the current scope of this Level II study, it was not feasible to quantitatively assess the magnitude of any such other funding and the effects it may have on project economics. However, none of the other potential funding sources discussed in Section 11.4 below appear likely to be able to provide a significant additional monetary contribution to these dam and reservoir or pumping projects.

11.1 Benefits Analysis

The economic benefits of supplemental irrigation water are measured by the marginal increase in farm income that would be generated by a given amount of additional water. This section develops an estimate of the marginal increase in farm income attributable to an additional acre-foot of water for a typical irrigated operation in the Upper Green Westside study area. To develop this estimate, several variables must be known or estimated, including:

- The efficiency with which the additional water would be utilized by the crop or crops under consideration;
- The yield response of the crop or crops to the application of the additional water;
- The market value of the additional yield that would be generated; and
- The marginal production costs that would be incurred in harvesting the additional yield.

Estimates of this type are typically developed through crop enterprise budget analyses. These analyses can consist of developing site-specific estimates of all relevant variables through exhaustive studies of local agronomic conditions and farm production practices. They can also be generated by adapting estimates developed for other areas with similar characteristics. Due to the conceptual level of this study, the latter approach was used.

Estimates of irrigation efficiency were adapted from the Wind/Bighorn Basin Plan, (BRS, et al., 2003); no specific estimates of efficiency were found in the Green River Basin Plan. The Wind/Bighorn Basin Plan estimates overall annual average irrigation efficiency at 28 percent for small watersheds thought to be generally comparable to the Upper Green Westside watershed. Irrigation efficiency was
assumed to vary during the irrigation season, however, from a low of 19 percent in April to a high of 42 percent in July. The average efficiency utilized in the StateMod model for the Upper Green River Basin was approximately 31 percent which is consistent with the preceding estimates drawn from the Wind/Bighorn Basin Plan. Because supplemental water presumably would be used later in the irrigation season, an efficiency estimate of 35 percent (slightly higher than average) was used in developing the benefit estimates described in this report.

Estimates of the crop yield response to additional irrigation water were adapted from studies undertaken for the North Platte River Basin in eastern Wyoming near Torrington (Pochop, et. al, 1992). Those studies indicate that an assumed crop mix of 50 percent alfalfa and 50 percent grass hay would have a yield response averaging 1.48 tons per acre-foot of consumptively used irrigation water. Studies by the University of Wyoming indicate that the average growing season in the Upper Green River Basin area is approximately thirty percent shorter than in the Torrington area (Pochop, et. al, 1992). Although the total hay production in the Upper Green River Basin is less per acre as compared to the Torrington area due to the shortened season, for this analysis it is assumed that the yield response to irrigation water consumptively used would be similar.

The market value of the additional yield that would be generated from an acre-foot of additional irrigation water is dependent upon crop prices. For the past four years (2004 – 2007) the market price of alfalfa hay in Wyoming has averaged $90.12 per ton. The corresponding average price for grass hay has been $88.25. Because hay production in the Upper Green River Basin (Sublette County) is estimated as about ten times as much grass as alfalfa, an average price of $88.42 per ton was used to derive the benefit estimates described in this report.

The final piece of data needed to arrive at an estimate of the marginal value of supplemental irrigation water is an estimate of the marginal increase in production costs that would be incurred to harvest the incremental yield. In the case of hay production, these marginal costs consist primarily of increased costs for irrigation, baling, loading, and stacking activities. A study of these costs for North Platte River irrigators resulted in an estimated cost increase of $26.12 per ton in 1995 dollars (Watts and Brookshire, 2000). Updating these costs to 2008 dollars (consistent with other cost data and estimates herein) results in a marginal production cost estimate of $39.06 per ton.

The information described above can be used to estimate the economic benefits of an acre-foot of supplemental irrigation water as follows. One acre-foot of water at an irrigation diversion point applied with 35 percent efficiency will result in an estimated increase in hay production of 0.35 X 1.48 = 0.52 tons. At an average market price of $88.42 per ton, the estimated value of the increased production is $45.98. Subtracting a marginal production cost increase of 0.52 X $39.06 = $20.31

1 The growing season for the Upper Green River Basin was estimated as the average of the Big Piney and Pinedale growing seasons, or 137 days. The average growing season for the Torrington area is 201 days.


3 Costs were updated using the index of production costs paid by Wyoming farmers and ranchers available from the Wyoming Office of the National Agricultural Statistics Service at the following website: http://www.nass.usda.gov/Statistics_by_State/Wyoming/index.asp
results in a net benefit estimate of $25.67 for each acre-foot of supplemental irrigation water available for diversion when and where it is needed.

11.1.1 Indirect Irrigation Benefits

Indirect benefits, sometimes referred to as secondary benefits, stem from the economic multiplier effect of increases in income in a regional economy. For example, if irrigators’ incomes increase because of a new irrigation project, some of that income will be spent locally, resulting in additional income increases in other sectors of the Wyoming economy. Thus, the total economic benefits associated with an irrigation project can be larger than direct income increases to irrigators alone.

Some economists argue that it is inappropriate to include indirect benefits in project evaluations because building an irrigation project in one part of Wyoming may result in economic losses elsewhere in the state. For example, in a report prepared for the U.S. Environmental Protection Agency, Huszar (1990) argued that indirect benefits should not be considered in an economic evaluation of the Sandstone Project. His reasoning was that funding for the project came from taxes on Wyoming citizens, and that without the project, taxes could be lowered with an equally large stimulating effect on the Wyoming economy. Although the logic of this argument is sound, the facts are incorrect. WWDC construction funds are derived from minerals severance taxes, not taxes on Wyoming citizens. If minerals severance taxes were lowered, the likely result would be a benefit to out-of-state users of Wyoming’s coal or out-of-state shareholders of energy companies doing business in Wyoming, not Wyoming residents. For this reason, it is appropriate to consider indirect benefits in evaluating projects funded largely by minerals severance taxes.

The Bureau of Economic Analysis of the U.S. Department of Commerce (USDOC) produces periodic estimates of indirect income multipliers for Wyoming’s agricultural sector. Their latest published estimate of this multiplier is 3.36 (USDOC, 1992); meaning that for each dollar of additional farm income, total income in Wyoming increases by $3.36. The $3.36 is comprised of $1.00 of farm income and $2.36 of indirect income, which can be an indirect benefit of new irrigation projects.

11.2 Ability to Pay Analysis

An irrigator’s ability to pay for irrigation water is bounded by the magnitude of direct irrigation benefits that would be generated by the additional water. For example, the analysis used in Section 11.1 is based on the estimate that supplemental irrigation water will generate a direct benefit of $25.67 per acre-foot. The benefit estimate reflects the market value of additional crop production minus the costs associated with producing the additional crop. Table 11.2-1 – Summary of Maximum Potential Benefits of Project Alternatives presents an analysis of maximum potential benefits of the various project alternatives based on estimated normal year shortages, available yield, and project benefits for each of the alternatives. The column labeled “Maximum Potential Annual Benefits From Supplemental Irrigation Only” is based on the estimated direct benefit of $25.67 per acre-foot of water utilized. The next to last column in the table is the “Present Value” of those benefits based on an interest rate of 4.0 percent and a loan period of 50 years (the maximum period for the loan portion of WWDC funding). Numbers in that column could be compared to the capital cost of an alternative which would represent a break-even project cost if no grant money was provided and if a loan of 4.0 percent for a 50-year period was received (and if operation, maintenance and replacement (OM&R) costs are ignored). The final column represents the total estimated value of the increased benefit of the
project to the state economy based on a ratio of 3.36 total benefit to increased direct farm income.

The above table represents an upper bound on ability to pay because the values are estimates of the total additional farm income that could be generated from additional storage. If irrigators were required to forfeit all of the additional income to repay project expenditures, however, they would have no incentive to participate in the project. Thus, ability-to-pay studies assume that ability to pay is some reasonable fraction of direct project benefits. For purposes of this analysis, ability to pay is assumed to be 50 percent of the additional income that could be generated from new storage, or $12.84 per acre foot. It is important to understand that the ability to pay numbers are based on the very preliminary values for the yield and benefit analysis from this Level II study.

11.3 Financing Under WWDC Guidelines

The current WWDC project financing default standard is 67 percent grant with the remaining 33 percent of project costs to be repaid by the project sponsor. Repayment can be financed over a maximum period of 50 years at the State Loan Board interest rate, which is currently four (4) percent. See Section 11.4 for additional discussion regarding the WWDC program. The implications of applying these funding criteria to the project surface water storage alternatives can be seen in the results in Table 11.3-1A – Ability to Pay Debt Service – 67% Grant. For comparison, additional funding scenarios of 75% Grant/ 25% Loan and 90% Grant/10% Loan are presented in Table 11.3-1B and Table 11.3-1C, respectively. Each of these three tables show the estimated Level III cost of each alternative (column 3), the project sponsor’s share of those costs based on the assumed grant (column 4), and the sponsor’s annual repayment amount assuming a 50-year loan at four percent interest (column 5). The estimated Level III cost is the estimated total project cost less the estimated Level II/Phase III costs paid by WWDC for qualifying dam and reservoir projects of the sizes envisioned here.

The remaining two columns of the tables show estimates of the maximum amount irrigators could repay each year based upon an ability-to-pay rate of $12.84 per acre-foot of storage. These amounts are substantially less than would be required to fund any of the alternatives under current WWDC guidelines for sponsored projects (67% funding), even at the maximum 50-year loan period. The last column of the tables presents ability to pay as a percentage of a sponsor’s share of total project costs, for the assumed funding percentage, interest rate and loan period. These results indicate a limited ability for project sponsors to repay estimated project costs without substantial additional state assistance in the form of a much higher than average grant (i.e., 90% or greater) or some other source(s) of significant funding.

Operation, Maintenance and Replacement (OM&R) costs will further reduce the sponsor’s ability to repay the loan as they will increase the total project annual costs, thereby offsetting a portion of the available income. These impacts will be most significant in Alternatives 1, 5 and 6 which include pumping (power costs), showing the greatest impact to Alternative 5, Pumping to Lower Piney Creek Subbasins from Green River. The ability to pay with consideration of debt service and OM&R is presented in Table 11.3-2A – Ability to Pay Debt Service (67% Grant) and OM&R. Again, for perspective, ability to pay at 75% and 90% grant scenarios is presented in Table 11.3-2B and Table 11.3-2C, respectively. The tables show the estimated sponsor’s annual OM&R for the alternative (column 6), and the combined
debt service and OM&R (column 7). Other information provided is similar to that described above for Tables 11.3-1A-C.

Table 11.3-3A – Annual Debt Service Costs Per Acre Served and Per Acre-Foot Yield presents the recurring annual cost over the life of a 50-year loan (i.e., the amortized non-grant share of total project cost) per irrigated area served and per acre-ft of available yield. The annual cost in Table 11.3-3A is the sponsor’s share of the total project cost based on the three assumed funding scenarios of 67%, 75% and 90% grant.

The “irrigated land served” is assumed to be the sum of all irrigated lands which could be benefited by the project either through direct release or through potential exchange. More refined modeling of each basin in a subsequent study would be required to further define the areas of potential benefits. If in fact some of the irrigated lands could not be served through exchange, and thus would not benefit from the storage, the unit cost to those lands that are benefited would increase proportionately. The results presented in Table 11.3-3A range from a low of $2/per acre to a high of $48/acre, depending on alternative, associated acreage served, and percent grant funding assumed. This wide range is due in large part to the funding scenario and the extent to which the area can be served (with varying degree of satisfying demand). A high percent funding assumption and a low cost alternative relative to the size of area served results in a low cost/acre; the opposite scenario yields a high result. However, it should be noted that not all alternatives provide the same degree of service. That is, the extent to which water is supplied and demand is met (or shortage is reduced) varies among alternatives. This situation can be seen further in Section 5.2 and Table 5.2-1. Additionally, the area shown for Alternative 6 is the total sum of the areas served within each of the individual basins; whereas, the area served by the other alternatives have overlapping boundaries and areas.

The “annual yield” used in the calculations in Table 11.3-3A is the average shortage satisfied over the period of record. The cost to the sponsor per acre-foot of yield on this basis ranges from a low of $7/ac-ft to a high of $70/ac-ft.

Table 11.3-3B Annual OM&R Costs – Per Acre Served and Per Acre-Foot Yield illustrates the respective unit costs for the various alternatives based on the estimated OM&R costs previously presented in Table 11.3-2. Table 11.3-3C Annual Debt Service & OM&R Costs - Per Acre Served and Per Acre-Foot Yield combines the results from Table 11.3-3A and Table 11.3-3B to include both debt service and OM&R as they relate to costs per acre served and per acre-foot of yield.

11.4 Potential Funding Sources

Potential sources of funding for the preferred alternative surface water storage/supply projects described in Sections 4.5 and 5.2 are identified and characterized in this section of the report. Based on this evaluation, it is apparent that the primary source of potential funding will be the Wyoming Water Development Commission (WWDC) as discussed in Section 11.3. The level of potential funding available from WWDC will depend in part on whether or not the proposed project can develop water in excess of the sponsors present and future needs to provide one or more of the potential secondary (multiple) benefits preliminarily identified in Section 4.6.

Regardless of whether secondary benefits are documented that would justify WWDC funding of the portion of the project promoting those benefits, some other potential
Funding sources discussed herein may be able to provide some additional monetary and/or in-kind contribution supportive of the proposed projects and potentially associated environmental and/or irrigation water conservation and management enhancement projects that cannot be funded by WWDC but that may ultimately required as part of a successful storage reservoir permitting process. It is not anticipated, however, that any of these potential sources would be able to fund other than a very small part of the overall sponsor’s share of total project costs.

The potential sources identified herein are not necessarily exhaustive of the resources that may be available, existing programs change and sometimes disappear over time, new programs arise, funding levels vary year to year, and competition for many of the programs is significant. Also, contact information for various programs and key people can also change.

Key aspects and information about the funding programs identified are discussed in the following subsections and are summarized in a matrix format (Table 11.4-1 – Potential Funding Sources).

11.4.1 Wyoming Water Development Program

The mission of the Wyoming Water Development Commission (WWDC) as defined in the enabling legislation is to:

“Provide, through the commission, procedures and policies for the planning, selection, financing, construction, acquisition and operation of projects and facilities for the conservation, storage, distribution and use of water, necessary in the public interest to develop and preserve Wyoming’s water and related land resources. The program shall encourage development of water facilities for irrigation...for abatement of pollution, for preservation and development of fish and wildlife resources...and shall help make available the waters of the state for all beneficial uses...” (W.S. 41-2-112(a))

The main Wyoming Water Development Program encompasses new development, rehabilitation, water resources planning, and master planning. Of most relevance in terms of implementing the preferred alternative dam and reservoir storage projects is the Dam and Reservoir Program. The Rehabilitation Program would be a potential source of funding for any significant rehabilitation or upgrades to the existing Green River Supply Canal and/or any other existing canals that may be able to be integrated into one or more of the preferred project alternatives of this study, if any. Information regarding these programs is available in the Operating Criteria of the Wyoming Water Development Program dated June 5, 2008 which can be downloaded at the following website: http://wwdc.state.wy.us/opcrit/final_opcrit.pdf and from a WWDC form titled Information for New Applicants which is available for download at: http://wwdc.state.wy.us/projappl/New_Ap_Info.pdf. The WWDC Dam and Reservoir Program and the Rehabilitation Program are discussed further below.

It is important to ensure that the most current information on funding is reviewed prior to making an application as WWDC’s policies and procedures can and do change over time in response to legislative direction and/or Commission action. Review of information available at the above websites and contact with the staff of the WWDO (307.777.7626) is recommended prior to beginning the application process.
**Dam and Reservoir Program.** This program provides technical assistance and funding to develop dam and reservoir projects to store waters of the state that are unused and/or unappropriated at present. WWDC has developed priorities relative to the types of projects the program should pursue to utilize available program funds effectively and efficiently. Relevant to dam and reservoir projects, priority is given to:

- Multipurpose Projects (including those serving agriculture, municipal, industrial, rural domestic, recreation, environmental, flood control, erosion control), and hydropower functions
- Storage Projects (dams and reservoirs that store water during times of surplus for use later when needed)

These project types are given highest priority by WWDC when determining what projects to pursue among all of the applications received for funding.

Two important criteria that apply specifically to eligible dam and reservoir projects are:

- "Level II, Phase III – Dam and Reservoir Program only  This phase of development pertains to projects that enlarge existing storage projects by 1,000 acre-feet or greater or for proposed new dam and reservoirs with a capacity of 2,000 acre-feet or greater. Work included under this phase includes final engineering design reviews required by the National Environmental Policy Acts consultations required by the Endangered Species Act, and acquisition of state and federal permits."

- "The WWDC may accept applications related to the construction of dams and reservoirs from applicants that are not public entities. As the evaluations of the feasibility of new dams are complex, this will allow the applicant to know if the proposed reservoir is feasible prior to becoming a public entity. However, the applicant must be a public entity before applying for Level II, Phase III funding."

**Rehabilitation Program.** The Rehabilitation Program addresses the improvement of water projects completed and in use for at least fifteen years in order to assist in keeping existing water supplies effective and viable for the future. Potentially relevant to the Upper Green River Westside storage project, the Rehabilitation Program can improve existing agricultural conveyance systems to insure safety, decrease operation and maintenance (O&M) costs, and increase the efficiency of agricultural water use.

An application may be made to proceed directly to Level II for eligible projects under the Rehabilitation Program. If the project is found technically and economically feasible the project can advance to construction.

**Financial Plan.** The current standard terms of the Wyoming Water Development Program financial plan for Level III (construction phase) funding are summarized as follows:

- Sixty-seven (67) percent grant to thirty-three (33) percent loan mix
- Maximum grant of 75 percent only where severe financial hardship has been successfully demonstrated to WWDC by applicant
- Minimum four (4) percent loan interest rate (current rate is 4 percent, but legislature may increase rate)
- Maximum 50-year term of loans; standard loan term is 30 years; term shall not exceed economic life of project
- Payment of loan interest and principal may be deferred up to 5 years after substantial completion at WWDC’s discretion under special circumstances

Special financial plan considerations for dams and reservoirs are summarized as follows:

- WWDC may recommend grant/loan mix based on sponsor’s ability to pay a portion of project costs and all operation, maintenance and replacement (OM&R) costs
- As noted previously, WWDC may recommend that program pay for final design and permitting costs
- WWDC may recommend that program pay for storage capacity needed to provide water for environmental mitigation and enhancement, thereby reducing cost applied to grant/loan mix

WWDC may recommend any combination of the above considerations.

The Commission will evaluate whether or not a project will be funded for Level III construction following review of the results of Level II studies. If the Commission determines that the project should not advance due to any of a number of considerations regarding the merits of the project and the ability and willingness of the applicant to assume their share of financial responsibility for the project, the sponsor has the option of making a formal presentation to WWDC relative to the sponsor’s ability and willingness to pay. This presentation must address the need for the project, the direct and indirect benefits of the project, and any other information the sponsor feels is relevant to the Commission’s final decision.

11.4.2 Local Agencies

The Sublette County Conservation District (SCCD) can help serve as a liaison between local landowners and resource users and state and federal government agencies in relation to potential secondary environmental and agricultural benefits that may be provided by the proposed project. In addition to its many other roles and responsibilities, the SCCD can also provide funding-related assistance as follows:

- In-kind technical assistance as local resources, capacity and expertise allow;
- Administration of programs, projects and grants on behalf of recipients of state and federal natural resources program funding; and
- Assistance in development of leveraged, partnered programs and projects.

The SCCD would also implement the grant program being developed by the Wyoming Association of Conservation Districts (WACD) to address locally driven watershed efforts.

11.4.3 Other State Agencies

**Wyoming Department of Environmental Quality.** The Wyoming Department of Environmental Quality (WDEQ) provides funding for implementation of best management practices (BMPs) to address non-point sources of pollution under
Section 319 of the Clean Water Act. Section 319 grant funding requires a non-federal (i.e., local) match of 40 percent from the applicant. These matching funds may be provided by landowners, a conservation district, other quasi-governmental entities (e.g., watershed improvement district, irrigation district, etc.), and/or non-profit organizations (e.g., Trout Unlimited, Ducks Unlimited, and the Rocky Mountain Elk Foundation). Applications (proposals) conforming to a specified format are required. The proposal describes in some detail the issues to be addressed and the proposed methods/BMPs to be implemented, as well as providing all other information required to evaluate the proposed project and matching fund entity(ies). These proposals are normally due in August or September of each year.

The Bureau of Land Management (BLM) in Wyoming is partnering in the implementation of several section 319 watershed plans statewide as part of their Watershed and Water Quality Improvement efforts. Given the distribution of private, state and federal (primarily BLM) lands within the study area, this type of partnering may be applicable to future BMP projects that might best be implemented across land ownerships.

Wyoming Game and Fish Department. The following summary of funding assistance available from the Wyoming Game and Fish Department (WGFD) is quoted from the Water Management & Conservation Assistance Program Directory (WWDC, 2005):

“The Wyoming Game and Fish Department offers a funding program to help landowners, conservation groups, institutions, land managers, government agencies, industry and non-profit organizations develop and/or maintain water sources for fish and wildlife. This program also provides funding for the improvement and/or protection of riparian/wetland areas for fish and wildlife resources in Wyoming. Applications for projects are accepted any time with approval on January 1 and August 1 of each year.

Riparian Habitat Improvement Grant. The purpose of this program is to improve or maintain riparian and wetland resources. Fencing, herding, stock water development, streambank stabilization, small damming projects and beaver transplanting are a few examples of efforts that qualify under this program. Permits, NEPA compliance, construction, maintenance, access and management planning are all grantee responsibilities. There is $10,000/project maximum available with 50% cash or in-kind required from grantee.

Water Development/Maintenance Habitat Project Grant. The purpose of this program is to develop or maintain water for fish and wildlife. Spring development, windmills, guzzlers, water protection and pumping payments are examples of the extent of this program. Permits, NEPA compliance, maintenance, access and water rights are responsibilities of the grantee. There is a maximum of $10,000/project and 50% cash or in-kind contribution required from the grantee.

Fish Wyoming. The purpose of this program is to develop public fishing opportunities. Examples of projects within this effort are boat ramps and fishing access. This program provides a 50% match of funding which is channeled through a private organization or municipality.”
**Wyoming Sage Grouse Conservation Fund.** WGFD also administers the Wyoming Sage-Grouse Conservation Fund (WSGCF). The WSGCF is a special fund established by the Wyoming State Legislature to support the efforts of Local Sage-Grouse Working Groups (LWG). The applicable LWG for the study area is the Upper Green River Sage-Grouse Working Group. The WSGCF funding is intended to promote conservation of sage grouse populations and habitat (sagebrush ecosystems), including socio-economic and human use of the habitat.

Requests for WSGCF funding must be made on a Project Proposal Form available at: [http://gf.state.wy.us/wildlife/wildlife_management/sagegrouse/](http://gf.state.wy.us/wildlife/wildlife_management/sagegrouse/). Funding is normally considered for projects ranging between $5,000 and $50,000, with priority given to those with matching funds, established partnerships, multi-species benefits, management relevance and consistency with the local sage-grouse conservation plan, highest wildlife impact, appropriate budgets, landscape scale, and a lasting legacy of benefits. Evaluation criteria include: consistency with the local plan, likelihood of project success, project readiness, availability of matching funds, multiple species benefits, significance at local/state/regional level, duration of benefits, and adequacy of funding.

Application may be made at any time, but should be made by February 1 to receive first round consideration. Funds awarded must be expended between July 1 of the year received and September 30 of the second year after award. The funds are normally distributed as reimbursable grants (i.e., payments are made for expenses incurred and not “up-front”). Requests for funding of habitat improvement projects, including water developments, must include a livestock grazing management plan. A Project Close-out Report must also be submitted upon completion to allow tracking of expenditures and tracking of results.

**Wyoming Wildlife and Natural Resource Trust.** The Wyoming Wildlife and Natural Resource Trust (WWNRT) was formed by the state legislature in 2005 to preserve and enhance Wyoming’s wildlife and natural resources. Projects funded by WWNRT must provide a public benefit such as continued agricultural production to maintain open space and healthy ecosystems, enhancements to water quality, and maintenance or enhancement of wildlife habitat. Allowable projects under this program that are potentially relevant to this watershed management plan study include:

- Improvement and maintenance of existing aquatic habitat necessary to maintain optimum fish populations.
- Conservation, maintenance, protection and development of wildlife resources, the environment, and Wyoming’s natural resource heritage.
- Participation in water enhancement projects to benefit aquatic habitat for fish populations and allow for other watershed enhancements that benefit wildlife.

Funding is by grant with no matching funds required. Non-profit and governmental organizations (including watershed improvement districts, conservation districts, etc.) are eligible for funding by WWNRT. Projects will be funded in July and January. Applications may be filed any time, but must be filed within 90 days of the next funding cycle to receive consideration in that cycle.
11.4.4 Federal Agencies

**Bureau of Land Management.** The Bureau of Land Management (BLM) administers the Riparian Habitat Management Program. The goals of this program are to maintain, restore, improve, protect and expand riparian-wetland areas to achieve “proper functioning condition for their productivity, biological diversity, and sustainability.” Funding is available (subject to budget allocations) for projects which include partnering with non-BLM interests.

**Bureau of Reclamation.** The Bureau of Reclamation (BOR) administers the Water 2025 Challenge Grant Program. This program provides funding on a competitive basis for projects focused on water conservation, efficiency and water marketing. Preference is given to projects that can be completed within 24 months that will help to prevent crises over water in areas identified as “hot spots” where potential for conflict is judged to be moderate to highly likely by 2025. Because the study area is not located in or near a BOR-defined “hot spot” and the primary purpose of the proposed projects is water storage for agricultural beneficial use, it would appear that the chances of successfully competing for a grant under this program are slim.

**Environmental Protection Agency.** The Targeted Watershed Grants Program administered by the Environmental Protection Agency (EPA) “encourages watershed practitioners to examine local water related problems in the context of the larger watershed in which they exist, to develop solutions to those problems by creatively applying the full array of available tools, including general, state and local programs, to restore and preserve water resources through strategic planning and coordinated project management that draw in public and private sector partners...” as described in: [http://www.epa.gov/twg/2006/2006faq.html#intro](http://www.epa.gov/twg/2006/2006faq.html#intro).

Organizations eligible for funding include nonprofits, tribes, and local governments. The assistance provided consists of grants for up to 75 percent of the total project costs. A match of at least 25 percent is required. The typical median amount awarded is $700,000 with a typical range of $300,000 to $900,000. It is important to note that application must be made by the governor, and that the competition for these grants is keen.

**Fish and Wildlife Service.** Technical and financial assistance are available to private landowners, profit or non-profit entities, public agencies and public-private partnerships under several programs addressing the management, conservation, restoration or enhancement of wildlife and aquatic habitat (including riparian areas, streams, wetlands and grasslands). These programs include, but are not necessarily limited to:

- **Partners for Wildlife Habitat Restoration** – technical and financial assistance to private landowners through Wildlife Extension Agreements (WEA) to implement and maintain restoration projects while the landowner retains full control of the land.

- **North American Wetlands Conservation Act Grant Program** – grant program promoting long-term conservation of wetlands ecosystems and the species that depend on them; requires cost-share partners to provide non-federal matching funds at least equal to the grant amount. Small Grants are typically for $50,000.
- **Landowner Incentive Program (Non-Tribal).** This program provides funding directly to the lead state wildlife service agency (WGFD in Wyoming) for programs addressing the issues noted previously.

**Natural Resources Conservation Service.** The Natural Resources Conservation Service (NRCS) administers a number of funding and technical assistance programs applicable to irrigation, range and watershed improvements. These programs are briefly described below and summarized in Table11.4-1.

**Environmental Quality Incentives Program.** The Environmental Quality Incentives Program (EQIP) is a voluntary program available to agricultural producers that provides technical assistance, cost sharing and incentive payments for projects and practices that improve water quality, enhance grazing lands, and/or increase water conservation. Current priorities used by NRCS in allocating EQIP funds that may be applicable to the study area include reduction of non-point source pollution of surface waters, reduction in soil erosion and sedimentation from agricultural lands, and promotion of at-risk species habitat conservation.

Non-federal landowners (including American Indian tribes) that engage in livestock operations or agricultural production are eligible for funding. Eligible land includes cropland, rangeland, pasture, forestland, and other farm and ranch lands. Eligibility also requires that the applicant develop an EQIP plan of operations that becomes the basis of the cost-sharing agreement between NRCS and the participant.

Funding assistance may include cost-sharing, incentive payments and technical assistance. Cost-sharing can provide up to 75 percent of the costs of eligible conservation practices important to improving and maintaining the health of natural resources in the area. The term of cost-sharing contracts is from one (1) to ten (10) years. Incentive payments may be made for up to three (3) years to encourage land, integrated pest, irrigation, and/or wildlife management practices. The maximum aggregate limit of cost-sharing and incentive payments to an individual or entity was $450,000 for all contracts entered into during FY 2002-2007.

Detailed information about the EQIP program is available at the following website: [http://www.nrcs.usda.gov/PROGRAMS/EQIP/](http://www.nrcs.usda.gov/PROGRAMS/EQIP/).

**Watershed Protection and Flood Prevention Program.** Also known as the “Small Watershed Program” or the “PL 566 Program”, this program provides technical and financial assistance to address resource and related economic problems on a watershed basis. Projects related to watershed protection, flood prevention, water supply, water quality, erosion and sediment control, wetland creation and restoration, fish and wildlife habitat enhancement, and public recreation are eligible for assistance. Technical and financial assistance is also available for planning and installation of works of improvement to protect, develop, and use land and water resources in small watersheds.

Applicants eligible for funding through this program that may be relevant to the study area include: local or state agencies, counties, conservation districts, or other subunits of state government (e.g., watershed improvement, water conservancy and irrigation districts) with the authority and capacity to carry out, operate, and maintain installed works of improvement. Projects are limited to watersheds containing less than 250,000 acres.
The assistance provided consists of technical assistance and cost sharing (amount varies) for implementation of NRCS-authorized watershed plans. Technical assistance is provided on watershed surveys and planning. Although projects vary significantly in scope and complexity, projects receiving $3.5 million to $5 million in federal financial assistance are not uncommon.

**Other NRCS Programs.** Other programs administered through NRCS that may be relevant to the broader aspects of irrigation conservation and management and watershed protection/enhancement include, but are not necessarily limited to the following:

- Wildlife Habitat Incentives Program (WHIP)
- Wetlands Reserve Program (WRP)
- Conservation Security Program (CSP)
- Farm and Ranchlands Protection Program (FRPP)
- Emergency Watershed Protection (ERP)
- Small Watershed Rehabilitation Program
- Sage Grouse Restoration Project (SGRP)
- Cooperative Conservation Partnership Initiative (CCPI)

### 11.4.5 Non-Profit and Other Organizations

**Ducks Unlimited.** Ducks Unlimited, Inc. (DU) is a potential funding source for wetlands and waterfowl restoration projects. Although direct grant funding is limited (to the extent that there is generally about $20,000 to $30,000 available annually statewide), in-kind assistance may be available from the local chapter of DU.

Additional information on DU’s funding programs and opportunities is available in the Water Management & Conservation Assistance Program Directory referenced previously.

**Mule Deer Foundation.** The Mule Deer Foundation’s (MDF) goals center on restoring, improving and protecting mule deer habitat. MDF achieves its goals through partnering with state and federal wildlife agencies, conservation groups, businesses and individuals to fund and implement habitat enhancement projects on both public and private lands.

**National Fish and Wildlife Foundation.** The National Fish and Wildlife Foundation (NFWF) is a private, non-profit, tax-exempt organization chartered by Congress in 1984 to sustain, restore and enhance the Nation’s fish, wildlife, plants and habitats. NFWF provides grant funding on a competitive basis through their Keystone Initiative Grants and Special Grant Program. Some of the grants/programs that may be applicable to potential projects in the study area include, but are not limited to the following:

- **Pulling Together Initiative** - provides support on a competitive basis for the formation of local Weed Management Area (WMA) partnerships that engage federal resource agencies, state and local governments, private landowners, and other interested parties in developing long-term weed management projects
within the scope of an integrated pest management strategy; minimum 1:1 non-federal match is required.

- **Native Plant Conservation Initiative** – funding preference for "on-the-ground" projects that involve local communities and citizen volunteers in the restoration of native plant communities.

- **Bring Back the Natives Grant Program** – funds to restore damaged or degraded riverine habitats and their native aquatic species provided by BLM, Bureau of Reclamation, FWS, Forest Service, and NFWF; minimum 2:1 non-federal match required.

- **Five-Star Restoration Program** - provides modest financial assistance on a competitive basis to support community-based wetland, riparian, and coastal habitat restoration projects that build diverse partnerships and foster local natural resource stewardship through education, outreach and training activities; average grant is $13,000.

**Rocky Mountain Elk Foundation (RMEF)** – The Rocky Mountain Elk Foundation (RMEF) is a wildlife conservation organization with an emphasis on elk. It advocates sustainable, ethical use of resources and seeks common ground among stakeholders. RMEF funds habitat restoration and improvement projects, acquires land or conservation easements.

**Trout Unlimited.** The Wyoming Council of Trout Unlimited (TU) provides funding and volunteer labor for a variety of stream and watershed projects such as erosion control and fish habitat structures, willow and other riparian plantings and stream protection fencing. Embrace-A-Stream grants are available for up to $10,000 per project. Partnerships are encouraged and can include local conservation districts and state and federal agencies.

**The Nature Conservancy.** The Nature Conservancy (TNC) works with conservation supporters and partner organizations to create funding for conservation worldwide using a variety of creative methods.

**Wildlife Heritage Foundation of Wyoming.** The Wyoming Wildlife Heritage Foundation is an independent, charitable organization whose purpose is to provide financial support, through philanthropy, to critical wildlife conservation efforts in Wyoming.

### 12.0 Conclusions and Recommendations

#### 12.1 Conclusions

- Because of the current lack of diversion records for many of the irrigation systems within the Upper Green River it was necessary to include numerous diversions within a single “aggregate” diversion in the hydrologic/water rights modeling; additional detailed correlation of diversions to acres actually served and records of actual diversions would improve the accuracy and detail of model results.

- Hydrologic modeling (StateMod) continues to improve with additional information incorporated. The current model includes additional gaged flows (data collected by the State of Wyoming). Results of current work relative to correlating water rights with mapped irrigated acreages should be incorporated in future studies as they become available.
Storage to serve each major subbasin is beneficial and/or necessary. Preliminary basin modeling indicates that each subbasin (North and South Horse, North and South Cottonwood, and North, Middle and South Piney Creeks) would generally benefit from some amount of storage in the basin to capture legally available flows (typically spring runoff) and release captured flow later in the irrigation season or as carryover to subsequent drier years, if possible. Thus, at least one or more alternatives should be included to provide storage and/or supplemental supply to each of the subbasins.

In some cases, transfer of water between subbasins is beneficial. Alternatives having the potential to balance excess water availability with water demand/shortages between subbasins have the potential to be more effective in addressing shortages, particularly where surplus legally available flows could be transferred from relatively water-rich subbasins such as Horse Creek and the Green River to relatively water-short subbasins such as Cottonwood and North and Middle Piney Creeks.

More promising storage alternatives generally lie within a discernible North-South corridor. Sites within the Wyoming Range (generally defined as sites lying within the Bridger-Teton National Forest) tend to exhibit generally less favorable characteristics such as difficulty of permitting and less favorable geologic and geotechnical conditions. These sites are also located below the area of highest unit runoff in the study area (i.e., the high elevation Wyoming Range). Conversely, sites lying far downstream in the study area, while having the ability to capture even more of the physically and legally available flow in the subbasin, miss opportunities to satisfy present demand and shortages by gravity release. The most favorable locations are generally above the majority of the irrigation demands and below the Wyoming Range/National Forest.

Cultural resources may have a significant impact on the permitting of some of the reservoir sites and should be given additional consideration early in the process should a project advance to further study.

Sites included in this report are considered to be representative of the need for a given alternative and were chosen as being positioned for favorable supply to various needs. Should issues be subsequently identified with given sites (i.e., ownership, environmental or other issues), alternative sites could be considered with the objective of providing similar ability to store and deliver water. These sites may be selected from among the short-list sites identified in this study.

Reservoir and canal sizes included in this report eliminate approximately 50-60 percent of the current average shortage and satisfy approximately 85 percent of the total average demand.

Reservoir sizes and project alternatives were selected to provide a reasonably consistent reduction in shortage and satisfaction of demand across the various subbasins. Although additional reduction in reservoir size would result in an increase in average annual shortage, the overall project economics may be enhanced by such a modification. Further, such refinements should include consideration of the goals of various irrigation users within the watershed both in terms of satisfying demand and ability to pay for additional infrastructure.

Pasture hay is the crop generally grown within the watershed. Additional net benefit due to increased water availability for pasture hay in Sublette County is estimated at $25.67/acre-foot of water.
Ability to pay the debt service associated with the infrastructure indicated in this report is on the order of 18 percent at a 67% grant to loan ratio, and 61 percent at a 90% grant to loan ratio. Ability to pay both combined debt service and operation, maintenance and replacement (OM&R) costs reduces to 16 percent and 41 percent for corresponding grant to loan ratios (based on Alternative 6).

Estimated total costs for the alternative dam and reservoir storage projects included in Alternative 6 (which is the sum of the other five alternatives) totals $228,400,000. It may be possible to reduce these costs by on the order of one third to one half should the refinement indicated in the recommendations below be explored, albeit with some less shortage reduction/demand satisfaction.

The primary source of funding for a new surface water storage dam and reservoir project is the WWDC’s Dam and Reservoir Program; no other funding sources were identified that would be able to provide significant funding for this type of project.

Standard financing under the WWDC programs includes: a 67/33 percent grant/loan mix (or up to 75/25 percent if extreme financial hardship can be demonstrated); 4 percent interest and 30-year term on the loan portion (with a maximum possible term of 50 years); and potential deferment of loan payments for up to 5 years under special circumstances.

Special financing considerations apply to funding under the WWDC Dam and Reservoir Program, including: grant/loan mix based on sponsor’s ability to pay a portion of project costs and all operation, maintenance and replacement (OM&R) costs; program payment of final design and permitting costs; and program payment for storage capacity needed to provide water for multiple or secondary benefits providing sufficient value to the State of Wyoming, thereby reducing the project cost applied to a grant/loan mix.

### 12.2 Recommendations

- Should the project advance to the next level, it is recommended that satisfying needs in the lower Piney subbasins by gravity delivery using the Green River Supply Canal be examined further due to the potential for serving the area without a sponsor incurring the ongoing seasonal costs of pumping.

- As a further step of refinement should the project proceed, it would be appropriate to model the different components (reservoirs and canals) with reduced capacities in order to evaluate the merits in terms of benefit to cost of incremental changes in reservoir capacity (and thus dam size). Although marginal reductions in percent of total demand met may be seen by reducing system capacities, cost reductions may be proportionately greater. By such an analysis, refinements could be made that would likely further enhance the economic potential of the project. This situation appears to apply to a more significant extent should the combined alternative (Alternative 6) be implemented as it appears to show mutual/overlapping benefits that could enable further reductions in capacity.

- Consider the merits of multiple (or secondary) benefits in modeling of reservoirs. Additional modeling and cost/benefit work should be considered to establish minimum pool conditions (and associated operations for irrigation) consistent with providing minimal pool storage for multiple benefits (e.g., recreational native trout lake fishery). Such operation could be considered for evaluation of
an increased percentage of funding and/or direct payment by WWDC for the cost of storage providing multiple benefits.

- Undertake additional refinement in economic analysis to verify local benefit of supplemental irrigation for pasture hay production and increased cost of production. Include economic consideration by irrigation users of implementing operations with increased irrigation efficiencies.

13.0 References

The following references include those specifically cited in the previous text and other key references utilized during the study but not directly cited.


Providing Additional Reservoir Storage (Part I – Report and Part II – Appendices).


List of Tables

Table 3.1-1 – Land Ownership
Table 3.2-1 – Land Owner Contacts
Table 4.3-1 – Alternative Surface Water Storage Sites – Characterization and Screening Matrix
Table 4.4-1 – Yearly Average Flows for the Period 1971-2006
Table 4.5-1 – Detailed Characterization of Preferred Water Supply Alternatives
Table 5.1-1 – Upper Green River Basin Westside Tributaries, Average Annual Baseline Irrigation Shortages (1971-2006)
Table 5.2-1 – Upper Green River Basin Westside Tributaries, Average Annual Irrigation Shortage Reductions (1971-2006)
Table 5.2-2 – Summary of Alternative 1 - Horse Creek/Cottonwood Creek Storage
Table 5.2-3 – Summary of Alternative 2 - South Cottonwood Creek Storage
Table 5.2-4 – Summary of Alternative 3 - North Piney Creek Storage
Table 5.2-5 – Summary of Alternative 4 - South/Middle Piney Creek Storage
Table 5.2-6 – Summary of Alternative 5 - Pumping to Lower Piney Creek Subbasins from Green River
Table 6.2-1 – Quaternary Fault Data
Table 10.2-1 – Summary of Estimated Costs of Alternatives
Table 10.2-2 – Alternative 1 - Horse Creek/Cottonwood Creek Storage, Conceptual-Level Cost Estimate
Table 10.2-3 – Alternative 2 - South Cottonwood Creek Storage, Conceptual-Level Cost Estimate
Table 10.2-4 – Alternative 3 - North Piney Creek Storage, Conceptual-Level Cost Estimate
Table 10.2-5 – Alternative 4 - South/Middle Piney Creek Storage, Conceptual-Level Cost Estimate
Table 10.2-6 – Alternative 5 - Pumping to Lower Piney Creek Subbasins from Green River, Conceptual-Level Cost Estimate
Table 10.2-7 – Alternative 6 - Combination of Alternatives 1-5, Conceptual-Level Cost Estimate
Table 10.2-8 – Cost Estimate Detail
Table 11.2-1 – Summary of Maximum Potential Benefits of Project Alternatives
Table 11.3-1A – Ability to Pay Debt Service - 67% Grant
Table 11.3-1B – Ability to Pay Debt Service - 75% Grant
Table 11.3-1C – Ability to Pay Debt Service - 90% Grant
Table 11.3-2A – Ability to Pay Debt Service (67% Grant) and OM&R
Table 11.3-2B – Ability to Pay Debt Service (75% Grant) and OM&R
Table 11.3-2C – Ability to Pay Debt Service (90% Grant) and OM&R
Table 11.3-3A – Annual Debt Service Costs - Per Acre Served and Per Acre-Foot Yield
Table 11.3-3B – Annual OM&R Costs - Per Acre Served and Per Acre-Foot Yield
Table 11.3-3C – Annual Debt Service and OM&R Costs - Per Acre Served and Per Acre-Foot Yield
Table 11.4-1 – Potential Funding Sources
Table 3.1-1
Land Ownership

<table>
<thead>
<tr>
<th>Class/Entity</th>
<th>Area (acres)</th>
<th>Percentage of Total Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal (BLM)</td>
<td>235,000</td>
<td>35%</td>
</tr>
<tr>
<td>Forest Service</td>
<td>194,000</td>
<td>29%</td>
</tr>
<tr>
<td>State</td>
<td>21,000</td>
<td>3%</td>
</tr>
<tr>
<td>Private</td>
<td>226,000</td>
<td>33%</td>
</tr>
<tr>
<td>Total Area</td>
<td>676,000</td>
<td>100%</td>
</tr>
<tr>
<td>Alt.</td>
<td>Owner</td>
<td>Location</td>
</tr>
<tr>
<td>------</td>
<td>--------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>1</td>
<td>Antelope Run Ranch, Inc.</td>
<td>Dam and Reservoir</td>
</tr>
<tr>
<td>2</td>
<td>Wind River Pastoral Company, LLC</td>
<td>Dam and Reservoir</td>
</tr>
<tr>
<td>3</td>
<td>High Lonesome Ranch</td>
<td>Dam and Reservoir</td>
</tr>
<tr>
<td>2</td>
<td>Hopkins, George W. Sr. Estate</td>
<td>Reservoir</td>
</tr>
<tr>
<td>3</td>
<td>Circle Cattle Company LTD.</td>
<td>Dam and Reservoir</td>
</tr>
<tr>
<td>2</td>
<td>MLN Enterprises LLC</td>
<td>Reservoir</td>
</tr>
<tr>
<td>4</td>
<td>Flying W Land &amp; Livestock Co.</td>
<td>Dam and Reservoir</td>
</tr>
<tr>
<td>4</td>
<td>Budd, Dan H. &amp; Sons</td>
<td>Dam and Reservoir</td>
</tr>
<tr>
<td>4</td>
<td>Cross Lazy Land Two Land &amp; Livestock</td>
<td>Dam and Reservoir</td>
</tr>
</tbody>
</table>
Table 4.3-1
Alternative Surface Water Storage Sites
Characterization and Screening Matrix

The site screening matrix contains a total of 91 storage alternatives or site variations. Due to the size, an electronic version is included in the accompanying CD.
# Table 4.4-1

**Yearly Average Flows for the Period 1971-2006**

## Horse Creek

<table>
<thead>
<tr>
<th>Node</th>
<th>1100402 North Horse</th>
<th>1100404 South Horse</th>
<th>1100408 Horse Below Confluence</th>
<th>1100412 Lower Horse</th>
<th>Total at Mouth</th>
<th>Available/Shortage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflow</td>
<td>57,740</td>
<td>14,435</td>
<td>50,789</td>
<td>48,457</td>
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<td>48,457</td>
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<tr>
<td>Legally Available</td>
<td>30,159</td>
<td>6,416</td>
<td>35,105</td>
<td>35,288</td>
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<td>35,288</td>
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<tr>
<td>Physically Available</td>
<td>33,001</td>
<td>6,470</td>
<td>42,835</td>
<td>35,288</td>
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<td>35,288</td>
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<tr>
<td>Demand</td>
<td>28,542</td>
<td>9,590</td>
<td>10,773</td>
<td>13,878</td>
<td></td>
<td>62,783</td>
</tr>
<tr>
<td>Shortage</td>
<td>3,803</td>
<td>1,624</td>
<td>2,818</td>
<td>709</td>
<td></td>
<td>8,955</td>
</tr>
</tbody>
</table>

Note: Flows in acre-foot per year are shown for each of the nodes identified in Section 5.1

## Cottonwood Creek

<table>
<thead>
<tr>
<th>Node</th>
<th>1000602 North Cottonwood</th>
<th>1000604 South Cottonwood</th>
<th>1000610 Lower Cottonwood</th>
<th>Total at Mouth</th>
<th>Available/Shortage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflow</td>
<td>33,068</td>
<td>29,837</td>
<td>49,266</td>
<td></td>
<td>49,266</td>
</tr>
<tr>
<td>Legally Available</td>
<td>18,069</td>
<td>11,464</td>
<td>29,137</td>
<td></td>
<td>29,137</td>
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<tr>
<td>Physically Available</td>
<td>23,750</td>
<td>11,963</td>
<td>29,137</td>
<td></td>
<td>29,137</td>
</tr>
<tr>
<td>Demand</td>
<td>14,755</td>
<td>34,523</td>
<td>26,473</td>
<td></td>
<td>75,751</td>
</tr>
<tr>
<td>Shortage</td>
<td>5,437</td>
<td>16,649</td>
<td>6,344</td>
<td></td>
<td>28,429</td>
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## North Piney Creek

<table>
<thead>
<tr>
<th>Node</th>
<th>1001502 North Piney Headwaters</th>
<th>1001506</th>
<th>1001508</th>
<th>1001510</th>
<th>1001512 at Confluence</th>
<th>Total at Mouth</th>
<th>Available/Shortage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflow</td>
<td>39,755</td>
<td>38,443</td>
<td>36,227</td>
<td>30,516</td>
<td>32,185</td>
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<tr>
<td>Legally Available</td>
<td>12,131</td>
<td>12,223</td>
<td>12,339</td>
<td>12,729</td>
<td>13,030</td>
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<tr>
<td>Physically Available</td>
<td>37,173</td>
<td>34,317</td>
<td>24,869</td>
<td>28,269</td>
<td>13,030</td>
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<tr>
<td>Demand</td>
<td>4,542</td>
<td>10,154</td>
<td>19,619</td>
<td>2,695</td>
<td>75,751</td>
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<tr>
<td>Shortage</td>
<td>1,960</td>
<td>6,029</td>
<td>8,262</td>
<td>448</td>
<td>10,815</td>
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## Middle Piney Creek

<table>
<thead>
<tr>
<th>Node</th>
<th>1001604</th>
<th>Total at Mouth</th>
<th>Available/Shortage</th>
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</thead>
<tbody>
<tr>
<td>Inflow</td>
<td>19,955</td>
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<tr>
<td>Legally Available</td>
<td>4,378</td>
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<td>Physically Available</td>
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<tr>
<td>Demand</td>
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<td>Shortage</td>
<td>15,323</td>
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## South Piney Creek

<table>
<thead>
<tr>
<th>Node</th>
<th>1001700 Upper South Piney</th>
<th>1001702 Fish Creek</th>
<th>1001704</th>
<th>1001706</th>
<th>1001708</th>
<th>1001710</th>
<th>1001712</th>
<th>1001714 at Confluence</th>
<th>Total at Mouth</th>
<th>Available/Shortage</th>
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<tbody>
<tr>
<td>Inflow</td>
<td>21,958</td>
<td>12,297</td>
<td>31,182</td>
<td>43,778</td>
<td>41,704</td>
<td>37,068</td>
<td>35,290</td>
<td>30,685</td>
<td>30,685</td>
<td>30,685</td>
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<tr>
<td>Physically Available</td>
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<td>6,089</td>
<td>26,651</td>
<td>39,612</td>
<td>37,068</td>
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<td>30,685</td>
<td>25,240</td>
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<td>Demand</td>
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<td>5,322</td>
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<td>5,911</td>
<td>5,730</td>
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<tr>
<td>Shortage</td>
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<td>10,683</td>
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Note: Flows in acre-foot per year are shown for each of the nodes identified in Section 5.1
Table 4.5-1
Detailed Characterization of Preferred Water Supply Alternatives

<table>
<thead>
<tr>
<th>Element</th>
<th>Source</th>
<th>SEH Site A</th>
<th>SEH Site B</th>
<th>SEH Site C</th>
<th>SEH Site D</th>
<th>SEH Site E</th>
<th>SEH Site F</th>
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<tbody>
<tr>
<td>Site Name</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Sage Grouse Leks</td>
<td>North Piney</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>Moose</td>
<td>Cottonwood Creek</td>
<td>2.3</td>
<td>0.0</td>
<td>4.0</td>
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<td>Elk</td>
<td>North Piney Creek</td>
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<tr>
<td>White Tail Deer</td>
<td>South Piney Creek and Canal</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Antelope</td>
<td>South Piney Creek</td>
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<td>0.0</td>
<td>0.0</td>
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<th>Mineral Resources</th>
<th>Borrow Section</th>
<th>Basin</th>
<th>Annual Peak Flow Characteristics</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Range</th>
<th>Onstream / Offstream</th>
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<tr>
<td>Conventional Gas Development Potential</td>
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<tr>
<td>Oil and Gas Leasing Category (applies only to portion of affected lands unless noted otherwise)</td>
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<tr>
<td>NWI Wetlands minus overlapping irrigated lands</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>NWI Wetlands (acres)</td>
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<td>Mean Annual Flow (cfs)</td>
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<td>5-year Peak Flow (cfs)</td>
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<td>Mean Annual Flow (cfs)</td>
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<td>25-year Peak Flow (cfs)</td>
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<td>5-year Peak Flow (cfs)</td>
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<td>2-year Peak Flow (cfs)</td>
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<td>Yield (ac-ft/yr)</td>
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<td>Estimated Runoff Volume (acre-feet)</td>
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<td>Normal Year Shortages (ac-ft)</td>
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<td>Shortages with Reservoir (ac-ft)</td>
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</table>
Table 4.5-1
Detailed Characterization of Preferred Water Supply Alternatives

<table>
<thead>
<tr>
<th>Alternative</th>
<th>SEH Site</th>
<th>Creek Supply</th>
<th>Creek Delivery</th>
<th>Station and Pumping</th>
<th>Dam</th>
<th>Creek Supply</th>
<th>Creek Delivery</th>
<th>Station and Pumping</th>
<th>Dam</th>
<th>Creek Supply</th>
<th>Creek Delivery</th>
<th>Station and Pumping</th>
<th>Dam</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEH Site 1</td>
<td>SEH-15</td>
<td>Creek Supply</td>
<td>Creek Delivery</td>
<td>Station and Pumping</td>
<td>Dam</td>
<td>Creek Supply</td>
<td>Creek Delivery</td>
<td>Station and Pumping</td>
<td>Dam</td>
<td>Creek Supply</td>
<td>Creek Delivery</td>
<td>Station and Pumping</td>
<td>Dam</td>
</tr>
<tr>
<td>SEH Site 2</td>
<td>SEH-24B</td>
<td>Creek Supply</td>
<td>Creek Delivery</td>
<td>Station and Pumping</td>
<td>Dam</td>
<td>Creek Supply</td>
<td>Creek Delivery</td>
<td>Station and Pumping</td>
<td>Dam</td>
<td>Creek Supply</td>
<td>Creek Delivery</td>
<td>Station and Pumping</td>
<td>Dam</td>
</tr>
<tr>
<td>SEH Site 3</td>
<td>SEH-36</td>
<td>Creek Supply</td>
<td>Creek Delivery</td>
<td>Station and Pumping</td>
<td>Dam</td>
<td>Creek Supply</td>
<td>Creek Delivery</td>
<td>Station and Pumping</td>
<td>Dam</td>
<td>Creek Supply</td>
<td>Creek Delivery</td>
<td>Station and Pumping</td>
<td>Dam</td>
</tr>
</tbody>
</table>

- Elements: Site Name, Creek Supply, Creek Delivery, Station and Pumping, Dam

- Site Name: Haines Flat, Mickelson Creek

- Creek Supply: Cottonwood, South, Cottonwood, North, Cottonwood, Northeast, Cottonwood, Southeast, Cottonwood, Southwest, Cottonwood, Middle Piney

- Creek Delivery: Cottonwood, South, Cottonwood, North, Cottonwood, Northeast, Cottonwood, Southeast, Cottonwood, Southwest, Cottonwood, Middle Piney

- Station and Pumping: Creek Supply, Creek Delivery, Station and Pumping

- Dam: Creek Supply, Creek Delivery, Station and Pumping

- Source: Creek Supply, Creek Delivery, Station and Pumping

- Possible fatal flaw: Unfavorable, Favorable, Marginal
### Table 5.1-1
Upper Green River Basin Westside Tributaries
Average Annual Baseline Irrigation Shortages (1971 - 2006)

<table>
<thead>
<tr>
<th>Tributary Basin</th>
<th>Demand (ac-ft)</th>
<th>Shortage (ac-ft)</th>
<th>%Short</th>
<th>Available Flow (ac-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horse Creek</td>
<td>62,783</td>
<td>8,955</td>
<td>14%</td>
<td>35,288</td>
</tr>
<tr>
<td>Cottonwood Creek</td>
<td>75,751</td>
<td>28,429</td>
<td>38%</td>
<td>29,137</td>
</tr>
<tr>
<td>North Piney Creek</td>
<td>63,281</td>
<td>23,814</td>
<td>38%</td>
<td>13,030</td>
</tr>
<tr>
<td>Middle Piney Creek</td>
<td>30,900</td>
<td>15,323</td>
<td>50%</td>
<td>4,378</td>
</tr>
<tr>
<td>South Piney Creek</td>
<td>42,073</td>
<td>10,683</td>
<td>25%</td>
<td>5,409</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>274,788</strong></td>
<td><strong>87,204</strong></td>
<td><strong>32%</strong></td>
<td><strong>n/a</strong></td>
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</tbody>
</table>

Notes:
1) River Demand = Variable Monthly CIR / Average monthly efficiency. Crop irrigation requirement (CIR) = PCU - 100% effective precipitation, per WWDC 92-06. Potential consumptive use (PCU) based on Pinedale weather station using Pochop calibrated crop coefficients and 5/1 to 9/15 growing season (WWDC 92-06). Average monthly efficiencies based on explicit nodes on tributaries, excluding tributaries on mainstem Green River.

2) Shortages equal demand minus simulated diversions from Upper Green River StateMod model.
3) Percent short equal to Shortage / Demand [(3) / (4)].
4) Available flow represents water available to junior water right at bottom of tributary after all direct flow rights satisfied with available physical flows.
### Table 5.2-1
Upper Green River Basin Westside Tributaries
Average Annual Irrigation Shortage Reductions (1971 - 2006)

<table>
<thead>
<tr>
<th>Infrastructure Components</th>
<th>Tributary Basin</th>
<th></th>
<th>StateMod Model Results</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acres</td>
<td>Baseline Short (ac-ft)</td>
<td>Shortage Reduction (ac-ft)</td>
<td>%Reduced</td>
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<tr>
<td><strong>Alternative 1</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Haines Flat</td>
<td>14,870</td>
<td>8,955</td>
<td>4,213</td>
<td>47%</td>
</tr>
<tr>
<td>Reservoir Cottonwood Creek</td>
<td>20,225</td>
<td>28,429</td>
<td>16,801</td>
<td>59%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>35,095</td>
<td>37,384</td>
<td>21,013</td>
<td>56%</td>
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<tr>
<td><strong>Alternative 2</strong></td>
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<tr>
<td>Mickelson Res. Cottonwood Creek</td>
<td>20,225</td>
<td>28,429</td>
<td>7,936</td>
<td>28%</td>
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<tr>
<td><strong>Alternative 3</strong></td>
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<tr>
<td>Whiskey Ck Res. North Piney Creek</td>
<td>17,913</td>
<td>23,814</td>
<td>11,076</td>
<td>47%</td>
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<tr>
<td><strong>Alternative 4</strong></td>
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<tr>
<td>Fish Creek South Piney Creek</td>
<td>11,637</td>
<td>10,683</td>
<td>2,651</td>
<td>25%</td>
</tr>
<tr>
<td>Reservoir Middle Piney Creek</td>
<td>8,392</td>
<td>15,323</td>
<td>6,687</td>
<td>44%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>20,029</td>
<td>26,006</td>
<td>9,339</td>
<td>36%</td>
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<tr>
<td><strong>Alternative 5</strong></td>
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<tr>
<td>Green River North Piney Creek</td>
<td>7,135</td>
<td>7,116</td>
<td>4,990</td>
<td>70%</td>
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<tr>
<td>Pump Middle Piney Creek</td>
<td>8,392</td>
<td>15,323</td>
<td>5,436</td>
<td>35%</td>
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<tr>
<td>South Piney Creek</td>
<td>5,443</td>
<td>3,309</td>
<td>3,309</td>
<td>100%</td>
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<tr>
<td><strong>Total</strong></td>
<td>20,970</td>
<td>25,748</td>
<td>13,735</td>
<td>53%</td>
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<td><strong>Combined Alternatives</strong></td>
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<tr>
<td>Combined Horse Creek</td>
<td>14,870</td>
<td>8,955</td>
<td>4,261</td>
<td>48%</td>
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<td><strong>Alternative 6</strong></td>
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<tr>
<td>Alternatives Cottonwood Creek</td>
<td>20,225</td>
<td>28,429</td>
<td>20,460</td>
<td>72%</td>
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<td>North Piney Creek</td>
<td>17,913</td>
<td>23,814</td>
<td>12,921</td>
<td>54%</td>
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<tr>
<td>Middle Piney Creek</td>
<td>8,392</td>
<td>15,323</td>
<td>7,945</td>
<td>52%</td>
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<tr>
<td>South Piney Creek</td>
<td>10,081</td>
<td>10,683</td>
<td>4,715</td>
<td>44%</td>
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<tr>
<td><strong>Total</strong></td>
<td>71,481</td>
<td>87,204</td>
<td>50,302</td>
<td>58%</td>
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</table>
## Table 5.2-2
### Summary of Alternative 1 – Horse Creek/Cottonwood Creek Storage

<table>
<thead>
<tr>
<th>Major Elements</th>
<th>Details</th>
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<tbody>
<tr>
<td>Haines Flat Reservoir (SEH-15)</td>
<td>One dam on South Horse Creek – 69 ft. high</td>
</tr>
<tr>
<td></td>
<td>One dam offstream to North Cottonwood Creek – 94 ft. high</td>
</tr>
<tr>
<td></td>
<td>Reservoir capacity – 40,000 ac.-ft.</td>
</tr>
<tr>
<td></td>
<td>Reservoir surface area – 2.2 sq. mi.</td>
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<tr>
<td>North Horse Creek Supply Canal</td>
<td>Canal length – 5.6 mi.</td>
</tr>
<tr>
<td></td>
<td>Capacity – up to 240 cfs</td>
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<tr>
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<td>Period of operation – non-winter months, primarily May-June</td>
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<tr>
<td>North Cottonwood Creek Supply Canal</td>
<td>Canal length – 6.1 mi.</td>
</tr>
<tr>
<td></td>
<td>Capacity – 165 cfs</td>
</tr>
<tr>
<td></td>
<td>Period of operation – non-winter months, primarily May-June</td>
</tr>
<tr>
<td>Horse Creek Delivery Canal</td>
<td>Canal length – 6.1 mi.</td>
</tr>
<tr>
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<td>Capacity – 110 cfs</td>
</tr>
<tr>
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<td>Period of operation – irrigation season</td>
</tr>
<tr>
<td></td>
<td>Delivery area – lower 2/3 of North Horse Creek</td>
</tr>
<tr>
<td>North Cottonwood Creek Pumping Station/Delivery</td>
<td>Canal length – 4.3 mi.</td>
</tr>
<tr>
<td>Canal to South Cottonwood Creek</td>
<td>Pumping station lift – 50 ft.</td>
</tr>
<tr>
<td></td>
<td>Pumping/canal capacity – 150 cfs</td>
</tr>
<tr>
<td></td>
<td>Delivery area – lower 1/3 of South Cottonwood Creek</td>
</tr>
</tbody>
</table>

### Function/Operation

- **Source(s) of Supply**
  - North Cottonwood Creek – 25,000 ac.-ft. physical inflow
  - South Horse Creek – 12,000 ac.-ft. physical inflow
  - North Horse Creek – 48,000 ac.-ft. physical inflow (as needed)

- **Irrigated Lands Served**
  - **Total Area Served**: 35,000 acres through direct or exchange, 21,000 ac.-ft. annual average yield (shortage reduction)
  - **Gravity release from storage**
    - Lower 2/3 of North Cottonwood Creek
    - Lower Cottonwood Creek
    - South Horse Creek
    - Horse Creek, Lower 2/3 of North Horse Creek
  - **Exchange**
    - Exchange from Cottonwood Creek to upper 1/3 of North Cottonwood Creek

### Key Assumptions/Comments
- Supply canals assumed to operate only March through October
Table 5.2-3  
**Summary of Alternative 2 – South Cottonwood Creek Storage**

<table>
<thead>
<tr>
<th>Major Elements</th>
<th>Details</th>
</tr>
</thead>
</table>
| Mickelson Creek Reservoir (Site15)                  | Dam on South Cottonwood Creek – 80 ft. high with closure dam on reservoir rim 20 ft. high  
  Reservoir capacity – 15,000 ac.-ft.  
  Reservoir surface area – 0.9 sq. mi. |
| South Cottonwood Creek Delivery Canal               | Canal length – 6.0 mi.  
  Capacity – 100 cfs  
  Delivery area – middle 1/2 of South Cottonwood Creek |

<table>
<thead>
<tr>
<th>Function/Operation</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source(s) of Supply</td>
<td>South Cottonwood Creek – 22,000 ac.-ft. physical inflow</td>
</tr>
</tbody>
</table>
| Irrigated Lands Served                              | **Total Area Served:** 20,225 acres through direct or exchange, 7950 ac.-ft. annual average yield (shortage reduction)  
  **Gravity release from storage:**  
  Lower 3/4 of South Cottonwood Creek and Cottonwood Creek  
  **Exchange:**  
  Exchange from lower South Cottonwood Creek and/or Cottonwood Creek to upper 1/4 of South Cottonwood Creek or to North Cottonwood Creek as necessary and appropriate |
# Table 5.2-4
## Summary of Alternative 3 – North Piney Creek Storage

<table>
<thead>
<tr>
<th>Major Elements</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Whiskey Creek Reservoir (SEH-10)</td>
<td>Dam on North Piney Creek – 102 ft. high Reservoir capacity – 20,000 ac.-ft. Reservoir surface area – 1.0 sq. mi.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function/Operation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Source(s) of Supply</td>
<td>North Piney Creek – 40,000 ac.-ft. physical inflow</td>
</tr>
<tr>
<td>Irrigated Lands Served</td>
<td>Total Area Served: 17,900 acres through direct or exchange, 11,100 ac.-ft. annual average yield (shortage reduction) Gravity release from storage: Upper 3/4 of North Piney Creek Exchange: Exchange from lower 3/4 of North Piney Creek to upper 1/4 of North Piney Creek as necessary and appropriate</td>
</tr>
</tbody>
</table>
## Table 5.2-5
### Summary of Alternative 4 – South/Middle Piney Creek Storage

<table>
<thead>
<tr>
<th>Major Elements</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish Creek Reservoir (SEH-12)</td>
<td>Dam on South Piney Creek and Fish Creek – 99 ft. high Reservoir capacity – 20,000 ac.-ft. Reservoir surface area – 0.8 sq. mi.</td>
</tr>
<tr>
<td>Middle Piney Creek Delivery Canal</td>
<td>Canal Length – 4.5 mi. Canal Capacity – 150 cfs Delivery area – lower 3/4 of Middle Piney Creek</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function/Operation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Source(s) of Supply</td>
<td>South Piney Creek – 20,000 ac.-ft. physical inflow Fish Creek - 11,000 ac.-ft. physical inflow Middle Piney Creek – not included in analysis at this time</td>
</tr>
<tr>
<td>Irrigated Lands Served</td>
<td><strong>Total Area Served:</strong> 20,000 acres through direct or exchange, 9,300 ac.-ft. annual average yield (shortage reduction) <strong>Gravity release from storage:</strong> Entire South Piney Creek and lower 3/4 of Middle Piney Creek <strong>Exchange:</strong> Exchange from lower South and/or Middle Piney Creek(s) to upper 1/4 of Middle Piney Creek as necessary and appropriate</td>
</tr>
<tr>
<td>Major Elements</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>-----------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Pumping Station</strong></td>
<td>Location – Green River (2.4 mi. ESE of Big Piney)</td>
</tr>
<tr>
<td><strong>Pumping station lift</strong></td>
<td>180 ft. (static lift)</td>
</tr>
<tr>
<td><strong>Pipeline (from pumping station to delivery canal)</strong></td>
<td>Pipeline length – 4.4 mi.</td>
</tr>
<tr>
<td><strong>Lower Piney Creeks Delivery Canal</strong></td>
<td>Canal length – 8.3 mi.</td>
</tr>
<tr>
<td></td>
<td>Capacity – up to 75 cfs</td>
</tr>
<tr>
<td></td>
<td>Period of operation – irrigation season</td>
</tr>
<tr>
<td></td>
<td>Delivery area – lower portions of North, Middle and South</td>
</tr>
<tr>
<td></td>
<td>Piney Creeks as determined in subsequent study refinements</td>
</tr>
<tr>
<td><strong>Function/Operation</strong></td>
<td><strong>Source(s) of Supply</strong></td>
</tr>
<tr>
<td><strong>Irrigated Lands Served</strong></td>
<td>Green River</td>
</tr>
<tr>
<td><strong>Total Area Served</strong></td>
<td>38,000 acres through direct or exchange, 13,700 ac.-ft. annual</td>
</tr>
<tr>
<td></td>
<td>average yield (shortage reduction)</td>
</tr>
<tr>
<td></td>
<td><strong>Direct service by pumping:</strong></td>
</tr>
<tr>
<td></td>
<td>Lower portions of North, Middle and South Piney Creek subbasins</td>
</tr>
<tr>
<td></td>
<td>– 5,000 ac. direct</td>
</tr>
<tr>
<td></td>
<td><strong>Exchange:</strong></td>
</tr>
<tr>
<td></td>
<td>Pumping to lower subbasins allows exchange of up to 13,700 ac.</td>
</tr>
<tr>
<td></td>
<td>- ft. to address shortages higher in subbasins</td>
</tr>
<tr>
<td>Fault Name</td>
<td>Fault Number</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Western Bear Lake fault</td>
<td>622</td>
</tr>
<tr>
<td>Grand Valley fault, Swan Valley section</td>
<td>726a</td>
</tr>
<tr>
<td>Grand Valley fault, Grand Valley section</td>
<td>726b</td>
</tr>
<tr>
<td>Grand Valley fault, Prater Mountain section</td>
<td>726c</td>
</tr>
<tr>
<td>Grand Valley fault, Star Valley section</td>
<td>726d</td>
</tr>
<tr>
<td>Unnamed piedmont fault</td>
<td>727</td>
</tr>
<tr>
<td>Greys River fault</td>
<td>728</td>
</tr>
<tr>
<td>Rock Creek fault</td>
<td>729</td>
</tr>
<tr>
<td>Sublette Flat fault</td>
<td>733</td>
</tr>
<tr>
<td>Eastern Bear Valley fault (Class B)</td>
<td>734</td>
</tr>
<tr>
<td>Western Bear Valley faults</td>
<td>735</td>
</tr>
<tr>
<td>East Gros Ventre fault (Class B)</td>
<td>756</td>
</tr>
<tr>
<td>Hoback fault (Class B)</td>
<td>772</td>
</tr>
<tr>
<td>Cedar Ridge fault</td>
<td>774</td>
</tr>
<tr>
<td>Leckie fault (Class B)</td>
<td>775</td>
</tr>
<tr>
<td>Eastern Bear Lake fault, northern section</td>
<td>2364a</td>
</tr>
<tr>
<td>Eastern Bear Lake fault, central section</td>
<td>2364b</td>
</tr>
</tbody>
</table>
### Table 10.2-1
Summary of Estimated Costs of Alternatives

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Storage Capacity (ac-ft)</th>
<th>Construction Cost Total</th>
<th>Total Project Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40,000</td>
<td>53,955,000</td>
<td>87,657,000</td>
</tr>
<tr>
<td>2</td>
<td>15,000</td>
<td>24,459,000</td>
<td>40,278,000</td>
</tr>
<tr>
<td>3</td>
<td>20,000</td>
<td>30,615,000</td>
<td>49,058,967</td>
</tr>
<tr>
<td>4</td>
<td>20,000</td>
<td>36,653,000</td>
<td>56,973,000</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>15,327,000</td>
<td>22,513,000</td>
</tr>
<tr>
<td>6</td>
<td>95,000</td>
<td>161,009,000</td>
<td>256,480,000</td>
</tr>
</tbody>
</table>
## Table 10.2-2
Alternative 1 - Horse Creek/Cottonwood Creek Storage
Conceptual-Level Cost Estimate

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation of Final Designs and Specifications</td>
<td>$6,475,000</td>
</tr>
<tr>
<td>Permitting</td>
<td>$3,500,000</td>
</tr>
<tr>
<td>Mitigation</td>
<td>$2,656,000</td>
</tr>
<tr>
<td>Legal Fees</td>
<td>$270,000</td>
</tr>
<tr>
<td>Acquisition of Access and Rights of Way</td>
<td>$6,503,000</td>
</tr>
<tr>
<td><strong>Non-Construction Cost Total</strong></td>
<td><strong>$19,404,000</strong></td>
</tr>
<tr>
<td>Project Components</td>
<td></td>
</tr>
<tr>
<td>Mobilization</td>
<td>$3,550,921</td>
</tr>
<tr>
<td>Dam</td>
<td>$36,008,086</td>
</tr>
<tr>
<td>Spillway(s)</td>
<td>$1,054,820</td>
</tr>
<tr>
<td>Outlet Works</td>
<td>$2,209,368</td>
</tr>
<tr>
<td>Other</td>
<td>$11,131,456</td>
</tr>
<tr>
<td><strong>Construction Cost Subtotal #1</strong></td>
<td><strong>$53,954,650</strong></td>
</tr>
<tr>
<td>Engineering Costs = CCS#1 x 10%</td>
<td>$5,395,465</td>
</tr>
<tr>
<td><strong>Subtotal #2</strong></td>
<td><strong>$59,350,115</strong></td>
</tr>
<tr>
<td>Contigency = Subtotal #2 x 15%</td>
<td>$8,902,517</td>
</tr>
<tr>
<td><strong>Construction Cost Total</strong></td>
<td><strong>$68,253,000</strong></td>
</tr>
<tr>
<td><strong>Project Cost Total</strong></td>
<td><strong>$87,657,000</strong></td>
</tr>
<tr>
<td>Less Level II/Phase III Costs (^1)</td>
<td>$9,975,000</td>
</tr>
<tr>
<td><strong>Project Cost Used in Ability to Pay Analysis</strong></td>
<td><strong>$77,682,000</strong></td>
</tr>
</tbody>
</table>

\(^1\) Preparation of Final Designs and Specifications; and Permitting
### Table 10.2-3
Alternative 2 - South Cottonwood Creek Storage
Conceptual-Level Cost Estimate

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation of Final Designs and Specifications</td>
<td>$2,935,000</td>
</tr>
<tr>
<td>Permitting</td>
<td>$1,250,000</td>
</tr>
<tr>
<td>Mitigation</td>
<td>$1,550,000</td>
</tr>
<tr>
<td>Legal Fees</td>
<td>$122,000</td>
</tr>
<tr>
<td>Acquisition of Access and Rights of Way</td>
<td>$3,480,000</td>
</tr>
<tr>
<td><strong>Non-Construction Cost Total</strong></td>
<td><strong>$9,337,000</strong></td>
</tr>
<tr>
<td>Project Components</td>
<td></td>
</tr>
<tr>
<td>Mobilization</td>
<td>$1,668,335</td>
</tr>
<tr>
<td>Dam</td>
<td>$15,629,449</td>
</tr>
<tr>
<td>Spillway(s)</td>
<td>$1,720,761</td>
</tr>
<tr>
<td>Outlet Works</td>
<td>$914,236</td>
</tr>
<tr>
<td>Other</td>
<td>$4,526,186</td>
</tr>
</tbody>
</table>

**Construction Cost Subtotal #1** $24,458,966

Engineering Costs = CCS#1 x 10% $2,445,897

**Subtotal #2** $26,904,863

Contingency = Subtotal #2 x 15% $4,035,729

**Construction Cost Total** $30,941,000

**Project Cost Total** $40,278,000

Less Level II/Phase III Costs $4,185,000

**Project Cost Used in Ability to Pay Analysis** $36,093,000

---

1 Preparation of Final Designs and Specifications; and Permitting
### Table 10.2-4
Alternative 3 - North Piney Creek Storage
Conceptual-Level Cost Estimate

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation of Final Designs and Specifications</td>
<td>$3,674,000</td>
</tr>
<tr>
<td>Permitting</td>
<td>$1,250,000</td>
</tr>
<tr>
<td>Mitigation</td>
<td>$1,773,000</td>
</tr>
<tr>
<td>Legal Fees</td>
<td>$153,000</td>
</tr>
<tr>
<td>Acquisition of Access and Rights of Way</td>
<td>$3,479,967</td>
</tr>
<tr>
<td><strong>Non-Construction Cost Total</strong></td>
<td><strong>$10,329,967</strong></td>
</tr>
<tr>
<td>Project Components</td>
<td></td>
</tr>
<tr>
<td>Mobilization</td>
<td>$1,944,740</td>
</tr>
<tr>
<td>Dam</td>
<td>$25,397,453</td>
</tr>
<tr>
<td>Spillway(s)</td>
<td>$1,548,830</td>
</tr>
<tr>
<td>Outlet Works</td>
<td>$1,243,678</td>
</tr>
<tr>
<td>Other</td>
<td>$480,000</td>
</tr>
<tr>
<td><strong>Construction Cost Subtotal #1</strong></td>
<td><strong>$30,614,701</strong></td>
</tr>
<tr>
<td>Engineering Costs = CCS#1 x 10%</td>
<td>$3,061,470</td>
</tr>
<tr>
<td><strong>Subtotal #2</strong></td>
<td><strong>$33,676,171</strong></td>
</tr>
<tr>
<td>Contingency = Subtotal #2 x 15%</td>
<td>$5,051,426</td>
</tr>
<tr>
<td><strong>Construction Cost Total</strong></td>
<td><strong>$38,728,000</strong></td>
</tr>
<tr>
<td><strong>Project Cost Total</strong></td>
<td><strong>$49,057,967</strong></td>
</tr>
<tr>
<td>Less Level II/Phase III Costs ¹</td>
<td>$4,924,000</td>
</tr>
<tr>
<td><strong>Project Cost Used in Ability to Pay Analysis</strong></td>
<td><strong>$44,133,967</strong></td>
</tr>
</tbody>
</table>

¹ Preparation of Final Designs and Specifications; and Permitting
Table 10.2-5
Alternative 4 - South/Middle Piney Creek Storage
Conceptual-Level Cost Estimate

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation of Final Designs and Specifications</td>
<td>$4,398,000</td>
</tr>
<tr>
<td>Permitting</td>
<td>$2,000,000</td>
</tr>
<tr>
<td>Mitigation</td>
<td>$2,068,000</td>
</tr>
<tr>
<td>Legal Fees</td>
<td>$183,000</td>
</tr>
<tr>
<td>Acquisition of Access and Rights of Way</td>
<td>$1,958,000</td>
</tr>
<tr>
<td><strong>Non-Construction Cost Total</strong></td>
<td><strong>$10,607,000</strong></td>
</tr>
<tr>
<td>Project Components</td>
<td></td>
</tr>
<tr>
<td>Mobilization</td>
<td>$2,285,175</td>
</tr>
<tr>
<td>Dam</td>
<td>$28,274,479</td>
</tr>
<tr>
<td>Spillway(s)</td>
<td>$2,105,804</td>
</tr>
<tr>
<td>Outlet Works</td>
<td>$1,217,314</td>
</tr>
<tr>
<td>Other</td>
<td>$2,770,310</td>
</tr>
<tr>
<td><strong>Construction Cost Subtotal #1</strong></td>
<td><strong>$36,653,082</strong></td>
</tr>
<tr>
<td>Engineering Costs = CCS#1 x 10%</td>
<td>$3,665,308</td>
</tr>
<tr>
<td><strong>Subtotal #2</strong></td>
<td><strong>$40,318,390</strong></td>
</tr>
<tr>
<td>Contingency = Subtotal #2 x 15%</td>
<td>$6,047,758</td>
</tr>
<tr>
<td><strong>Construction Cost Total</strong></td>
<td><strong>$46,366,000</strong></td>
</tr>
<tr>
<td><strong>Project Cost Total</strong></td>
<td><strong>$56,973,000</strong></td>
</tr>
<tr>
<td>Less Level II/Phase III Costs (^1)</td>
<td>$6,398,000</td>
</tr>
<tr>
<td><strong>Project Cost Used in Ability to Pay Analysis</strong></td>
<td><strong>$50,575,000</strong></td>
</tr>
</tbody>
</table>

\(^1\) Preparation of Final Designs and Specifications; and Permitting
Table 10.2-6
Alternative 5 - Pumping to Lower Piney Creek Subbasins from Green River
Conceptual-Level Cost Estimate

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation of Final Designs and Specifications</td>
<td>$1,839,000</td>
</tr>
<tr>
<td>Permitting</td>
<td>$750,000</td>
</tr>
<tr>
<td>Mitigation</td>
<td>$315,000</td>
</tr>
<tr>
<td>Legal Fees</td>
<td>$77,000</td>
</tr>
<tr>
<td>Acquisition of Access and Rights of Way</td>
<td>$143,000</td>
</tr>
<tr>
<td><strong>Non-Construction Cost Total</strong></td>
<td><strong>$3,124,000</strong></td>
</tr>
<tr>
<td>Project Components</td>
<td></td>
</tr>
<tr>
<td>Mobilization</td>
<td>$899,152</td>
</tr>
<tr>
<td>Dam</td>
<td>$0</td>
</tr>
<tr>
<td>Spillway(s)</td>
<td>$0</td>
</tr>
<tr>
<td>Outlet Works</td>
<td>$0</td>
</tr>
<tr>
<td>Other</td>
<td>$14,427,354</td>
</tr>
<tr>
<td><strong>Construction Cost Subtotal #1</strong></td>
<td><strong>$15,326,506</strong></td>
</tr>
<tr>
<td>Engineering Costs = CCS#1 x 10%</td>
<td>$1,532,651</td>
</tr>
<tr>
<td><strong>Subtotal #2</strong></td>
<td><strong>$16,859,157</strong></td>
</tr>
<tr>
<td>Contingency = Subtotal #2 x 15%</td>
<td>$2,528,874</td>
</tr>
<tr>
<td><strong>Construction Cost Total</strong></td>
<td><strong>$19,388,000</strong></td>
</tr>
<tr>
<td><strong>Project Cost Total</strong></td>
<td><strong>$22,512,000</strong></td>
</tr>
<tr>
<td>Less Level II/Phase III Costs (^1)</td>
<td>$2,589,000</td>
</tr>
<tr>
<td><strong>Project Cost Used in Ability to Pay Analysis</strong></td>
<td><strong>$19,923,000</strong></td>
</tr>
</tbody>
</table>

\(^1\) Preparation of Final Designs and Specifications; and Permitting
### Table 10.2-7
**Alternative 6 - Combination of Alternatives 1-5**
**Conceptual-Level Cost Estimate**

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation of Final Designs and Specifications</td>
<td>$19,321,000</td>
</tr>
<tr>
<td>Permitting</td>
<td>$8,750,000</td>
</tr>
<tr>
<td>Mitigation</td>
<td>$8,362,000</td>
</tr>
<tr>
<td>Legal Fees</td>
<td>$805,000</td>
</tr>
<tr>
<td>Acquisition of Access and Rights of Way</td>
<td>$15,563,967</td>
</tr>
<tr>
<td><strong>Non-Construction Cost Total</strong></td>
<td><strong>$52,801,967</strong></td>
</tr>
<tr>
<td>Project Components</td>
<td></td>
</tr>
<tr>
<td>Mobilization</td>
<td>$10,348,323</td>
</tr>
<tr>
<td>Dam</td>
<td>$105,309,467</td>
</tr>
<tr>
<td>Spillway(s)</td>
<td>$6,430,214</td>
</tr>
<tr>
<td>Outlet Works</td>
<td>$5,584,596</td>
</tr>
<tr>
<td>Other</td>
<td>$33,335,305</td>
</tr>
<tr>
<td><strong>Construction Cost Subtotal #1</strong></td>
<td><strong>$161,007,905</strong></td>
</tr>
<tr>
<td>Engineering Costs = CCS#1 x 10%</td>
<td>$16,100,790</td>
</tr>
<tr>
<td><strong>Subtotal #2</strong></td>
<td><strong>$177,108,695</strong></td>
</tr>
<tr>
<td>Contingency = Subtotal #2 x 15%</td>
<td>$26,566,304</td>
</tr>
<tr>
<td><strong>Construction Cost Total</strong></td>
<td><strong>$203,675,000</strong></td>
</tr>
<tr>
<td><strong>Project Cost Total</strong></td>
<td><strong>$256,476,967</strong></td>
</tr>
<tr>
<td>Less Level II/Phase III Costs (^1)</td>
<td>$28,071,000</td>
</tr>
<tr>
<td><strong>Project Cost Used in Ability to Pay Analysis</strong></td>
<td><strong>$228,405,967</strong></td>
</tr>
</tbody>
</table>

\(^1\) Preparation of Final Designs and Specifications; and Permitting
<table>
<thead>
<tr>
<th>Alternative</th>
<th>Unit Cost ($)</th>
<th>South Dam</th>
<th>North Dam</th>
<th>Home Habitat</th>
<th>Cottonwood</th>
<th>Horse</th>
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### Mitigation

- **Construction engineering**
  - **Total** (Level II/Phase III Costs)

**TOTAL - Level II/Phase III Costs**

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Table 11.2-1
Summary of Maximum Potential Benefits of Project Alternatives

<table>
<thead>
<tr>
<th>Alternative Number</th>
<th>Name</th>
<th>Reservoir Capacity (ac-ft)</th>
<th>&quot;Average Yearly&quot; Irrigation Shortage Satisfied (acre-ft)</th>
<th>Assumed Annual Reservoir Yield - Normal Year (ac-ft)</th>
<th>Maximum Potential Annual Benefits From Supplemental Irrigation Only ($ per year)</th>
<th>Maximum Potential Present Value of All Direct Irrigation Benefits ($)</th>
<th>Maximum Potential Value of Direct and Indirect Irrigation Benefits ($)</th>
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<tbody>
<tr>
<td>1</td>
<td>Horse Creek/Cottonwood Creek Storage</td>
<td>40000</td>
<td>21,013</td>
<td>21,013</td>
<td>539,400</td>
<td>11,587,000</td>
<td>38,932,000</td>
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<tr>
<td>2</td>
<td>South Cottonwood Creek Storage</td>
<td>15000</td>
<td>7,956</td>
<td>7,956</td>
<td>204,230</td>
<td>4,387,000</td>
<td>14,740,000</td>
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<td>3</td>
<td>North Piney Creek Storage</td>
<td>20000</td>
<td>11,101</td>
<td>11,101</td>
<td>284,960</td>
<td>6,122,000</td>
<td>20,570,000</td>
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<tr>
<td>4</td>
<td>South/Middle Piney Creek Storage</td>
<td>20000</td>
<td>9,770</td>
<td>9,770</td>
<td>250,800</td>
<td>5,388,000</td>
<td>18,104,000</td>
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<tr>
<td>5</td>
<td>Pumping to Lower Piney Creek Subbasins from Green River</td>
<td>N/A</td>
<td>13,735</td>
<td>13,735</td>
<td>352,580</td>
<td>7,574,000</td>
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Note 1  Analysis assumes no new area placed under irrigation; interest rate of 4.0% assumed, for fifty years
### Table 11.3-1A
**Ability to Pay Debt Service - 67 % Grant**

<table>
<thead>
<tr>
<th>Alternative Number</th>
<th>Site</th>
<th>Level III Project Cost ($ Millions)</th>
<th>Sponsor's Share of Project Costs ($ Millions)</th>
<th>Sponsor's Annual Payment ($)</th>
<th>Sponsor's Maximum Ability to Pay ($)</th>
<th>Sponsor's Percentage Ability to Pay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Horse Creek/Cottonwood Creek Storage</td>
<td>77.7</td>
<td>25.64</td>
<td>1,193,300</td>
<td>269,700</td>
<td>22.6</td>
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<tr>
<td>2</td>
<td>South Cottonwood Creek Storage</td>
<td>36.1</td>
<td>11.91</td>
<td>554,400</td>
<td>204,230</td>
<td>36.8</td>
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<tr>
<td>3</td>
<td>North Piney Creek Storage</td>
<td>44.1</td>
<td>14.56</td>
<td>678,000</td>
<td>142,500</td>
<td>21.0</td>
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<tr>
<td>4</td>
<td>South/Middle Piney Creek Storage</td>
<td>50.6</td>
<td>16.69</td>
<td>776,900</td>
<td>125,400</td>
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<td>5</td>
<td>Pumping to Lower Piney Creek Subbasins</td>
<td>19.9</td>
<td>6.57</td>
<td>306,100</td>
<td>176,300</td>
<td>57.6</td>
</tr>
<tr>
<td>6</td>
<td>Combination of Alternatives 1-5</td>
<td>228.4</td>
<td>75.37</td>
<td>3,508,700</td>
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### Table 11.3-1B
**Ability to Pay Debt Service - 75 % Grant**

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<th>Sponsor's Share of Project Costs ($ Millions)</th>
<th>Sponsor's Annual Payment ($)</th>
<th>Sponsor's Maximum Ability to Pay ($)</th>
<th>Sponsor's Percentage Ability to Pay (%)</th>
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<td>1</td>
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<td>77.7</td>
<td>19.42</td>
<td>904,000</td>
<td>269,700</td>
<td>74.6</td>
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<td>2</td>
<td>South Cottonwood Creek Storage</td>
<td>36.1</td>
<td>9.02</td>
<td>420,000</td>
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<td>11.03</td>
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<td>5</td>
<td>Pumping to Lower Piney Creek Subbasins</td>
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<td>76.0</td>
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<td>57.10</td>
<td>2,658,100</td>
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### Table 11.3-1C
**Ability to Pay Debt Service - 90 % Grant**

<table>
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<th>Level III Project Cost ($ Millions)</th>
<th>Sponsor's Share of Project Costs ($ Millions)</th>
<th>Sponsor's Annual Payment ($)</th>
<th>Sponsor's Maximum Ability to Pay ($)</th>
<th>Sponsor's Percentage Ability to Pay (%)</th>
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<tr>
<td>1</td>
<td>Horse Creek/Cottonwood Creek Storage</td>
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<td>74.6</td>
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<td>2</td>
<td>South Cottonwood Creek Storage</td>
<td>36.1</td>
<td>3.61</td>
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<td>North Piney Creek Storage</td>
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<td>205,400</td>
<td>142,500</td>
<td>69.4</td>
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<td>4</td>
<td>South/Middle Piney Creek Storage</td>
<td>50.6</td>
<td>5.06</td>
<td>235,400</td>
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<td>Pumping to Lower Piney Creek Subbasins</td>
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Table 11.3-2A
Ability to Pay Debt Service (67% Grant) and OM&R

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<th>Alternative Number</th>
<th>Site</th>
<th>Level III Project Cost ($ Millions)</th>
<th>Sponsor's Share of Project Costs ($ Millions)</th>
<th>Sponsor's Annual Debt Service Payment ($)</th>
<th>Sponsor's Annual OM&amp;R Cost ($)</th>
<th>Sponsor's Total Annual Cost ($)</th>
<th>Sponsor's Maximum Ability to Pay ($)</th>
<th>Sponsor's Percentage Ability to Pay (%)</th>
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<tbody>
<tr>
<td>1</td>
<td>Horse Creek/Cottonwood Creek Storage</td>
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<td>155,000</td>
<td>1,348,300</td>
<td>269,700</td>
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<td>2</td>
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<td>11.91</td>
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<td>32,000</td>
<td>710,000</td>
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<td>4</td>
<td>South/Middle Piney Creek Storage</td>
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<tr>
<td>5</td>
<td>Pumping to Lower Piney Creek Subb</td>
<td>19.9</td>
<td>6.57</td>
<td>306,100</td>
<td>321,000</td>
<td>627,100</td>
<td>176,300</td>
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<td>6</td>
<td>Combination of Alternatives 1-5</td>
<td>228.4</td>
<td>75.37</td>
<td>3,508,700</td>
<td>525,000</td>
<td>4,033,700</td>
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Table 11.3-2B
Ability to Pay Debt Service (75% Grant) and OM&R

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<th>Sponsor's Annual Debt Service Payment ($)</th>
<th>Sponsor's Annual OM&amp;R Cost ($)</th>
<th>Sponsor's Total Annual Cost ($)</th>
<th>Sponsor's Maximum Ability to Pay ($)</th>
<th>Sponsor's Percentage Ability to Pay (%)</th>
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<td>473,000</td>
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<td>12.64</td>
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<td>638,600</td>
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Table 11.3-2C
Ability to Pay Debt Service (90% Grant) and OM&R

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<th>Sponsor's Percentage Ability to Pay (%)</th>
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<td>7.77</td>
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<td>516,600</td>
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<td>South Cottonwood Creek Stor</td>
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### Table 11.3-3A
Annual Debt Service Costs - Per Acre Served and Per Acre-Foot Yield

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<th>Site Name</th>
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<th>Annual Cost Per Acre Served</th>
<th>Annual Cost Per Acre-Foot Yield</th>
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<td>With 75 Percent Grant ($/ac)</td>
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<td>South Cottonwood Creek Storage</td>
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<td>$27</td>
<td>$21</td>
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<td>3</td>
<td>North Piney Creek Storage</td>
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<td>$29</td>
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<td>4</td>
<td>South/Middle Piney Creek Storage</td>
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<td>$29</td>
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<td>5</td>
<td>Pumping to Lower Piney Creek Subbasins from Green River</td>
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<td>$8</td>
<td>$6</td>
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<tr>
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<td>Combination of Alternatives 1-5</td>
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### Table 11.3-3B
Annual OM&R Costs - Per Acre Served and Per Acre-Foot Yield

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<th>Site Number</th>
<th>Site Name</th>
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<th>Annual Cost Per Acre Served</th>
<th>Assumed Yield (ac-ft)</th>
<th>Annual Cost Per Acre-Foot Yield</th>
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### Table 11.3-3C
Annual Debt Service & OM&R Costs - Per Acre Served and Per Acre-Foot Yield

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<th>Site Number</th>
<th>Site Name</th>
<th>Irrigated Lands Served (ac)</th>
<th>Debt &amp; OM&amp;R Cost Per Acre Served</th>
<th>Assumed Yield (ac-ft)</th>
<th>Debt &amp; OM&amp;R Cost/Acre-Foot Yield</th>
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<td>With 75 Percent Grant ($/ac)</td>
<td>With 90 Percent Grant ($/ac)</td>
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<td>2</td>
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<td>20,225</td>
<td>$30</td>
<td>$23</td>
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<td>3</td>
<td>North Piney Creek Storage</td>
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<td>4</td>
<td>South/Middle Piney Creek Storage</td>
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<td>6</td>
<td>Combination of Alternatives 1-5</td>
<td>73,037</td>
<td>$55</td>
<td>$44</td>
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1. "Irrigated lands served" is the sum of all existing irrigated lands located in the basin(s) which could benefit from the project either through direct release or through exchange potential.
2. The "assumed yield" is the average shortage satisfied as presented in Table 11.2-1.
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<th>Agency/Entity</th>
<th>Program Name</th>
<th>Project Type(s)</th>
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<th>Email</th>
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<td>Riparian Habitat Improvement Grant</td>
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<tr>
<td>Wyoming Game and Fish Department</td>
<td>Water Development/Maintenance Grant</td>
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<td>Environmental Protection Agency</td>
<td>Targeted Watersheds Grant Program</td>
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<td>Fish and Wildlife Service</td>
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### Table 11.4-1: Potential Funding Sources

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### Federal

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List of Figures

Figure 1.1-1 – Study Area
Figure 3.1-1 – Land Ownership
Figure 4.2-1 – Alternative Surface Water Storage Sites - Long List
Figure 4.4-1 – Alternative Surface Water Storage Sites - Short List
Figure 4.5-1 – Preferred Water Supply Alternatives
Figure 5.1-1 – Model Network Diagram, Upper Green River - Westside Storage Study, Water Resources Planning Operational Model
Figure 5.1-2 – Gage Stations
Figure 5.2-1 – Model Network Diagram With Alternatives, Upper Green River - Westside Storage Study, Water Resources Planning Operational Model
Figure 5.2-2 – Alternative 1, Haines Flat Reservoir Simulated Storage Contents
Figure 5.2-3 – Alternative 2, Mickelson Creek Reservoir Simulated Storage Contents
Figure 5.2-4 – Alternative 3, Whiskey Creek Reservoir Simulated Storage Contents
Figure 5.2-5 – Alternative 4, Fish Creek Reservoir Simulated Storage Contents
Figure 5.2-6 – Alternative 5, Green River Pump Simulated Diversion
Figure 5.2-7A – Alternative 6, Haines Flat Reservoir Simulated Storage Contents
Figure 5.2-7B – Alternative 6, Mickelson Creek Reservoir Simulated Storage Contents
Figure 5.2-7C – Alternative 6, Whiskey Creek Reservoir Simulated Storage Contents
Figure 5.2-7D – Alternative 6, Fish Creek Reservoir Simulated Storage Contents
Figure 5.2-7E – Alternative 6, Green River Pump Simulated Diversion
Figure 6.1-1 – Topography
Figure 6.1-2A – Surficial Geology
Figure 6.1-2B – Surficial Units Key
Figure 6.1-3A – Bedrock Geology
Figure 6.1-3B – Bedrock Units Key
Figure 6.1-4A – Geologic Map
Figure 6.1-4B – Geologic Units Key
Figure 6.1-5 – Landslides
Figure 6.2-1 – Quaternary Faults
Figure 6.2-2 – Historic Seismicity
Figure 6.2-3 – Peak Horizontal Ground Acceleration
Figure 6.3-1A – Alternative 1 - Geologic Map
Figure 6.3-1B – Alternative 1 – Haines Flat Dams and Reservoir Site Geology
Figure 6.3-2 – Alternative 2 - Geologic Map
Figure 6.3-3 – Alternative 3 - Geologic Map
Figure 6.3-4 – Alternative 4 - Geologic Map
Figure 6.3-5 – Alternative 5 - Geologic Map
Figure 7.1-1 – Species of Concern
Figure 7.1-2 – Sage Grouse Leks
Figure 7.1-3A – Crucial Habitat - Antelope
Figure 7.1-3B – Crucial Habitat - Elk
Figure 7.1-3C – Crucial Habitat - Moose
Figure 7.1-3D – Crucial Habitat - Mule Deer
Figure 7.1-4A – Parturition - Antelope
Figure 7.1-4B – Parturition - Elk
Figure 7.1-4C – Parturition - Moose
Figure 7.1-4D – Parturition - Mule Deer
Figure 7.1-5 – NWI Wetlands
Figure 8.1-1 – Historical Sites and Trails
Figure 9.3-1 – Alternative 1 - Horse Creek/Cottonwood Creek Storage Facilities Layout
Figure 9.3-2 – Alternative 1 - Haines Flat Reservoir, Dam and Appurtenances Layout
Figure 9.3-3A – Alternative 1 - Haines Flat North Dam Profile and Maximum Section
Figure 9.3-3B – Alternative 1 - Haines Flat South Dam Profile and Maximum Section
Figure 9.4-1 – Alternative 2 - South Cottonwood Creek Storage Facilities Layout
Figure 9.4-2 – Alternative 2 - Mickelson Creek Reservoir, Dam and Appurtenances Layout
Figure 9.4-3 – Alternative 2 - Mickelson Creek Dam Profile and Maximum Section
Figure 9.5-1 – Alternative 3 - North Piney Creek Storage Facilities Layout
Figure 9.5-2 – Alternative 3 - Whiskey Creek Reservoir, Dam and Appurtenances Layout
Figure 9.5-3 – Alternative 3 - Whiskey Creek Dam Profile and Maximum Section
Figure 9.6-1 – Alternative 4 - South/Middle Piney Creek Storage Facilities Layout
Figure 9.6-2 – Alternative 4 - Fish Creek Reservoir, Dam and Appurtenances Layout
Figure 9.6-3 – Alternative 4 - Fish Creek Dam Profile and Maximum Section
Figure 9.7-1A – Alternative 5 - Green River Pumping Station, Pipeline and Canal (Aerial Photo Base)
Figure 9.7-1B – Alternative 5 - Green River Pumping Station, Pipeline and Canal (Topographic Base)
FIGURE 5.1-1  MODEL NETWORK DIAGRAM
UPPER GREEN RIVER - Westside Storage Study
WATER RESOURCES PLANNING OPERATIONAL MODEL

Legend:
- Most Downstream Node
- Streamflow (no gage / structure)
- Reservoir
- Instream Flow
- Diversion
- Well
- Other

Node labels are short identifiers
FIGURE 5.2-1  MODEL NETWORK DIAGRAM WITH ALTERNATIVES  
UPPER GREEN RIVER - Westside Storage Study  
WATER RESOURCES PLANNING OPERATIONAL MODEL  

Legend:  
- Most Downstream Node  
- Streamflow Gage  
- Reservoir  
- Instream Flow  
- Diversion + Well(s)  
- Well  
- Diversion  
- Other  
- Other / Baseflow  

Node labels are short identifiers.
FIGURE 5.2-2  ALTERNATIVE 1
HAINES FLAT RESERVOIR SIMULATED STORAGE CONTENTS

ACFT


Haines.Flat_Reservoir, HainesRes.StateMod.Sim_EOM.Month (1971-01 to 2006-12)
FIGURE 5.2-5
ALTERNATIVE 4
FISH CREEK RESERVOIR SIMULATED STORAGE CONTENTS

ACFT

Fish_Creek_Reservoir, FishCkRes.StateMod.Sim_EOM.Month (1971-01 to 2006-12)
FIGURE 5.2-6  ALTERNATIVE 5
GREEN RIVER PUMP SIMULATED DIVERSION

ACFT


GreenRiverPump, GRPump.StateMod.Carried_Water.Month (1971-01 to 2006-12)
FIGURE 5.2-7A ALTERNATIVE 6
HAINES FLAT RESERVOIR SIMULATED STORAGE CONTENTS

Haines Flat Reservoir, HainesRes.StateMod.Sim_EOM.Month (1971-01 to 2006-12)
FIGURE 5.2-7B  ALTERNATIVE 6
MICKELSON CREEK SIMULATED STORAGE CONTENTS

ACFT

16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0


Mickelson_Reservoir, MickelsonRes.StateMod.Sim_EOM.Month (1971-01 to 2006-12)
FIGURE 5.2-7C  ALTERNATIVE 6
WHISKEY CREEK RESERVOIR SIMULATED STORAGE CONTENTS

ACFT

0 2000 0.0
4000.0 6000.0 8000.0 10000.0 12000.0 14000.0 16000.0 18000.0 20000.0


Whiskey_Creek_Reservoir, WhiskeyRes.StateMod.Sim_EOM.Month (1971-01 to 2006-12)
FIGURE 5.2-7E  ALTERNATIVE 6
GREEN RIVER PUMP SIMULATED DIVERSION

GreenRiverPump, GRPump.StateMod.Carried_Water.Month (1971-01 to 2006-12)
The classification scheme has two phases, with the first phase being a simple classification of single units, such as alluvium (a), colluvium (c), eolian (e), bedrock (R), and grus (u). The complete single-element classification is as follows:

<table>
<thead>
<tr>
<th>letter</th>
<th>description</th>
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<tbody>
<tr>
<td>a</td>
<td>alluvium</td>
</tr>
<tr>
<td>b</td>
<td>bench</td>
</tr>
<tr>
<td>c</td>
<td>colluvium</td>
</tr>
<tr>
<td>d</td>
<td>dissected</td>
</tr>
<tr>
<td>e</td>
<td>eolian</td>
</tr>
<tr>
<td>f</td>
<td>alluvial fan deposits</td>
</tr>
<tr>
<td>g</td>
<td>glacial deposits</td>
</tr>
<tr>
<td>h</td>
<td>hot spring deposits</td>
</tr>
<tr>
<td>i</td>
<td>karst</td>
</tr>
<tr>
<td>j</td>
<td>clinker</td>
</tr>
</tbody>
</table>

The second phase of the classification combines the single elements into a multi-element classification for a specific mapping unit. In many cases, a specific mapping unit may be composed of many single elements, such as slopewash (s), colluvium (c), and bedrock (R), that in certain areas can be shown separately at scales of 1:100,000 or 1:500,000. In such cases, the single elements were combined into a more complex unit (sr), with the single elements ranked from most dominant to least dominant. The mapping unit sr would then represent a complex deposit composed of slopewash, colluvium, and bedrock outcrops, with more slopewash present than either colluvium or bedrock outcrop. Approximately 650 complex units were mapped for the 1:100,000-scale map and 577 units were mapped for the 1:500,000-scale map, with a simple description of each unit presented in Appendix A. These complex units for the 1:500,000-scale map are stored in the attribute SG_UNIT.

In order to achieve the objectives of the Ground-Water Vulnerability to Pesticide Contamination Project (Hamerlinck and Amraen, 1998), it was necessary to devise a classification scheme that was a simplification of the complex 650-unit scheme described above. A 25-element classification scheme that delineated simplified mapping units of most significance to contaminant migration was devised. The 25-element classification was composed of simple combinations of the single elements described above, and also included each of the 650 complex units as subsets. For example, the classification bi represents a bench that includes eolian, slopewash, outwash, and bench/mesa deposits. These attributes are stored in the layer item RECLASS. The complete association between the 25-element classification and the 650-unit classification is presented in Appendix B. The 25- element classification is presented below:

<table>
<thead>
<tr>
<th>letter</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Old alluvial plain with scattered deposits of eolian, residuum, and slopewash</td>
</tr>
<tr>
<td>a</td>
<td>Alluvium with scattered deposits of terrace, slopewash, eolian, residuum, grus and glacial</td>
</tr>
<tr>
<td>b</td>
<td>Shallow Alluvium mixed with scattered bedrock outcrops</td>
</tr>
<tr>
<td>s</td>
<td>Dissected bench with scattered deposits of residuum, slopewash, landslide, and eolian</td>
</tr>
<tr>
<td>t</td>
<td>Bench including eolian, slopewash, outwash and bench and/or mesa</td>
</tr>
<tr>
<td>c</td>
<td>Eolian mixed with scattered deposits of residuum, alluvium, and slopewash</td>
</tr>
<tr>
<td>s</td>
<td>Dissected alluvial fan and gradational fan deposits mixed with scattered deposits of slopewash and residuum</td>
</tr>
<tr>
<td>f</td>
<td>Alluvial fan and gradational fan deposits mixed with scattered deposits of slopewash, residuum, and eolian</td>
</tr>
<tr>
<td>p</td>
<td>Eolian deposits mixed with scattered deposits of slopewash, residuum, grus, alluvium, colluvium, landslide, and/or bedrock outcrops</td>
</tr>
<tr>
<td>k</td>
<td>Karst areas mixed with scattered deposits of residuum, slopewash, alluvium and/or bedrock outcrops</td>
</tr>
<tr>
<td>l</td>
<td>Clinker mixed with scattered deposits of residuum, slopewash, alluvium and/or bedrock outcrops</td>
</tr>
<tr>
<td>s</td>
<td>Landslide mixed with scattered deposits of slopewash, residuum, Tertiary landslides, and bedrock outcrops; landslides too small and numerous to show separately</td>
</tr>
<tr>
<td>m</td>
<td>Mesa including scattered deposits of residuum and eolian</td>
</tr>
<tr>
<td>b</td>
<td>Mixed areas mixed with scattered deposits of residuum, slopewash, and/or bedrock outcrops</td>
</tr>
<tr>
<td>a</td>
<td>Glacial outwash and alluvium mixed with scattered deposits of glacial, terrace, hot spring, bedrock outcrops, residuum, slopewash and grus</td>
</tr>
<tr>
<td>p</td>
<td>Playa deposits mixed with scattered deposits of alluvium, eolian, and r, playa deposits too small to show separately</td>
</tr>
<tr>
<td>b</td>
<td>Residuum mixed with alluvium, eolian, slopewash, grus, and/or bedrock outcrops</td>
</tr>
<tr>
<td>r</td>
<td>Bedrock and glaciated bedrock including hot spring deposits and volcanic necks; mixed with scattered shallow deposits of eolian, grus, slopewash, colluvium, residuum, glacial, and alluvium</td>
</tr>
<tr>
<td>s</td>
<td>Slopewash and colluvium mixed with scattered deposits of slopewash, residuum, grus, glacial, periglacial, alluvium, eolian, and/or bedrock outcrops</td>
</tr>
<tr>
<td>l</td>
<td>Dissected terrace deposits mixed with alluvium, residuum, eolian, and slopewash</td>
</tr>
<tr>
<td>t</td>
<td>Terrace deposits mixed with scattered deposits of alluvium, residuum, eolian, slopewash, and outwash</td>
</tr>
<tr>
<td>r</td>
<td>Structural terrace including and/or mixed with deposits of alluvium, residuum, slopewash, and terrace</td>
</tr>
<tr>
<td>s</td>
<td>Shallow terrace deposits mixed with scattered deposits of eolian and residuum</td>
</tr>
<tr>
<td>r</td>
<td>Ults mixed with alluvium, eolian, slopewash, grus, and/or bedrock outcrops</td>
</tr>
<tr>
<td>s</td>
<td>Truncated bedrock mixed with scattered shallow deposits of eolian, terrace, residuum, alluvium, old alluvial plain, bench, and slopewash</td>
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### Figure 6.1-3B

**Bedrock Units Key**

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<th>Symbol</th>
<th>Name</th>
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<tr>
<td>@ad</td>
<td>Ankareh formation, Thaynes limestone, Woodside shale, and Dinwoody formation</td>
</tr>
<tr>
<td>H2O</td>
<td>Water</td>
</tr>
<tr>
<td>J@n</td>
<td>Nugget sandstone</td>
</tr>
<tr>
<td>Jst</td>
<td>Stump formation, Preuss sandstone or redbeds, and Twin Creek limestone</td>
</tr>
<tr>
<td>Ka</td>
<td>Aspen shale</td>
</tr>
<tr>
<td>Kbb</td>
<td>Blind Bull formation</td>
</tr>
<tr>
<td>Kbr</td>
<td>Bear River formation</td>
</tr>
<tr>
<td>Kg</td>
<td>Gannett group</td>
</tr>
<tr>
<td>Kss</td>
<td>Sage Junction, Quely, Cokeville, Thomas Fork, and Smiths formations</td>
</tr>
<tr>
<td>MD</td>
<td>Madison limestone and Darby formation</td>
</tr>
<tr>
<td>O</td>
<td>Bighorn dolomite, Gallatin limestone, GrosVentre formation, and Flathead sandstone</td>
</tr>
<tr>
<td>P&amp;M</td>
<td>Wells and Amsden formations</td>
</tr>
<tr>
<td>P&amp;Ma</td>
<td>Phosphoria, Wells, and Amsden formations</td>
</tr>
<tr>
<td>Pp</td>
<td>Phosphoria formation and related rocks</td>
</tr>
<tr>
<td>Qa</td>
<td>Alluvium and colluvium</td>
</tr>
<tr>
<td>Qg</td>
<td>Glacial deposits</td>
</tr>
<tr>
<td>Qls</td>
<td>Landslide deposits</td>
</tr>
<tr>
<td>Qt</td>
<td>Gravel, pediment, and fan deposits</td>
</tr>
<tr>
<td>Th</td>
<td>Hoback formation</td>
</tr>
<tr>
<td>Tp</td>
<td>Bass Peak formation and equivalents</td>
</tr>
<tr>
<td>Tsl</td>
<td>Salt Lake Formation</td>
</tr>
<tr>
<td>Tle</td>
<td>Teewinot formation, Central Jackson Hole</td>
</tr>
<tr>
<td>Twd</td>
<td>Wasatch formation, diamicite and sandstone</td>
</tr>
<tr>
<td>Twg</td>
<td>Wasatch and Green River formations: New Fork tongue of Wastach and Fontenelle tongue or member of Green River</td>
</tr>
<tr>
<td>Twlc</td>
<td>Wasatch formation: La Barge and Chappo members</td>
</tr>
</tbody>
</table>
Peak acceleration (%g) with 2% probability of exceedence in 50 years

UPPER GREEN RIVER WESTSIDE STORAGE LEVEL II STUDY

PEAK HORIZONTAL GROUND ACCELERATIONS

PROJECT: AWWDC0704.00  DATE: 10/31/08  FIGURE: 6.2-3

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www.delorme.com
UPPER GREEN RIVER WESTSIDE STORAGE
LEVEL II STUDY

ALTERNATIVE 3 - NORTH PINEY CREEK
STORAGE FACILITIES LAYOUT

Short Elliott Hendrickson Inc.
Multi-disciplined. Single Source.

Leonard Rice Engineers, Inc.

PROJECT: AWWDC0704.00   DATE: 10/31/08   FIGURE: 9.5-1
Appendix A

Meetings
Upper Green River Westside Storage Project
Level II Study

Scoping Meeting

Presentation for:

Wyoming Water Development Commission
and
Upper Green River Basin Joint Powers Water Board

by:

Short Elliott Hendrickson Inc.
Leonard Rice Engineers, Inc.
Anderson Consulting Engineers, Inc.
Watts & Associates, Inc.
Plumley & Associates, Inc.

June 20, 2007
Roles and Communication

WWDC

SEH Team

UGRB

JPWB
Literature and Model Review

• Model Review
  – Knowledge transfer from LRE to other team members
  – Comparison of StateMod model shortages to those predicted in the GRBWPP

• ACE in-house peer review of StateMod model and available data

• SEH compilation and review of all other relevant literature and information (much of which is already available to team member LRE)
Identification of Water Supply Alternatives

• Alternative types
  – Previously identified storage sites (existing and proposed)
  – Newly identified in-subbasins storage sites
  – Combined alternatives (including subbasin transfers)
  – Out of subbasins source of supply (e.g., Fontenelle)
  – Non-structural measures (enhanced water management and conservation)

• Matrix compilation of relevant information for all alternatives

• Summary narrative discussions of new alternatives

• Screening criteria (develop with input and/or direct participation of WWDC/JPWB)
Potential Alternative Characteristics and Screening Criteria

- Location (including on-stream versus off-stream)
- *Demonstrated need(s) served (location, amount)*
- *Water source (stream/river; existing reservoir; in-subbasin versus out-subbasin)*
- Water rights/contracts
- Dam size and reservoir capacity
- Appurtenant supply/delivery facilities (diversions, canals, pipelines, pumping plants)
- Operational scheme/issues (e.g., exchange, bypass)
- Geologic conditions (favorable, unfavorable, fatal flaw potential)
- *Environmental conditions/issues* (wetlands, T&E species, fisheries, cultural resources, etc.)
- *Land ownership*
- Access/utilities opportunities/constraints
- Relative cost
## Example Alternatives
### Characteristics/Screening Matrix

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Quadrangle</th>
<th>Arapahoe Ranch</th>
<th>Arapahoe Ranch</th>
<th>Arapahoe Ranch</th>
<th>Arapahoe Ranch</th>
<th>Embar</th>
<th>Arapahoe Ranch</th>
<th>Arapahoe Ranch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (miles)</td>
<td>Hamilton Dome</td>
<td>1.9</td>
<td>0.0</td>
<td>2.7</td>
<td>5.6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Terrain</td>
<td>Hamilton Dome</td>
<td>Favorable</td>
<td>None</td>
<td>Favorable</td>
<td>Moderate</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Outlet</td>
<td>Hamilton Dome</td>
<td>0.8</td>
<td>0.0</td>
<td>1.7</td>
<td>5.6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Terrain</td>
<td>Hamilton Dome</td>
<td>Favorable</td>
<td>Favorable</td>
<td>Favorable</td>
<td>Favorable</td>
<td>None</td>
<td>None</td>
<td>None</td>
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<tr>
<td>Potential Supply Diversions</td>
<td>Owl Creek North to South</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Owl Creek South to North</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
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<td></td>
<td>Cottonwood Creek</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
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<td>Hamilton Dome</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

### Drainage Areas (square miles)

- **Direct Runoff to Reservoir**
  - Hamilton Dome: 2.7
  - Arapahoe Ranch: 104.4
  - Arapahoe Ranch: 2.0
  - Arapahoe Ranch: 7.4
  - Embar: 100.9
  - Arapahoe Ranch: 22.6
  - Arapahoe Ranch: 21.5

- **Primary Reservoir Diversion**
  - Hamilton Dome: 100.9
  - Arapahoe Ranch: 0.8
  - Arapahoe Ranch: 168.3
  - Arapahoe Ranch: 168.3
  - Embar: 0.0
  - Arapahoe Ranch: 0.0
  - Arapahoe Ranch: 0.0

### Potential Supplemental Diversions

- **Owl Creek North to South**
  - Hamilton Dome: unknown
  - Arapahoe Ranch: unknown
  - Arapahoe Ranch: unknown
  - Embar: unknown
  - Arapahoe Ranch: unknown
  - Arapahoe Ranch: unknown

### Potential Diversions Subtotal

- Hamilton Dome: unknown
- Arapahoe Ranch: 168.3
- Arapahoe Ranch: 168.3
- Embar: 0.0
- Arapahoe Ranch: 145.5
- Arapahoe Ranch: 145.5

### Assessment of water supply

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<tr>
<th>Height Efficiency (feet/thousand ac-ft)</th>
<th>In-basin</th>
<th>In-basin</th>
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### Supply Source

- Hamilton Dome: In-basin
- Arapahoe Ranch: In-basin
- Arapahoe Ranch: In-basin
- Arapahoe Ranch: In-basin
- Embar: In-basin
- Arapahoe Ranch: In-basin
- Arapahoe Ranch: In-basin

### Maximum Storage Capacity (ac-ft)

- Hamilton Dome: 31234
- Arapahoe Ranch: 31552
- Arapahoe Ranch: 13552
- Arapahoe Ranch: 26613
- Embar: 16111
- Arapahoe Ranch: 15533
- Arapahoe Ranch: 33394

### Cost

- Hamilton Dome: $29.42
- Arapahoe Ranch: $17.73
- Arapahoe Ranch: $19.50
- Arapahoe Ranch: $16.67
- Embar: $25.75
- Arapahoe Ranch: $20.88
- Arapahoe Ranch: $18.19

### Serves as backup to Site #

- Hamilton Dome: Excellent or more than adequate
- Arapahoe Ranch: Favorable or adequate
- Arapahoe Ranch: Potential fatal flaw or unfavorable value
- Arapahoe Ranch: Probable fatal flaw or very unfavorable value
Alternative Westside Storage Sites
Out of Subbasin Water Supply Alternatives
Alternatives Analysis

Monthly Planning Model
1971 to 2003

- Uses generic water allocation model ➔ StateMod
- Distributes water supplies based on physical flow available, in priority, to water rights
- Provides direct comparison of effects of future operational scenarios against baseline conditions
Alternatives Analysis -- Baseline Scenario

- Upper Green Level II Study
  - Simulate physical supply to meet river headgate demands by priority
  - Irrigation Shortage = Headgate Demand – Simulated Diversion
  - Identified tributaries with excess water

- Reservoirs, filled using junior storage rights, modeled to reduce irrigation shortages
Figure 4 - Mickelson Creek Reservoir
Simulated End-of-Month Contents

- MICKELSON RES, MickelsonRes.StateMod.Sim_EDM.Month (1971-01 to 2003-12) (REF TS)
- MICKELSON RES, MickelsonRes.StateMod.Sim_EDM.Month (1971-01 to 2003-12)
Alternatives Analysis

- Proposed Reservoirs, Pipelines, Feeder Ditches
Preliminary Geotechnical Investigations

• Surface Geological Conditions
  – Foundation conditions
  – Borrow materials availability and quality
  – Slope stability
  – Reservoir leakage

• Seismic Considerations
  – Potential source structures
  – Historic earthquakes
  – Seismic risk (estimated site ground motions)
Permitting and Mitigation

• Identify all key permits, clearances, and environmental issues

• Perform pre-application consultation(s)

• Conduct field reconnaissance

• Characterize permits
  – Application requirements
  – Environmental studies/evaluations
  – Scheduling
Conceptual Designs and Cost Estimates

• Design elements
  – Dam/foundation
  – Inlet/outlet facilities
  – Spillway
  – Supply/delivery facilities (canal, pipeline, pumping plant)
  – Access/utilities

• Cost factors
  – Design and oversight
  – Construction
  – O&M
  – Other (mitigation, land, legal, etc.)
Economic Analysis
Ability-to-Pay

- Collect, review and analyze appropriate crop enterprise budgets
- Interview selected beneficiary irrigators for basin-specific information
- Develop “composite” crop enterprise budgets
- Estimate changes in farm income assuming implementation of water supply alternatives
- Recommend appropriate level of annual financial commitment by project beneficiaries
Economic Analysis
Benefit-Cost

• Objective
  – Estimate magnitude of potential benefits attributable to selected water supply alternatives

• Benefit Types
  – Irrigation (direct and indirect)
  – Recreational
  – Environmental
  – Municipal (if applicable)
  – Industrial (if applicable)

• Analysis
  – Utilize project cost estimates and ability-to-pay results
  – Compare estimated value of benefits to project costs
## Work Schedule

**Upper Green River Westside Storage, Level II Study**

<table>
<thead>
<tr>
<th>Task</th>
<th>Task Description</th>
<th>2007</th>
<th>2008</th>
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<td>1</td>
<td>Scoping and Project Meetings</td>
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<td>2</td>
<td>Literature and Model Review</td>
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<td>3</td>
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<td>4</td>
<td>Identification of Potential Water Supply Project Alternatives</td>
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<td>JUN AUG JUL</td>
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<td>5</td>
<td>Alternative Analysis</td>
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<td>Environmental and Permitting Issues</td>
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<td>Archeological Investigation</td>
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<td>Economic Analysis</td>
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<td>Develop Preferred Alternatives</td>
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<td>14</td>
<td>Reports and Project Materials</td>
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- ▲: Conference or meeting
- ■: Deliverable
- 🌊: Scheduled effort
- ⬤: Intermittent effort
- 🎨: Discretionary work per WWDC direction

---

**Legend:**
Questions and Answers
Team Qualifications

Key People

• Doug Yadon, PE – Project Manager (SEH)
  – 30 years dams/water resources experience on over 40 relevant projects
  – Managed 10 previous WWDC projects; currently completing Level II Owl Creek Storage Project

• Alan Jewell, PE (SEH)
  – 20 years dams/water resources experience
  – Responsible for dam and reservoir siting and planning on numerous projects for WWDC and other clients

• Bill Kelly, PE (SEH)
  – 36 years experience in H&H elements of water resources projects from planning through construction

• Chris Wichmann (SEH)
  – 11 years of environmental experience including NEPA, Categorical Exclusions, wetlands delineation, fisheries evaluations, T&E determinations

• Rick Parsons, PE (LRE)
  – 12 years water resources engineering experience
  – Specializing in river basin analysis and modeling including water rights, hydrology, historical use and needs and demands

• Brad Anderson, PE (ACE)
  – 27 years water resources experience including river basin hydrologic analysis and modeling

• Gary Watts (W&A)
  – 40 years economic analysis experience including numerous studies of water resources and irrigated agriculture projects for needs/demands, ability to pay, and direct and indirect benefits

• Patrick Plumley, PG (P&A)
  – 21 years of engineering geologic experience, including serving as Project Geologist for seven WWDC dam siting and/or design projects
## Team Qualifications

### Key Projects

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<tr>
<td>Kirby Area Water Supply Project</td>
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<tr>
<td>Upper Wind River Storage Project</td>
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<td>Upper Green River Basin Study</td>
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<tr>
<td>Little Snake River Basin Planning Study</td>
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<td>Owl Creek Master Plan</td>
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<td>Owl Creek Irrigation District Storage Study</td>
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<td>Big Horn Basin – Clarks Fork Project</td>
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<td>Lake Adelaide Dam Project</td>
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<td>High Savery Dam (Embankment/Foundation)</td>
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| **LRE**        |
| Bear River Basin Plan                                                  | I          |
| Clarks Fork Reservoir Hydrology Study                                   | I          |
| Upper Green River Storage Study                                         | II         |
RFP NO. 07-22
ATTACHMENT "C"
PRICE PROPOSAL SUMMARY

UPPER GREEN RIVER WESTSIDE STORAGE LEVEL II STUDY

<table>
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<th>Task</th>
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<td>Task 1. Scoping &amp; Project Meetings</td>
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<td>Task 2. Literature and Model Review</td>
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**PROJECT TOTAL COST**

$198,000
MEETING NOTES

Upper Green River Westside Storage Level II Project
June 20, 2007
1:00 pm
Pinedale, Wyoming - Pinedale Library

Meeting Chair: John Zebre - UGRJPWB
Notes by: Doug Yadon/SEH, Rick Parsons/LRE
Present: (see separate attendance list)
Copies to: Jason Mead/Jodie Pavlica - WWDC; John Zebre - UGRJPWB

Warren Bridge Storage Site Alternative

John Zebre clarified that the JPWB had not requested inclusion of the Warren Bridge alternative in the current Level II Westside Storage project scope. Jason Mead noted that this alternative had been removed from the scope of work during negotiations with SEH and that an adjustment (savings) in cost resulted. John and Jason further noted that WWDC staff have been tasked to perform an evaluation of the overall feasibility of this alternative outside of the SEH contract, and that the results of that evaluation would be discussed with the JPWB at their regular August meeting.

SEH Presentation of Scope of Study

Doug Yadon/SEH and Rick Parsons/LRE discussed the proposed scope of work for the Upper Green River Westside Storage Project Level II Study with the aid of a PowerPoint presentation. Copies of the presentation were left with the JPWB.

During and after the PowerPoint presentation a number of questions and comments from the audience were discussed. Summarized here are several of the key questions/issues with some of the discussion from the meeting and additional thoughts on the topics that have arisen during preparation of these notes.

1) Will hydroelectric potential be evaluated for the various alternatives? Detailed evaluations of hydroelectric potential are not included in the contract scope of work. However, if any potentially significant opportunity(ies) become apparent during the course of the alternatives identification task the study team will bring it(them) to the attention of WWDC and the JPWB. A determination can then be made by WWDC if the opportunity(ies) merit further evaluation at this level of study under the Discretionary Task.

2) Will the “purpose and need” for the various alternatives selected for more detailed study be expanded to include more than irrigation shortages? Purpose and need must ultimately be firmly established for any alternative to successfully meet the challenges of the NEPA environmental permitting process. Based on the previous studies it appears that purpose and need can certainly
be established based on irrigation shortages in the subbasins under study. Other potential beneficial uses (or multiple uses) will be sought for all of the alternatives. Multiple use storage projects are favored for funding under WWDC enabling legislation and operating criteria, and can be the basis for additional sponsors (and accompanying monetary and/or in-kind support) for any given alternative project. These other potential multiple uses (e.g., for environmental enhancement, but not mitigation; municipal/industrial water supply; meeting Compact calls; and possibly even recreation) could also contribute to permitting “purpose and need” and will be considered during the course of the project.

3) Which project characteristics (purpose and need, beneficial uses) are most important to ultimately being able to permit a project? Is there a numerical scoring/ranking of needs/uses? “Purpose” is a statement of specific goals and objectives that the applicant intends to fulfill by taking the proposed action. “Need” is a discussion of existing conditions that need to be changed, problems that need to be remedied, and/or policies or mandates that need to be implemented. In other words, it explains and justifies why the applicant is proposing an action at this time. Purpose and need should provide the basis for identifying a reasonable range of alternatives for study (i.e., not so narrow that only one alternative (the proposed action) can meet the need, and not so broad that the alternatives process gets out of hand).

The lead agency implementing the NEPA process must determine that there is a real “purpose and need” for the proposed action. In other words, there must be a real problem to be solved, a policy mandate to be implemented, or some other strong impetus for the proposed action (and not just that the applicant would like to construct and operate the project). There is not a numerical ranking/scoring for purpose and need. This is not to say that the lead agency may not consider some element(s) of purpose and need (where there are more than one) to be more compelling than another(s). In general, being able to demonstrate more than one need (i.e., multiple uses) is very desirable in the permitting process.

In response to a specific question during this overall discussion, it was the study team’s preliminary opinion that “storing Wyoming’s water for the sake of preserving it for future beneficial use” would not meet the test of present “purpose and need” under NEPA nor the Wyoming SEO’s requirement that a present beneficial use be shown to justify issuance of a new storage right. Note that further consideration of if/how operation of new storage might relate to Wyoming’s obligations under the Colorado River Compact(s) is included in the current scope of work under Task 5.

4) Funding of any new water storage project will require very significant support from the State of Wyoming; agriculture cannot bear additional costs beyond those already incurred. The project scope of work includes an evaluation of the ability of the JPWB (or another legal entity or entities that might be formed to pursue one or more alternative storage projects) to repay the portion of any alternative project cost not covered by a WWDC or other agency/entity grant. WWDC and the study team recognize the challenge of funding the non-grant portion of new water storage projects that are solely or primarily to serve irrigation shortages for alfalfa/grass hay and watering of pastures for grazing. An important part of this study will be to identify any other potential beneficial uses for each of the short-listed water supply alternatives, including those that appear to provide overall public benefit, and assessing the associated value of those benefits to the degree practicable at this level of study.
<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Phone Office - or Home - x</th>
<th>Cell Phone</th>
<th>Email</th>
<th>Address</th>
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<tr>
<td>Jason Mead</td>
<td>WWDC (Project Manager)</td>
<td>307.777.6636 (C)</td>
<td>307.777.6819</td>
<td><a href="mailto:jmead@klarman.com">jmead@klarman.com</a></td>
<td>3820 Yellowblow Road, Cheyenne, WY 82006</td>
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<tr>
<td>Jodie Pavlica</td>
<td>WWDC (Assistant Project Manager)</td>
<td>307.777.6819 (C)</td>
<td>307.777.6819</td>
<td>UPWAVC</td>
<td>6020 Yellowblow Road, Cheyenne, WY 82006</td>
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<tr>
<td>Doug Yarlow</td>
<td>SEH (Project Manager)</td>
<td>307.466.9611 (C)</td>
<td>307.466.4115</td>
<td><a href="mailto:duyarlow@sehinc.com">duyarlow@sehinc.com</a></td>
<td>2657 Maderia Drive, Suite 200, Fort Collins, CO 80522</td>
</tr>
<tr>
<td>Rick Pearson</td>
<td>SEH (SEH Team Member)</td>
<td>303.468.6860 (C)</td>
<td>303.468.6115</td>
<td><a href="mailto:rpearson@sehinc.com">rpearson@sehinc.com</a></td>
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<tr>
<td>Stan Cooper</td>
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</table>
I. Introductions

II. Purpose of Meeting - To discuss hydrologic modeling protocols and data needs for different levels of modeling efforts used to define water availability.

III. Level I Reconnaissance Effort– Basin Plans
   a. Demand Estimates, Data Requirements
      i. Irrigated Acreage
      ii. Crop demand established using crop irrigation requirements or 1 cfs/70 acres duty of water
      iii. System Efficiencies – Is an estimate of 50% sufficient at this level?
   b. Supply Estimates –
      i. Stream gauge data
      ii. Linear regression to fill data gaps
      iii. Transfer of data where stream gauges are adequate to basins that lack either gauges or adequate data
      iv. Use of elevation vs drainage area graphs to estimate run off
      v. Monthly time step
   c. Water Availability/Shortage Estimates – Is it imperative to account for priority administration at this level or should we base projections of water availability strictly on consumptive use?

IV. Level II Feasibility Estimates - Dams and Reservoirs – Project Level
   a. Demand Estimates, Data Requirements
      i. Irrigated Acreage
      ii. Types of crops and associated acreage
      iii. Crop demand established using crop irrigation requirements for estimated cropping patterns
      iv. Crop demand established using a 1cfs/70 acres duty of water and decree or compact considerations
      v. Crop demand established using legal entitlements, including the 1 cfs/70 acres duty of water and an additional 1 cfs/70 acres described by Wyoming surplus or excess water law, and compact or decree considerations
      vi. System efficiencies established using diversion records and stream gauges
1. How does diversion of more than the legal entitlement (free river situation) impact estimates of system efficiency?
2. Should we only use legal entitlements in the calculation of system efficiency?

vii. Techniques to estimate system efficiencies w/o diversion records and gauged stream flow- ideas?

viii. Diversion Requirements – Crop demand/system efficiency

b. Supply Estimates
   i. Stream gauge data
   ii. Linear regression to fill data gaps
   iii. Transfer of data from basins where stream gauges are adequate to basins that lack either gauges or adequate data
   iv. Use of elevation vs drainage area graphs to estimate run off
   v. Daily time step vs monthly time step
   vi. Would short term flow measuring of streams and diversions provide any utility for modelers when attempting to establish a daily time step or when calculating system efficiencies? Is a daily time step useful?

c. Shortage/Water Availability Estimates Data Requirements
   i. Water rights and decree/compact limitations superimposed on associated diversion demands to determine water availability/shortages. Modeling routine to reflect Wyoming’s water administration scheme.

V. State Engineer/Water Administrator’s Data Needs

   i. Stream gauge data
   ii. Irrigated acreage
   iii. Diversion records
   iv. Crop irrigation requirements
   v. System efficiencies
      1. Use of diversion records and stream gauges
      2. Rule of thumb estimates
   vi. Legal entitlements
      1. Reservoir storage
      2. Direct flow appropriations
      3. Instream flow limitations
      4. Consideration of Decree/Compact limitations
   vii. Estimate of consumptive use/depletions
      1. Municipal diversion records less return flow
      2. Irrigation diversion demand less return flow
      3. Industrial diversions less return flow
      4. Reservoir Evaporation
VI. Level II, Phase III Final Design and NEPA review - Dams and Reservoirs

a. System Demand established using diversion requirements determined with crop irrigation requirement and compact/decreed considerations
b. System Demand established using legal entitlements
c. Estimate of storable flow based on consumptive use/water right priorities and appropriator’s cooperation
d. Estimate of storable flow or “legally available flow” based on legal entitlements rather than crop irrigation requirements

Swap locations for V and VI to keep D&R work together?
MEMORANDUM

TO: Jason Mead, PE/WWDO
FROM: Douglas M. Yadon, PE/SEH
DATE: August 11, 2008
RE: Status Report - Upper Green River Westside Storage, Level II Study
    SEH No. AWWDCO070400 FC

This memorandum summarizes project status by task and presents selected preliminary findings. The project is currently scheduled for completion of a preliminary draft report by no later than the end of October 2008 as a basis for presentation of key study findings during seminars to be held by WWDO in mid November in the study area. The overall project is scheduled for completion by the end of calendar year 2008.

Task 1. Scoping and Project Meetings

The Scoping Meeting was held in Pinedale, WY on June 20, 2007. Meeting Notes were prepared by SEH and submitted to WWDO on July 2, 2007. A number of informal project meetings and teleconferences have been held to date with WWDO’s Project Manager and other staff to discuss and resolve issues regarding the hydrologic and water rights modeling for the project.

Task 2. Literature and Model Review

A total of more than 50 references have been compiled and reviewed to date for information relevant to the study. These include five previous studies from 1944 to 2007 that identified potential surface water storage sites within the Horse, Cottonwood and Piney Creeks subbasins that are the focus of this study. Other information gathered includes topography, soils, geology, seismotectonics (faults and earthquakes), hydrology (including all relevant historic gage data), and environmental conditions (as discussed further under Task 7 below).

The pre-existing StateMod water rights/hydrology model developed as part of the prior Upper Green River Storage Level II Study (Kleinfelder and Leonard Rice Engineers, Inc., 2007) has undergone an initial and several subsequent reviews and enhancements/corrections as discussed further under Tasks 4 and 5. The modeling effort for this project was appropriately delayed for several months in late 2007 to early 2008 while WWDO conducted an overall review of the water rights/hydrology modeling previously used for WWDC projects (see related discussion under Task 15 below).

Task 3. Access

Work on this task to date has included compilation of land ownership data acquired from the Sublette County Assessors Office into the project geographic information system (GIS). Additional effort is pending final selection of short-list water supply project alternatives as discussed below under Task 4.
Task 4. Identification of Potential Water Supply Project Alternatives

A total of 24 distinct sites were identified from the studies compiled under Task 2, of which 2 were potential enlargements of existing reservoirs. An additional 2 existing sites were identified from available U.S. Geological Survey digital topographic mapping. Finally, a total of 34 new (previously unidentified) potential dam and reservoir sites have been identified to date by review of available U.S. Geological Survey topographic mapping and digital orthophoto quarter quadrangle (DOQQ) color infrared aerial photos. All of these sites have been entered into a spreadsheet-based site data compilation, screening and conceptual design tool previously developed by SEH for use on dam and reservoir siting projects such as this. Relevant, available data compiled to date for each site has been entered into the spreadsheet model.

In addition to the spreadsheet model, the results of preliminary runs of the StateMod model noted under Task 2 above and discussed further under Task 5 below have been and are currently being used to finalize identification of the three to five most favorable appearing alternatives to address modeled irrigation water shortages in the Horse, Cottonwood and Piney Creeks subbasins.

Task 5. Alternatives Analysis

The work to date on Task 5 has involved implementing a series of improvements, enhancements and corrections to the pre-existing StateMod model for the Upper Green River Basin developed during the prior Level II study. These changes have addressed the following issues:

- Extend streamflow and diversion records through 2006 to incorporate data on ongoing drought
- Incorporate recent local temperature and precipitation data to extend climate data in input files
- Calculate consumptive use demands and re-analyze modeled crop demands versus original work developed by Pochop, et al. (WWRC 92-06)
- Develop revised calibrated crop coefficients for use in the consumptive use model
- Revise estimates of crop demands at farm and at river headgate based on calibrated crop coefficients
- Update structure efficiencies and river headgate demands
- Update irrigated acreages used in model based on mapping from Green River Basin Plan
- Develop synthetic gage record in South Piney Creek drainage
- Correct/revise data entry from the prior Level II study relative to natural runoff in the Horse Creek subbasin
- Review and revise natural runoff inputs on subbasins and tributaries as appropriate based on previously unused historical gage data
- Revise monthly distribution of runoff based on tributary versus mainstem gage data

The preliminary results of the latest model improvements and corrections indicate that surplus (storable) flows on Horse Creek are very much less and the unmet demands significantly higher than previously modeled (but still showing a modest overall excess of supply to unmet demand). On South Piney Creek the storable flows are now modeled as exceeding the unmet demand on an overall basis whereas previous results indicated very low available (storable) flow and very high unmet demands. Results for Cottonwood Creek changed from a slight excess of supply over unmet demand to a slight deficit. North Piney and Middle Piney Creeks still show a substantially greater overall unmet demand over storable flow. It is believed that these latest StateMod model results are substantially more reliable than previous results as a basis for finalizing development and recommendation of three to five alternative water supply projects. Some minor additional refinements (including the manner in which return flows are handled in
some subbasins or tributaries) are planned to be implemented as part of the forthcoming more detailed modeling of the recommended alternatives.

**Task 6 – Preliminary Geotechnical Investigations**

Available published reports and mapping of soils, surficial geology, bedrock geology, structural geology and seismotectonics have been preliminarily reviewed and key relevant information has been input to the alternatives screening/conceptual design spreadsheet model.

**Task 7 – Environmental and Permitting Issues**

Known and potential environmental and permitting issues have been identified generally within the study area. These include, but are not necessarily limited to:

- Crucial big game range, birthing areas and migration corridors
- Salmonid fisheries habitat
- Wetlands/riparian habitat
- Sage grouse nesting/brooding habitat
- Cultural (historical and archeological) resources

Initial contacts have been made with key state and federal land/resource management agencies to begin soliciting their input on these issues.

**Task 8 – Archeological Investigation**

Work on this task is pending final selection of the preferred three to five project alternatives.

**Task 9 – Conceptual Designs**

Work on this task is pending final selection of the preferred three to five project alternatives.

**Task 10 – Preliminary Cost Estimates**

Work on this task is pending completion of all prior work tasks.

**Task 11 – Economic Analysis**

Work on this task is pending completion of all prior work tasks.

**Task 12 – Develop Preferred Alternatives**

Work on this task is pending completion of all prior work tasks.

**Task 13 – Discretionary Task**

This task has not yet been utilized on the project.
Task 14 – Reports and Project Materials

Work on this task is pending completion of all prior work tasks.

Task 15 – Technical Modeling Memo

An additional non-project specific task was added to the contract for this study to devise general guidelines for moving from hydrologic spreadsheet models, developed in the first round of WWDC basin plans, to StateMod models capable of providing information germane to the missions of both the WWDO and the State Engineer’s Office. This effort was documented in a technical memorandum addressing the following topics:

- Background
- Terminology – a glossary of terms used throughout the memorandum, and for reference when
- Comparisons - Spreadsheet and Simulation Models (including multiple scenarios with simulation model)
- Input data (the “Protocol”)
- Documentation guidelines
- IT guidelines

Memorandum_Upper Green Status Report_8-11-08.doc
Upper Green River Westside Storage Project
Level II Study
Project Meeting

Presentation for:
Wyoming Water Development Commission
and
Upper Green River Basin Joint Powers Water Board

by:
Short Elliott Hendrickson Inc.
Leonard Rice Engineers, Inc.

September 30, 2008
Agenda

- Introductions
- Project Status
- Overall Approach
- Methodology
  - Compilation and Evaluation of Available Data/Information
  - Hydrologic/Water Rights Modeling
  - Identification of Alternatives
  - Screening and Characterization of Alternatives
- Preliminary Results
- Next Steps
- Questions and Answers
Overall Approach

• Consider the study area as a whole, not necessarily as individual subbasins

• Identify and characterize *needs* (supplemental irrigation supply)

• Identify and characterize *resources* (legally and physically available surface water)

• Identify and characterize reservoir storage sites and/or other water supply concepts to link *needs* to *resources*
Methodology

• Compilation and Evaluation of Available Data/Information
Sources of Supply (Resources)
Areas of Demand

(Needs)
Modeled Diversions

- Explicit
- Aggregated
Association of Irrigated Lands to Aggregated Diversion Model Nodes
Methodology

• Hydrologic/Water Rights Modeling
Update Existing Network To Represent Alternative Scenarios

NEW / ENLARGED RESERVOIRS
Improvements To Representation Of Basin Hydrology And Demands

• Update irrigated acreage from Green River Basin Plan (2000)
  – Revise crop demands and structure efficiencies

• Extend streamflow and diversion records through 2006
  – Includes recent drought

• Incorporate WY SEO gage data previously unavailable
  – Explicitly include South Piney Creek near Snyder Basin
  – Improve upper basin natural flows to better represent South Piney and Fish Creek contributions
Methodology

• Identification of Alternatives
• Screening and Characterization of Alternatives
Long List Of Potential Storage Reservoir Alternatives
Location of Supply vs. Demand
Preliminary Results

- Four storage reservoirs with associated supply and/or delivery canals
- One pumping station-pipeline-canal system
Preferred Storage and Pumping Alternatives
Alternative 1 – Horse Creek/Cottonwood Creek Storage
## Alternative 1 – Horse Creek/Cottonwood Creek Storage

### Major Elements

<table>
<thead>
<tr>
<th>Item</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haines Flat Reservoir (SEH-15)</td>
<td>One dam on South Horse Creek – 60 ft. high</td>
</tr>
<tr>
<td></td>
<td>One dam offstream to North Cottonwood Creek – 110 ft. high</td>
</tr>
<tr>
<td></td>
<td>Reservoir capacity – 42,000 ac.-ft.</td>
</tr>
<tr>
<td></td>
<td>Reservoir surface area – 2.2 sq. mi.</td>
</tr>
<tr>
<td>North Horse Creek Supply Canal</td>
<td>Canal length – 6.0 mi.</td>
</tr>
<tr>
<td></td>
<td>Capacity – up to 400 cfs</td>
</tr>
<tr>
<td></td>
<td>Period of operation – non-winter months, primarily May-June</td>
</tr>
<tr>
<td>North Cottonwood Creek Supply Canal</td>
<td>Canal length – 6.1 mi.</td>
</tr>
<tr>
<td></td>
<td>Capacity – 200 cfs</td>
</tr>
<tr>
<td></td>
<td>Period of operation – non-winter months, primarily May-June</td>
</tr>
<tr>
<td>Horse Creek Delivery Canal</td>
<td>Canal length – 6.3 mi.</td>
</tr>
<tr>
<td></td>
<td>Capacity – 80 cfs</td>
</tr>
<tr>
<td></td>
<td>Period of operation – irrigation season</td>
</tr>
<tr>
<td></td>
<td>Delivery area – lower 2/3 of North Horse Creek</td>
</tr>
<tr>
<td>North Cottonwood Creek Pumping Station/Delivery Canal to South</td>
<td>Canal length – 4.3 mi.</td>
</tr>
<tr>
<td>Cottonwood Creek</td>
<td>Pumping station lift – 60 ft.</td>
</tr>
<tr>
<td></td>
<td>Pumping/canal capacity – 30 cfs</td>
</tr>
<tr>
<td></td>
<td>Delivery area – lower 1/3 of South Cottonwood Creek</td>
</tr>
</tbody>
</table>

### Function/Operation

<table>
<thead>
<tr>
<th>Source(s) of Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Cottonwood Creek – 25,000 ac.-ft. physical inflow</td>
</tr>
<tr>
<td>South Horse Creek – 12,000 ac.-ft. physical inflow</td>
</tr>
<tr>
<td>North Horse Creek – 48,000 ac.-ft. physical inflow (as needed)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Irrigated Lands Served</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity release from storage:</td>
</tr>
<tr>
<td>Lower 2/3 of North Cottonwood Creek – 5,000 ac./up to 3,800 ac.-ft. shortage</td>
</tr>
<tr>
<td>South Horse Creek – 800 ac./up to 1,000 ac.-ft. shortage</td>
</tr>
<tr>
<td>Horse Creek – 1,500 ac./up to 3,000 ac.-ft. shortage</td>
</tr>
<tr>
<td>Exchange:</td>
</tr>
<tr>
<td>Exchange from Cottonwood Creek to upper 1/3 of North Cottonwood Creek as necessary and appropriate</td>
</tr>
</tbody>
</table>

### Key Assumptions/Comments

- Evaluate advantages of North Horse Creek Delivery Canal vs. larger carryover storage in Haines Flat Reservoir relative to meeting shortages
- Evaluate ability to satisfy South Cottonwood Creek shortages from Mickelson Reservoir only, without pump station/delivery canal from North Cottonwood Creek
- Supply canals assumed to operate only March through October (check implications of one-fill rule)
- Evaluate exchange potential to satisfy shortages in approximately upper 1/3 of North Horse Creek
**Alternative 2 – South Cottonwood Creek Storage**

<table>
<thead>
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<th>Major Elements</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mickelson Creek Reservoir (Site15)</strong></td>
<td>Dam on South Cottonwood Creek – 100 ft. high</td>
</tr>
<tr>
<td></td>
<td>Reservoir capacity – 32,000 ac.-ft.</td>
</tr>
<tr>
<td></td>
<td>Reservoir surface area – 1.7 sq. mi.</td>
</tr>
<tr>
<td><strong>South Cottonwood Creek Supply Canal</strong></td>
<td>Canal length – 6.0 mi.</td>
</tr>
<tr>
<td></td>
<td>Capacity – 65 cfs</td>
</tr>
<tr>
<td></td>
<td>Delivery area – middle 1/2 of South Cottonwood Creek</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function/Operation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source(s) of Supply</strong></td>
<td>South Cottonwood Creek – 22,000 ac.-ft. physical inflow</td>
</tr>
<tr>
<td><strong>Irrigated Lands Served</strong></td>
<td>Gravity release from storage:</td>
</tr>
<tr>
<td></td>
<td>Middle 1/2 of South Cottonwood Creek – 4,000 ac./up to</td>
</tr>
<tr>
<td></td>
<td>10,000 ac.-ft. shortage</td>
</tr>
<tr>
<td></td>
<td>Exchange:</td>
</tr>
<tr>
<td></td>
<td>Exchange from lower South Cottonwood Creek and/or</td>
</tr>
<tr>
<td></td>
<td>Cottonwood Creek to upper 1/4 of South Cottonwood</td>
</tr>
<tr>
<td></td>
<td>Creek as necessary and appropriate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key Assumptions/Comments</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Evaluate ability to satisfy South Cottonwood Creek shortages from Mickelson Creek Reservoir only, without pump station/canal from North Cottonwood Creek delivering release from Haines Flat Reservoir (Alternative 1)</td>
<td></td>
</tr>
<tr>
<td>▪ Evaluate exchange potential to satisfy shortages in approximately upper 1/4 of South Cottonwood Creek</td>
<td></td>
</tr>
</tbody>
</table>
Alternative 3 – North Piney Creek Storage

Alternative 3 (SEH-10): Whiskey Creek Reservoir

North Piney Creek
<table>
<thead>
<tr>
<th>Major Elements</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Whiskey Creek Reservoir (SEH-10)</strong></td>
<td></td>
</tr>
<tr>
<td>Dam on North Piney Creek – 140 ft. high</td>
<td></td>
</tr>
<tr>
<td>Reservoir capacity – 33,000 ac.-ft.</td>
<td></td>
</tr>
<tr>
<td>Reservoir surface area – 1.0 sq. mi.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function/Operation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source(s) of Supply</strong></td>
<td></td>
</tr>
<tr>
<td>North Piney Creek – 40,000 ac.-ft. physical inflow</td>
<td></td>
</tr>
<tr>
<td><strong>Irrigated Lands Served</strong></td>
<td></td>
</tr>
<tr>
<td>Gravity release from storage:</td>
<td></td>
</tr>
<tr>
<td>Upper 3/4 of North Piney Creek – 13,500 ac./up to</td>
<td></td>
</tr>
<tr>
<td>11,000 ac.-ft. shortage</td>
<td></td>
</tr>
<tr>
<td>Exchange:</td>
<td></td>
</tr>
<tr>
<td>Exchange from lower 1/4 to upper 3/4 of North Piney</td>
<td></td>
</tr>
<tr>
<td>Creek as necessary and appropriate</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key Assumptions/Comments</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Coordinate gravity release operation/exchange potential with pumping/canal from mainstem Green River (Alternative 5) to best serve all of North Piney Creek</td>
<td></td>
</tr>
</tbody>
</table>
Alternative 4 – South/Middle Piney Creek Storage

Fish Creek

Alternative 4 (Site 12): Fish Creek Reservoir

South Piney Creek
# Alternative 4 – South/Middle Piney Creek Storage

## Major Elements

<table>
<thead>
<tr>
<th>Major Element</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish Creek Reservoir (SEH-12)</td>
<td>Dam on South Piney Creek and Fish Creek – 80 ft. high</td>
</tr>
<tr>
<td></td>
<td>Reservoir capacity – 46,000 ac.-ft.</td>
</tr>
<tr>
<td></td>
<td>Reservoir surface area – 1.9 sq. mi.</td>
</tr>
<tr>
<td>Middle Piney Creek Delivery Canal</td>
<td>Canal Length – 4.5 mi.</td>
</tr>
<tr>
<td></td>
<td>Canal Capacity – 50 cfs</td>
</tr>
<tr>
<td></td>
<td>Delivery area – middle 1/2 of Middle Piney Creek</td>
</tr>
</tbody>
</table>

## Function/Operation

<table>
<thead>
<tr>
<th>Source(s) of Supply</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Piney Creek</td>
<td>20,000 ac.-ft. physical inflow</td>
</tr>
<tr>
<td>Fish Creek</td>
<td>11,000 ac.-ft. physical inflow</td>
</tr>
<tr>
<td>Middle Piney Creek</td>
<td>12,500 ac.-ft. physical inflow if needed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Irrigated Lands Served</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity release from storage:</td>
<td></td>
</tr>
<tr>
<td>Upper 3/4 of South Piney Creek</td>
<td></td>
</tr>
<tr>
<td>and middle 1/2 of Middle Piney Creek</td>
<td></td>
</tr>
<tr>
<td>Middle Piney Creek – 12,000 ac./up to</td>
<td></td>
</tr>
<tr>
<td>20,000 ac.-ft. shortage</td>
<td></td>
</tr>
<tr>
<td>Exchange:</td>
<td></td>
</tr>
<tr>
<td>Exchange from lower South and/or</td>
<td></td>
</tr>
<tr>
<td>Middle Piney Creek(s) as necessary</td>
<td></td>
</tr>
<tr>
<td>and appropriate</td>
<td></td>
</tr>
</tbody>
</table>

## Key Assumptions/Comments

- Modeling required to check for inflow (supply) limitation on reservoir sizing/operations
- Evaluate need/feasibility to capture available flows (up to 4,400 ac.-ft.) on Middle Piney Creek, including existing Middle Piney Reservoir
- Coordinate gravity release operation/exchange potential with pumping/canal from mainstem Green River (Alternative 5) to best serve all of South and Middle Piney Creeks
Alternative 5 – Pumping to Lower Piney Creek Subbasins from Green River Creek Storage
# Alternative 5 – Pumping to Lower Piney Creek Subbasins from Green River

## Major Elements

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumping Station</td>
<td>Location – Green River (2.4 mi. ESE of Big Piney)</td>
</tr>
<tr>
<td></td>
<td>Pumping station lift – 180 ft.</td>
</tr>
<tr>
<td>Pipeline (from pumping station to delivery canal)</td>
<td>Pipeline length – 4.4 mi.</td>
</tr>
<tr>
<td>Lower Piney Creeks Delivery Canal</td>
<td>Canal length – 8.3 mi.</td>
</tr>
<tr>
<td></td>
<td>Capacity – up to 75 cfs</td>
</tr>
<tr>
<td></td>
<td>Period of operation – irrigation season</td>
</tr>
<tr>
<td></td>
<td>Delivery area – lower portions of North, Middle and South Piney Creeks</td>
</tr>
</tbody>
</table>

## Function/Operation

<table>
<thead>
<tr>
<th>Source(s) of Supply</th>
<th>Green River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated Lands Served</td>
<td>Direct service by pumping: Lower portions of North, Middle and South Piney Creek subbasins – 5,000 ac. Exchange: Pumping to lower subbasins allows exchange of up to 15,000 ac.-ft. to address shortages higher in subbasins</td>
</tr>
</tbody>
</table>

## Key Assumptions/Comments

- Assumed that water is available from mainstem Green River in the amount and at the time needed during the irrigation season
- Coordinate gravity release operation/exchange potential under Alternatives 3 and 4 (North Piney Creek Storage and South/Middle Piney Creek Storage, respectively) with pumping from mainstem Green River to best serve all of Piney Creeks shortages
# Detailed Characterization of Preferred Alternatives

<table>
<thead>
<tr>
<th>Alternative</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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</thead>
<tbody>
<tr>
<td><strong>SIH Site #</strong></td>
<td>SEH-15</td>
<td>15</td>
<td>SEH-10</td>
<td>SEH-12</td>
<td>SEH-36</td>
</tr>
<tr>
<td><strong>Element</strong></td>
<td>South Dam</td>
<td>North Dam</td>
<td>North Horsetooth Creek, South Branch</td>
<td>Horse Creek</td>
<td>North Horsetooth Creek, Rampage Station and Delivery Canal</td>
</tr>
<tr>
<td><strong>Location Information</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>State</strong></td>
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<tr>
<td><strong>County</strong></td>
<td>Larimer</td>
<td>Larimer</td>
<td>Larimer</td>
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<td>Larimer</td>
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<tr>
<td><strong>Location</strong></td>
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<tr>
<td><strong>City</strong></td>
<td>Fort Collins</td>
<td>Fort Collins</td>
<td>Fort Collins</td>
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<tr>
<td><strong>Township</strong></td>
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<tr>
<td><strong>Range</strong></td>
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<tr>
<td><strong>Section</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Basin Characteristics and Hydrology</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Drainage Area (sq. miles)</strong></td>
<td>26</td>
<td>45</td>
<td>48</td>
<td>76</td>
<td>47</td>
</tr>
<tr>
<td><strong>Average Annual Precipitation (in.)</strong></td>
<td>29.5</td>
<td>20.9</td>
<td>30.6</td>
<td>24.6</td>
<td>27.5</td>
</tr>
<tr>
<td><strong>Reservoir Characteristics and Operation</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Capacity ( acre-ft)</strong></td>
<td>42,000</td>
<td>52,000</td>
<td>80,000</td>
<td>81,000</td>
<td>81,000</td>
</tr>
<tr>
<td><strong>Normal Pool Elevation-feet</strong></td>
<td>7,295</td>
<td>7,680</td>
<td>7,791</td>
<td>7,680</td>
<td>7,791</td>
</tr>
<tr>
<td><strong>Normal Maximum Reservoir Elevation (feet)</strong></td>
<td>7,585</td>
<td>7,560</td>
<td>7,560</td>
<td>7,560</td>
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</tr>
<tr>
<td><strong>Surface Area (acres)</strong></td>
<td>1,024</td>
<td>1,024</td>
<td>1,024</td>
<td>1,024</td>
<td>1,024</td>
</tr>
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**Site Environmental Conditions**

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## Detailed Characterization of Preferred Alternatives

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<td>North-Collinswood Creek Pumping/Collecting Canal</td>
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<td>Wilkesley Creek</td>
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<td>122.8 m (399 ft) buffer, leased</td>
<td>122.8 m (399 ft) buffer, leased</td>
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<td>Low (&lt;3 wells per township)</td>
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<td>1 Ranch building, 1 house (depending on reserve size)</td>
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<td>1 Ranch building, 1 house (depending on reserve size)</td>
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### Detailed Characterization of Preferred Alternatives

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</table>

| Access | | | | | |
| Grazing Allotments | | | | | |

Legend:  
- **Green**: Excellent or more than adequate  
- **Yellow**: Favorable or adequate  
- **Orange**: Marginal or unfavorable value  
- **Red**: Very unfavorable value  
- **Pink**: Possible total blow
Next Steps

• Confirm moving ahead with preferred alternatives
• Run operational scenarios/size reservoirs with hydrologic/water rights model
• Seek agency input on environmental issues
• Complete conceptual designs and cost estimates for alternatives
• Perform conceptual-level economic analyses of alternatives
• Prepare draft report, present final results, and submit final report
Questions and Answers
# Upper Green River Westside Storage - Level II Study

**Project Meeting Attendance List**  
**September 30, 2008**

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Phone (Office - O; Home - H)</th>
<th>Email</th>
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<tr>
<td>Jason Mead</td>
<td>WWDO (Project Manager)</td>
<td>307.777.7626 (O)</td>
<td><a href="mailto:jmead@state.wy.us">jmead@state.wy.us</a></td>
<td>6920 Yellowtail Road, Cheyenne, WY 82009</td>
</tr>
<tr>
<td>Doug Yadon</td>
<td>SEH (Project Manager)</td>
<td>970.484.3611, x32 (O)</td>
<td><a href="mailto:dyadon@sehinc.com">dyadon@sehinc.com</a></td>
<td>2637 Midpoint Drive, Suite F, Fort Collins, CO 80525</td>
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<tr>
<td>Rick Parsons</td>
<td>Leonard Rice Engineers</td>
<td>303.455.9589 (O)</td>
<td><a href="mailto:parsons@lrce.com">parsons@lrce.com</a></td>
<td>2000 Clay St., Ste. 300, Denver, CO 80211</td>
</tr>
<tr>
<td>Kelly Close</td>
<td>Leonard Rice Engineers</td>
<td>303.455.9589 (O)</td>
<td><a href="mailto:close@lrce.com">close@lrce.com</a></td>
<td>2000 Clay St., Ste. 300, Denver, CO 80211</td>
</tr>
<tr>
<td>Stan Cooper</td>
<td>Joint Power Bd. UGR</td>
<td>307-872-8006</td>
<td><a href="mailto:scooperwy@gmail.com">scooperwy@gmail.com</a></td>
<td>417 Agate St, Kemmerer, WY 83101</td>
</tr>
<tr>
<td>Ann Strand</td>
<td>GRBA G</td>
<td>362-6944</td>
<td><a href="mailto:anstrand@prodigy.com">anstrand@prodigy.com</a></td>
<td>721 BS, AHS 82901</td>
</tr>
<tr>
<td>Daves Budd</td>
<td></td>
<td>276-3557</td>
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<td>13x650 P.O. Box, WY 83105</td>
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<tr>
<td>Gary Zaborin</td>
<td>Eden Valley Irry</td>
<td>273-8481</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ed Burton</td>
<td>Eden Valley Irry</td>
<td>303-5644</td>
<td></td>
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<tr>
<td>Don Straker</td>
<td>Eden Valley Irry</td>
<td>223-9871</td>
<td></td>
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<tr>
<td>Ron Varle</td>
<td>WWDO</td>
<td>777-7626</td>
<td><a href="mailto:rvarle@state.wy.us">rvarle@state.wy.us</a></td>
<td>6920 Yellowtail Road, Cheyenne, WY 82009</td>
</tr>
<tr>
<td>John A. Zebrun</td>
<td>Joint Power Bd. UGR</td>
<td>307-382-9405</td>
<td><a href="mailto:Jazzbreezy@prim.com">Jazzbreezy@prim.com</a></td>
<td>P.O. Box 746, Rock Springs, WY 82902</td>
</tr>
<tr>
<td>Randy Bolgiano</td>
<td>GRBIPB</td>
<td>307-537-5280</td>
<td><a href="mailto:eastfork@wyoming.com">eastfork@wyoming.com</a></td>
<td>Box 116, Boulder, WY 82923</td>
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<tr>
<td>Don Hartley</td>
<td>UCR 5 PB</td>
<td>389-8028</td>
<td><a href="mailto:hantley@ucr.edu">hantley@ucr.edu</a></td>
<td>P.O. Box 1665, R.S. 82901</td>
</tr>
<tr>
<td>Tom Crank</td>
<td>U.G.R.I.P. A.</td>
<td>307-877-9093</td>
<td><a href="mailto:tcrank@uclark.co.com">tcrank@uclark.co.com</a></td>
<td>P.O. Box 365, Rawlins, WY 82316</td>
</tr>
</tbody>
</table>
NOTICE OF PUBLIC MEETING
Wyoming Water Development Commission is conducting a public meeting on November 14, 2008 at 10:30AM in Pinedale at the Sublette County Courthouse (21 S Tyler St.) in the County Commissioner’s Room. The meeting will include a presentation of the findings of the Upper Green Westside Storage Level II Study and will be open to public comment.
Upper Green River Westside Storage Project
Level II Study
Results Presentation Meeting

Presentation for:
Wyoming Water Development Commission
and
Upper Green River Basin Joint Powers Water Board

by:
Short Elliott Hendrickson Inc.
Leonard Rice Engineers, Inc.

November 14, 2008
Agenda

• Introductions
• Project Status
• Overall Approach
• Methodology
• Study Results
• Next Steps
• Questions and Answers
Overall Approach

- Identify and characterize needs (supplemental irrigation supply)
- Identify and characterize resources (legally and physically available surface water)
- Identify and characterize reservoir storage sites and/or other water supply concepts to link needs to resources
Methodology

• Compilation and Evaluation of Available Data/Information
• Hydrologic/Water Rights Modeling
• Identification of Alternatives
• Screening and Characterization of Alternatives
• Environmental Characterization and Permitting Evaluation
• Conceptual Design and Cost Estimates
• Economic Analyses
UPPER GREEN RIVER WESTSIDE STORAGE LEVEL II STUDY

PREFERRED WATER SUPPLY ALTERNATIVES

PROJECT: AWWD0704.00 DATE: 10/1/06 FIGURE: 4.5-1
<table>
<thead>
<tr>
<th>Alternative</th>
<th>Infrastructure Components</th>
<th>Tributary Basin</th>
<th>Acres</th>
<th>Baseline Short (ac-ft)</th>
<th>Shortage Reduction (ac-ft)</th>
<th>% Reduced</th>
<th>% Total Demand Met</th>
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<td>Alternative 1</td>
<td>Haines Flat</td>
<td>Horse Creek</td>
<td>14,870</td>
<td>8,955</td>
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<td>Reservoir</td>
<td>Cottonwood Creek</td>
<td>20,225</td>
<td>28,429</td>
<td>16,801</td>
<td>59%</td>
<td>85%</td>
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<tr>
<td></td>
<td>Total</td>
<td></td>
<td>35,095</td>
<td>37,384</td>
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<td>Mickelson Res.</td>
<td>Cottonwood Creek</td>
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<td>28,429</td>
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<td>73%</td>
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<td>Alternative 3</td>
<td>Whiskey Ck Res.</td>
<td>North Piney Creek</td>
<td>17,913</td>
<td>23,814</td>
<td>11,076</td>
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<td>80%</td>
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<td>Fish Creek</td>
<td>South Piney Creek</td>
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<td>81%</td>
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<td>Middle Piney Creek</td>
<td>8,392</td>
<td>15,323</td>
<td>6,687</td>
<td>44%</td>
<td>72%</td>
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<td></td>
<td>Total</td>
<td></td>
<td>20,029</td>
<td>26,006</td>
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<td>Alternative 5</td>
<td>Green River</td>
<td>North Piney Creek</td>
<td>7,135</td>
<td>7,116</td>
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<td>97%</td>
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<td>Pump</td>
<td>Middle Piney Creek</td>
<td>8,392</td>
<td>15,323</td>
<td>5,436</td>
<td>35%</td>
<td>68%</td>
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<td></td>
<td>South Piney Creek</td>
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<td>5,443</td>
<td>3,309</td>
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<td></td>
<td>Total</td>
<td></td>
<td>20,970</td>
<td>25,748</td>
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<td>53%</td>
<td>91%</td>
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<td>Alternative 6</td>
<td>Combined</td>
<td>Horse Creek</td>
<td>14,870</td>
<td>8,955</td>
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<td>93%</td>
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<td>Cottonwood Creek</td>
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<td>72%</td>
<td>89%</td>
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<td>17,913</td>
<td>23,814</td>
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<td>83%</td>
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<td>8,392</td>
<td>15,323</td>
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<td>76%</td>
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<td></td>
<td>South Piney Creek</td>
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<td>10,081</td>
<td>10,683</td>
<td>4,715</td>
<td>44%</td>
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<td>Total</td>
<td></td>
<td>71,481</td>
<td>87,204</td>
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<td>58%</td>
<td>87%</td>
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<td>Alternative</td>
<td>Storage Capacity (ac-ft)</td>
<td>Construction Cost Total</td>
<td>Total Project Cost</td>
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<td>15,000</td>
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<td>40,136,000</td>
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<td>49,058,967</td>
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<td>20,000</td>
<td>36,424,000</td>
<td>58,855,000</td>
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<td>15,327,000</td>
<td>22,513,000</td>
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<td>6</td>
<td>95,000</td>
<td>160,677,000</td>
<td>256,020,000</td>
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### Table 11.2-1
Summary of Maximum Potential Benefits of Project Alternatives

<table>
<thead>
<tr>
<th>Alternative Number</th>
<th>Name</th>
<th>Reservoir Capacity (ac-ft)</th>
<th>&quot;Average Yearly&quot; Irrigation Shortage Satisfied (acre-ft)</th>
<th>Assumed Annual Reservoir Yield - Normal Year (ac-ft)</th>
<th>Maximum Potential Annual Benefits From Supplemental Irrigation Only ($ per year)</th>
<th>Maximum Potential Present Value of All Direct Irrigation Benefits ($)</th>
<th>Maximum Potential Value of Direct and Indirect Irrigation Benefits ($)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Horse Creek/Cottonwood Creek Storage</td>
<td>40000</td>
<td>21,013</td>
<td>21,013</td>
<td>539,400</td>
<td>11,587,000</td>
<td>38,932,000</td>
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<tr>
<td>2</td>
<td>South Cottonwood Creek Storage</td>
<td>15000</td>
<td>7,956</td>
<td>7,956</td>
<td>204,230</td>
<td>4,387,000</td>
<td>14,740,000</td>
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<tr>
<td>3</td>
<td>North Piney Creek Storge</td>
<td>20000</td>
<td>11,101</td>
<td>11,101</td>
<td>284,960</td>
<td>6,122,000</td>
<td>20,570,000</td>
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<tr>
<td>4</td>
<td>South/Middle Piney Creek Storage</td>
<td>20000</td>
<td>9,770</td>
<td>9,770</td>
<td>250,800</td>
<td>5,388,000</td>
<td>18,104,000</td>
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<td>5</td>
<td>Pumping to Lower Piney Creek Subbasins from Green River</td>
<td>N/A</td>
<td>13,735</td>
<td>13,735</td>
<td>352,580</td>
<td>7,574,000</td>
<td>25,449,000</td>
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<td>Combination of Alternatives 1-5</td>
<td>95000</td>
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<td>1,291,250</td>
<td>27,739,000</td>
<td>93,203,000</td>
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Note 1: Analysis assumes no new area placed under irrigation; interest rate of 4.0% assumed, for fifty years
# Table 11.3-2A

Ability to Pay Debt Service (67% Grant) and OM&R

<table>
<thead>
<tr>
<th>Alternative Number</th>
<th>Site</th>
<th>Level III Project Cost ($ Millions)</th>
<th>Sponsor's Share of Project Costs ($ Millions)</th>
<th>Sponsor's Annual Debt Service Payment ($)</th>
<th>Sponsor's Annual OM&amp;R Cost ($)</th>
<th>Sponsor's Total Annual Cost ($)</th>
<th>Sponsor's Maximum Ability to Pay ($)</th>
<th>Sponsor's Percentage Ability to Pay (%)</th>
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<tbody>
<tr>
<td>1</td>
<td>Horse Creek/Cottonwood Creek Storm</td>
<td>77.7</td>
<td>25.84</td>
<td>1,195,300</td>
<td>165,000</td>
<td>1,360,300</td>
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<td>2</td>
<td>South Cottonwood Creek Storage</td>
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<td>11.87</td>
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<td>73,000</td>
<td>625,400</td>
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<td>North Pinney Creek Storage</td>
<td>44.1</td>
<td>14.56</td>
<td>678,000</td>
<td>92,000</td>
<td>770,000</td>
<td>127,500</td>
<td>20.1</td>
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<tr>
<td>4</td>
<td>South/Middle Pinney Creek Storage</td>
<td>50.3</td>
<td>14.56</td>
<td>722,400</td>
<td>90,000</td>
<td>812,400</td>
<td>125,400</td>
<td>15.2</td>
</tr>
<tr>
<td>5</td>
<td>Pumping to Lower Pinney Creek Subs</td>
<td>50.3</td>
<td>18.59</td>
<td>722,400</td>
<td>90,000</td>
<td>812,400</td>
<td>125,400</td>
<td>15.2</td>
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# Table 11.3-2B

Ability to Pay Debt Service (75% Grant) and OM&R

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<th>Alternative Number</th>
<th>Site</th>
<th>Level III Project Cost ($ Millions)</th>
<th>Sponsor's Share of Project Costs ($ Millions)</th>
<th>Sponsor's Annual Debt Service Payment ($)</th>
<th>Sponsor's Annual OM&amp;R Cost ($)</th>
<th>Sponsor's Total Annual Cost ($)</th>
<th>Sponsor's Maximum Ability to Pay ($)</th>
<th>Sponsor's Percentage Ability to Pay (%)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Horse Creek/Cottonwood Creek Storm</td>
<td>77.7</td>
<td>19.42</td>
<td>904,000</td>
<td>165,000</td>
<td>1,069,000</td>
<td>209,700</td>
<td>25.5</td>
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<tr>
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<td>South Cottonwood Creek Storage</td>
<td>30.0</td>
<td>9.90</td>
<td>418,500</td>
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<td>471,500</td>
<td>204,230</td>
<td>43.3</td>
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<tr>
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<td>North Pinney Creek Storm</td>
<td>44.1</td>
<td>11.03</td>
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<td>63,000</td>
<td>576,600</td>
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<tr>
<td>4</td>
<td>South/Middle Pinney Creek Storage</td>
<td>50.3</td>
<td>12.57</td>
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<td>79,000</td>
<td>744,400</td>
<td>125,400</td>
<td>15.2</td>
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<tr>
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<td>Pumping to Lower Pinney Creek Subs</td>
<td>50.3</td>
<td>14.56</td>
<td>722,400</td>
<td>90,000</td>
<td>812,400</td>
<td>125,400</td>
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# Table 11.3-2C

Ability to Pay Debt Service (90% Grant) and OM&R

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<th>Level III Project Cost ($ Millions)</th>
<th>Sponsor's Share of Project Costs ($ Millions)</th>
<th>Sponsor's Annual Debt Service Payment ($)</th>
<th>Sponsor's Annual OM&amp;R Cost ($)</th>
<th>Sponsor's Total Annual Cost ($)</th>
<th>Sponsor's Maximum Ability to Pay ($)</th>
<th>Sponsor's Percentage Ability to Pay (%)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Horse Creek/Cottonwood Creek Storm</td>
<td>77.7</td>
<td>19.42</td>
<td>904,000</td>
<td>165,000</td>
<td>1,069,000</td>
<td>209,700</td>
<td>25.5</td>
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<tr>
<td>2</td>
<td>South Cottonwood Creek Storage</td>
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<td>9.90</td>
<td>418,500</td>
<td>53,000</td>
<td>471,500</td>
<td>204,230</td>
<td>43.3</td>
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<tr>
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<td>North Pinney Creek Storm</td>
<td>44.1</td>
<td>11.03</td>
<td>513,600</td>
<td>63,000</td>
<td>576,600</td>
<td>127,500</td>
<td>20.1</td>
</tr>
<tr>
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<td>12.57</td>
<td>665,400</td>
<td>79,000</td>
<td>744,400</td>
<td>125,400</td>
<td>15.2</td>
</tr>
<tr>
<td>5</td>
<td>Pumping to Lower Pinney Creek Subs</td>
<td>50.3</td>
<td>14.56</td>
<td>722,400</td>
<td>90,000</td>
<td>812,400</td>
<td>125,400</td>
<td>15.2</td>
</tr>
<tr>
<td>6</td>
<td>Combination of Alternatives 1-5</td>
<td>228.0</td>
<td>57.00</td>
<td>2,053,200</td>
<td>245,000</td>
<td>2,298,200</td>
<td>645,000</td>
<td>20.3</td>
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### Table 11.3-3A
Annual Debt Service Costs - Per Acre Served and Per Acre-Foot Yield

<table>
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<th>Site Number</th>
<th>Site Name</th>
<th>Irrigated Lands Served(^1) (ac)</th>
<th>Annual Cost Per Acre Served</th>
<th>Annual Cost Per Acre-Foot Yield</th>
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<tr>
<td>1</td>
<td>Horse Creek/Cottonwood Creek Storage</td>
<td>35,095</td>
<td>$34</td>
<td>$26</td>
</tr>
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<td>3</td>
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### Table 11.3-3B
Annual OM&R Costs - Per Acre Served and Per Acre-Foot Yield

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<th>Annual Cost Per Acre Served</th>
<th>Annual Cost Per Acre-Foot Yield</th>
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<td>37,942</td>
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<tr>
<td>6</td>
<td>Combination of Alternatives 1 &amp; 5</td>
<td>73,037</td>
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### Table 11.3-3C
Annual Debt Service & OM&R Costs - Per Acre Served and Per Acre-Foot Yield

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<tr>
<th>Site Number</th>
<th>Site Name</th>
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<th>Debt &amp; OM&amp;R Cost Per Acre Served</th>
<th>Debt &amp; OM&amp;R Cost/Acre-Foot Yield</th>
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<td>5</td>
<td>Pumping to Lower Pliny Creek Subbasins from Green River</td>
<td>37,942</td>
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<tr>
<td>6</td>
<td>Combination of Alternatives 1 &amp; 5</td>
<td>73,037</td>
<td>$50,382</td>
<td>$64</td>
</tr>
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</table>

\(^1\) Irrigated lands served is the sum of all existing irrigated lands in the basin(s) which would be supported by the project.

\(^2\) Assumed yield is the average shortage satisfied as presented in Table 11.2-1.
Key Conclusions

• Alternatives 1 through 5 and the combined Alternative 6 appear *technically feasible* and achieve *significant reduction of* existing irrigation *shortages*

• Environmental *permitting* of all alternatives will be *difficult at best*; mitigation of loss of moose critical riparian and birthing habitat may be infeasible

• *Costs* for all alternatives are *very high relative to* direct irrigation and related indirect *benefits*

• *Smaller, less costly off-stream sites* may be feasible, but would provide *less shortage reduction* and require relatively more supply and/or delivery conveyance (with associated *permitting challenges*)
Key Recommendations

• Consider additional *operational studies* to assess relationship of *shortage reduction* with *decreased* storage capacity and *project cost*

• Evaluate *potential for* and economic *value of* developing *secondary (multiple) benefits* for storage alternatives

• Further analyze *use of existing Green River Supply Canal* versus pumping from Green River to supply lower Piney Creeks subbasins
Next Steps

• Receive comments on Draft Report
• Incorporate responses to comments in Final Report
• Prepare and submit Final Report, Executive Summary and Project Notebook
Questions and Answers
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<th>Name</th>
<th>Affiliation</th>
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<tr>
<td>Mike Besson</td>
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<td>307.777.7626 (O)</td>
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<tr>
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</tr>
<tr>
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<td>cooper窗户@gmail.com</td>
<td>412 Agate St, Kemmerer, 83108</td>
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<td>Ann Strand</td>
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<td><a href="mailto:ann.strand@johnson.com">ann.strand@johnson.com</a></td>
<td>121 B, Aks, 82901</td>
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<td>Dan Bracken</td>
<td>UCCO</td>
<td>276-3557</td>
<td></td>
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<tr>
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<td>P.O. Box 1239 GR 82935</td>
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<tr>
<td>Randy Belgard</td>
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<td>Box 116 Boulder 82923</td>
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## Appendix B
### GIS Inventory

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Appendix C

Seismotectonics
Basic Seismological Characterization
for
Sublette County, Wyoming

by

James C. Case, Rachel N. Toner, and Robert Kirkwood
Wyoming State Geological Survey
September 2002

BACKGROUND

Seismological characterizations of an area can range from an analysis of historic seismicity to a long-term probabilistic seismic hazard assessment. A complete characterization usually includes a summary of historic seismicity, an analysis of the Seismic Zone Map of the Uniform Building Code, deterministic analyses on active faults, “floating earthquake” analyses, and short- or long-term probabilistic seismic hazard analyses.

Presented below, for Sublette County, Wyoming, are an analysis of historic seismicity, an analysis of the Uniform Building Code, deterministic analyses of nearby active faults, an analysis of the maximum credible “floating earthquake”, and current short- and long-term probabilistic seismic hazard analyses.

Historic Seismicity in Sublette County

The enclosed map of “Earthquake Epicenters and Suspected Active Faults with Surficial Expression in Wyoming” (Case and others, 1997) shows the historic distribution of earthquakes in Wyoming. Eighteen magnitude 2.5 or intensity III and greater earthquakes have been recorded in Sublette County.

On October 24, 1936, two earthquakes occurred in western Wyoming. The U.S.G.S. National Earthquake Information Center reported these two intensity III earthquakes as occurring in Sublette County, approximately 3 miles southwest of Cora. The original reference and description of these events, however, indicates that these earthquakes originated in the Star Valley of Lincoln County (Neumann, 1936).

In June of 1945, two earthquakes occurred in southwestern Sublette County. These intensity III earthquakes were recorded on June 7, 1945, approximately 4 miles northwest of Calpet, and on June 23, 1945, approximately 3 miles northeast of Calpet. Although people reported feeling the
earthquakes, no damage resulted from them (Casper Tribune-Herald, June, 1945). The earthquakes did cause several camp buildings to creak.

On February 21, 1951, the U.S.G.S. National Earthquake Information Center reported that an intensity III earthquake occurred in Sublette County. A check of the original reference and description of this event, however, suggests a location error, as only three people in Rock Springs felt the earthquake (Murphy and Cloud, 1951). The epicenter of this earthquake will therefore be tentatively located in northwestern Sweetwater County.

No other earthquakes were recorded in the county until the 1960s. A magnitude 4.3, intensity V earthquake occurred in southeastern Sublette County on February 25, 1963, approximately 15 miles north-northeast of Big Sandy. The earthquake was felt for over a minute in Atlantic City, and for approximately six seconds in the Lander and Hudson areas (Casper Star-Tribune, February 26, 1963). Windows, doors, and dishes were rattled in Fort Washakie as a result of the earthquake (von Hake and Cloud, 1965). Four more earthquakes were detected in Sublette County in the 1960s, but no one reported feeling the earthquakes and no damage was reported (U.S.G.S. National Earthquake Information Center). On July 31, 1965, a magnitude 2.8 earthquake occurred in western Sublette County, approximately 9 miles northwest of Calpet. A magnitude 2.7 earthquake occurred on August 18, 1967, approximately 7 miles northwest of Calpet. On December 18, 1967, an earthquake of no specific magnitude or intensity was recorded in northeastern Sublette County, which was centered approximately 34 miles northeast of Bondurant. On June 6, 1969, a magnitude 2.5 earthquake was recorded in the southern portion of the county, approximately 5 miles west of Calpet. Again, no one reported feeling these 1965-1969 earthquakes in Sublette County (U.S.G.S. National Earthquake Information Center).

In December 1971, two earthquakes occurred in southwestern Sublette County. On December 2, 1971, a magnitude 4.1 earthquake was detected approximately 15 miles southwest of Big Piney. A day later, on December 3, 1971, a magnitude 4.2 earthquake was recorded approximately 12 miles southwest of Big Piney. No one reported feeling either event (U.S.G.S. National Earthquake Information Center). A magnitude 3.3 earthquake was detected in the same area on February 6, 1978. No one felt this earthquake, which was centered approximately 13 miles southwest of Big Piney (U.S.G.S. National Earthquake Information Center).

Only one earthquake was recorded in the county in the 1980s. On October 21, 1988, a magnitude 3.6 earthquake occurred near the Teton County – Sublette County border. The epicenter of this earthquake was located approximately 4.5 miles north-northeast of Bondurant. No one felt this earthquake (U.S.G.S. National Earthquake Information Center).

Three earthquakes occurred in Sublette County in the 1990s. A magnitude 2.9 earthquake was reported on September 4, 1993, in southern Sublette County. No one reported feeling this earthquake that was centered approximately 2 miles north-northeast of Calpet. On October 21, 1996, a magnitude 3.7 earthquake was recorded approximately 13 miles southeast of Big Sandy. No one felt this earthquake and no damage was reported (U.S.G.S. National Earthquake Information Center). On November 16, 1999, a magnitude 3.1 event occurred on the Teton County – Sublette County border. Again, no one felt this earthquake that was centered
approximately 9 miles north-northeast of Bondurant. (U.S.G.S. National Earthquake Information Center).

On June 27, 2000, the University of Utah Seismograph Stations detected a magnitude 2.7 earthquake in southwestern Sublette County, approximately 8 miles north-northeast of Calpet. No one reported feeling this event (U.S.G.S. National Earthquake Information Center).

Most recently, on September 27, 2001, an earthquake was recorded near the Fremont County-Teton County-Sublette County borders. Area residents reported feeling this magnitude 4.3 event that was centered approximately 25 miles northeast of Bondurant (U.S.G.S. National Earthquake Information Center).

Regional Historic Seismicity

Numerous earthquakes have also occurred near Sublette County. The first took place on December 6, 1921, in northeastern Lincoln County. No damage was reported from this intensity III earthquake that was located approximately 26 miles southwest of Merna. On December 12, 1923, an intensity V earthquake was detected in Fremont County, approximately 37 miles east-southeast of Big Sandy (Humphreys, 1924). No significant damage was reported. This area experienced another non-damaging, intensity III earthquake on October 30, 1925.

On November 23, 1934, an intensity V earthquake was reported in Fremont County, approximately 37 miles northeast of Big Sandy. Residents in a 10-mile radius around Lander reported that dishes were thrown from cupboards and pictures fell from walls. Buildings in two business blocks were cracked, and the brick chimney of the Fremont County Courthouse was moved two inches away from the building. The earthquake was felt as far away as Rock Springs and Green River (Casper Tribune-Herald, November 25, 1934).

On August 22, 1959, an intensity IV earthquake was detected in western Fremont County, approximately 37 miles east-southeast of Big Sandy. No damage was associated with this earthquake.

Several earthquakes occurred near Sublette County in the 1960s. On May 7, 1964, an earthquake of no specific magnitude or intensity was detected in southeastern Teton County. No one felt this event, which was centered approximately 6 miles north-northeast of Bondurant. Another earthquake of no specific magnitude or intensity occurred in eastern Lincoln County on July 10, 1964, approximately 19 miles west-southwest of Merna. No damage was reported. A non-damaging earthquake occurred in eastern Lincoln County on September 17, 1964. The epicenter of the magnitude 4.0 event was located approximately 26 miles southwest of Merna. On May 20, 1965, the U.S.G.S. National Earthquake Information Center recorded another earthquake of no specific magnitude or intensity in Lincoln County. This event was centered approximately 13 miles southwest of Bondurant. A magnitude 3.3 earthquake occurred in Lincoln County on August 22, 1965, approximately 18 miles west of Calpet. No one reported feeling the earthquake (U.S.G.S. National Earthquake Information Center). A non-damaging, magnitude 3.9 earthquake occurred in Lincoln County on December 24, 1965. This earthquake’s epicenter was located...
approximately 21 miles southwest of Merna. On July 12, 1966, an earthquake occurred approximately 22 miles west-southwest of Calpet. No damage was reported from this magnitude 2.5 earthquake. On March 10, 1967, a magnitude 3.7 earthquake was recorded in Lincoln County approximately 16 miles south of Calpet. Residents in the area reported feeling this event, but no damage was reported (U.S.G.S. National Earthquake Information Center). A magnitude 2.5 earthquake was detected in Lincoln County on July 30, 1968. No damage was reported from this event that was centered approximately 18 miles west-southwest of Calpet. On August 27, 1969, a magnitude 4.2, intensity III earthquake was reported in Lincoln County, approximately 24 miles west-southwest of Merna. Residents of Auburn reported feeling this earthquake, but no damage was caused. On the same day, a magnitude 3.9 earthquake was detected roughly 21 miles northwest of Merna. No one reported feeling this event (U.S.G.S. National Earthquake Information Center). A second 3.9 earthquake occurred a few days later on August 30, 1969. This event was located in northeastern Lincoln County, approximately 16 miles southwest of Bondurant. Again, no one reported feeling this event (U.S.G.S. National Earthquake Information Center).

Seven earthquakes occurred in the region in the 1970s. The largest earthquake recorded in northern Lincoln County in the 1970s occurred on September 21, 1970, approximately 17 miles west-southwest of Bondurant. The magnitude 4.4 earthquake, which occurred near the Elbow Campground in the Snake river Canyon, was primarily felt in Teton and Sublette Counties. The Jackson Hole Guide (September 24, 1970) reported that residents from Jackson through the Hoback Canyon to Bondurant felt the earthquake. Some residents in Jackson thought that the event was a sonic boom. At Camp Davis, a resident reported a figurine knocked off a television set and a “vibrating” staircase. Eleven miles south of Jackson, a resident reported rattling windows and a shaking bed. Near Bondurant, a resident reported that windows rattled and her whole house shook. This event was followed by a magnitude 3.1 earthquake on December 27, 1975. Its epicenter was located in the northern part of Lincoln County, approximately 17 miles west-southwest of Bondurant. No damage was reported. In March of 1976, a series of earthquakes occurred in southern Teton County. On March 14, 1976, a magnitude 3.7 earthquake was recorded approximately 16 miles west-northwest of Bondurant. This event was followed by a magnitude 3.9 earthquake on March 17, 1976. This earthquake was centered approximately 13 miles west-northwest of Bondurant. On March 21, 1976, a magnitude 2.9 earthquake and a magnitude 2.8 earthquake occurred approximately 14 miles west-northwest of Bondurant. No one reported feeling any of the March 1976 earthquakes, and no damage was associated with them. On July 3, 1979, a magnitude 3.2, intensity IV earthquake occurred approximately 19 miles northwest of Bondurant. Jackson residents reported that dishes rattled and that pictures on walls moved. Horses at the Teton County Fairgrounds were also noticeably disturbed (Casper Star-Tribune, July 4, 1979).

The first regional earthquake that was felt in the 1980s occurred on May 6, 1981. The epicenter of the magnitude 3.7, intensity IV earthquake was located in Teton County, approximately 18 miles northwest of Bondurant. A local disc jockey reported that “window frames changed position briefly, and the turntable and the seat of my pants came up and down at the same time”. A local secretary said her desk moved during the event (Casper Star-Tribune, May 7, 1981). A magnitude 3.2, intensity IV earthquake occurred in Fremont County on August 31, 1982. No
significant damage was reported from this earthquake, which was centered approximately 34 miles east-northeast of Big Sandy (Case, 1994). The next earthquake to occur in Teton County took place on December 20, 1983, approximately 18 miles west-northwest of Bondurant. This magnitude 4.5, intensity IV earthquake was felt from Jackson to the Palisades Reservoir in Idaho. In Jackson, there were reports of Christmas trees falling over and dishes breaking (Laramie Daily Boomerang, December 21, 1983). A number of aftershocks followed the December 20, 1983 event, the largest of which was a magnitude 3.4 earthquake that occurred on December 22, 1983. On January 5, 1984, a magnitude 3.0 aftershock occurred in the same area. A magnitude 2.8 earthquake was detected on March 23, 1984, approximately 20 miles northwest of Bondurant. Residents near Hoback Junction reported feeling it as an intensity II event. On November 3, 1984, a magnitude 5.1, intensity VI earthquake was detected in Fremont County, approximately 35 miles southeast of Big Sandy. The earthquake was felt in Lander, Dubois, Atlantic City, and Casper. Residents in Lander and Atlantic City reported cracked walls, foundations, and windows (Casper Star-Tribune, November 4, 1984). This event was one of the largest earthquakes to occur in the southwestern quarter of the state. A magnitude 4.8 earthquake occurred on August 21, 1985, approximately 18 miles west-southwest of Bondurant. It was felt as an intensity V event at Alpine, and intensity IV event at Wilson in Teton County, an intensity IV event at Lander in Fremont County, and was lightly felt in Jackson. No major damage was reported, although the Teton County Sheriff’s Department reported that the earthquake caused a motorist to drive off the highway in the Snake River Canyon (Casper Star-Tribune, August 22, 1985). A second earthquake, a magnitude 4.3 event, occurred on August 22, 1985, approximately 21 miles southwest of Bondurant. It was felt as an intensity IV event in Alpine, with no significant damage reported (Laramie Daily boomerang, August 23, 1985). Magnitude 3.4 and magnitude 3.2 earthquakes also occurred in Lincoln County on August 22, 1985. No one reported feeling these earthquakes, which were centered approximately 24 miles southwest of Bondurant. On August 30, 1985, a magnitude 4.3, intensity V earthquake was recorded approximately 24 miles west-southwest of Bondurant. It was felt as an intensity V event at Alpine, and was also felt in Jackson. A magnitude 4.6, intensity V earthquake occurred on September 6, 1985, approximately fifteen miles west-southwest of Bondurant. It was felt as an intensity V event at Alpine, and as an intensity IV event in Wilson. An earthquake-induced landslide temporarily closed a portion of U.S. Highway 89 in the Snake River Canyon (Casper Star-Tribune, September 8, 1985). A second earthquake occurred on September 6, 1985 in the same area. No one reported feeling this magnitude 3.6 earthquake. Two earthquakes occurred in Lincoln County on November 17, 1986, approximately 19 miles west-southwest of Bondurant. The first was a magnitude 3.9 event, which was felt by residents in the area. The second, a magnitude 3.7 earthquake, was not felt. Two non-damaging magnitude 2.9 earthquakes occurred in Sweetwater County on December 4, 1986. No one reported feeling these earthquakes that were centered approximately 27 and 31 miles west-southwest of Calpet (Stover and Brewer, 1994). No major earthquakes occurred in the region until 1988 and 1989, when several were recorded in southeastern Teton County. On August 24, 1988, two earthquakes occurred approximately 24 miles northwest of Bondurant. Jackson area residents reported feeling the first earthquake, which was a magnitude 2.8 event, but no one reported feeling the second, magnitude 2.4 earthquake. The U.S.G.S. National Earthquake Information Center detected two earthquakes in southern Teton County on October 21, 1988. The first, a magnitude 3.6 earthquake, was centered near the Teton County-Sublette County border, approximately 4.5 miles north-northeast of Bondurant. The second earthquake...
was a magnitude 3.5 event, located approximately 10 miles north-northeast of Bondurant. Neither earthquake was felt. A magnitude 3.6 earthquake on December 4, 1988, was centered approximately 17 miles north-northeast of Bondurant. No one felt this earthquake. On May 12, 1989, a magnitude 2.6 earthquake occurred in southeastern Teton County, approximately 24 miles northwest of Bondurant. No one reported feeling this earthquake. It was followed closely by a magnitude 3.1 earthquake approximately 20 miles northwest of Bondurant. The U.S.G.S. National Earthquake Information Center reported that the earthquake was felt as an intensity III event in Jackson, but no damage occurred. On June 24, 1989, two earthquakes were felt strongly at Jackson. They both were centered approximately 26 miles northwest of Bondurant. The first earthquake, which occurred at 3:25 a.m., had a magnitude of 3.8. The second earthquake, which occurred one hour later, had a magnitude of 3.7. People reported windows rattling, but no damage was associated with these earthquakes (Casper Star-Tribune, June 25, 1989). Two more earthquakes were detected by the U.S.G.S. National Earthquake Information Center later that same day in the same area. Both were magnitude 3.0, but neither was felt.

Many earthquakes also occurred near Sublette County in the 1990s. The first was recorded in southeastern Teton County on March 4, 1990. This magnitude 4.1 earthquake was centered approximately 20 miles northwest of Bondurant. Jackson area residents felt the earthquake as an intensity IV event, but no damage was reported (Casper Star-Tribune, March 6, 1990). On April 9, 1990, a magnitude 3.5 earthquake was detected in northeastern Lincoln County. The earthquake, which was located approximately 11 miles southwest of Bondurant, did not cause any damage. On November 17, 1990, a magnitude 3.1 earthquake also occurred in northeastern Lincoln County, roughly 17 miles southwest of Bondurant. No one reported feeling this event. Between 1991 and 1999, several earthquakes occurred in southeastern Teton County. They ranged in magnitude between 2.8 and 4.7. Only the two that were felt are discussed below. A non-damaging earthquake occurred in western Fremont County on January 31, 1992, approximately 39 miles northeast of Big Sandy (Case, 1994). Area residents reported feeling this magnitude 2.8 event (U.S.G.S. National Earthquake Information Center). A magnitude 3.1 earthquake was also recorded in northwestern Fremont County, on August 22, 1993, approximately 36 miles northeast of Bondurant. No one felt this earthquake. The next regional earthquake that was felt occurred on December 28, 1993, in southeastern Teton County. This magnitude 4.7 earthquake, intensity V earthquake was centered approximately 23 miles northeast of Bondurant. The earthquake was felt in Jackson, Dubois, Hudson, Lander, and Rock Springs. Most reports indicated that the earthquake felt like a heavy truck passing by. A ranch near the epicenter reported swinging lights, but no damage. Another magnitude 4.7 earthquake occurred in southeastern Teton County on June 20, 1998, approximately 13 miles west-northwest of Bondurant. No damage was reported from the magnitude 4.7 event, but it was distinctly felt at Hoback Junction and was felt by many residents of Jackson. Approximately 14 aftershocks of magnitude 2.0 and greater occurred in the same area through June 22, 1998. A series of seven earthquakes were detected on January 30, 1999 through February 1, 1999, in northern Lincoln County. These events, located approximately 17-20 miles west-southwest of Bondurant, ranged from magnitude 2.8 to magnitude 3.9. On June 18, 1999, a magnitude 3.5 earthquake occurred in the same area. No one reported feeling these 1999 earthquakes in Lincoln County.
On January 8, 2000, a magnitude 3.5 earthquake was recorded in northern Lincoln County, approximately 13 miles south-southwest of Calpet. Two earthquakes also occurred in Lincoln County on April 20, 2000. These magnitude 2.7 and magnitude 2.3 events were centered approximately 14 miles west of Bondurant. A magnitude 3.9 earthquake occurred in southeastern Teton County on October 3, 2000, approximately 25 miles north of Bondurant. The last regional earthquake to occur in 2000 took place in Lincoln County on December 1, 2000. The epicenter of this magnitude 3.2 event was located approximately 17 miles west-southwest of Bondurant. None of these 2000 earthquakes were felt and no damage was reported.

No major regional earthquakes were recorded until January 2, 2002, when a magnitude 3.1 earthquake occurred in southern Teton County. No one reported feeling the event, which was located approximately 20 miles north-northeast of Bondurant. On January 29, 2002, an earthquake was also detected in Teton County, approximately 27 miles north-northwest of Bondurant. According to the U.S.G.S. National Earthquake Information Center, Jackson area residents reported feeling this magnitude 3.7 earthquake. In March 2002, a series of earthquakes were recorded in northern Lincoln County near Alpine. A magnitude 3.4 earthquake occurred on March 24, 2002, approximately 19 miles west-southwest of Bondurant. This event was followed by magnitude 2.8 and magnitude 3.1 events on March 25, 2002, in the same area. A week later, on March 31, 2002, a magnitude 3.5 earthquake was reported approximately 15 miles west-southwest of Bondurant. No one felt the March earthquakes and no damage was reported. On May 8, 2002, the U.S. Bureau of Reclamation recorded three earthquakes in the same area as the March events. Again, no one felt these magnitude 3.3, 2.7, and 3.2 earthquakes. Three earthquakes also occurred in the Alpine area in October 2002. On October 21, 2002, a magnitude 3.2 earthquake was detected approximately 27 miles west of Bondurant. This event was followed closely by a magnitude 4.4 earthquake centered approximately 21 miles west-southwest of Bondurant. Residents in the area reported feeling both of these earthquakes. No damage was reported from either event. On October 23, 2002, a magnitude 3.4 earthquake was reported approximately 28 miles west of Bondurant. No one reported feeling this earthquake. The most recent event to occur in the region took place in Teton County on November 9, 2002. This magnitude 3.0 earthquake was centered approximately 23 miles north-northeast of Bondurant. No one felt this event.

**Uniform Building Code**

The Uniform Building Code (UBC) is a document prepared by the International Conference of Building Officials. Its stated intent is to “provide minimum standards to safeguard life or limb, health, property, and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of all buildings and structures within this jurisdiction and certain equipment specifically regulated herein.”

The UBC contains information and guidance on designing buildings and structures to withstand seismic events. With safety in mind, the UBC provides Seismic Zone Maps to help identify which design factors are critical to specific areas of the country. In addition, depending upon the type of
building, there is also an “importance factor”. The “importance factor” can, in effect, raise the standards that are applied to a building.

The current UBC Seismic Zone Map (Figure 1) (1997) has five seismic zones, ranging from Zone 0 to Zone 4, as can be seen on the enclosed map. The seismic zones are in part defined by the probability of having a certain level of ground shaking (horizontal acceleration) in 50 years. The criteria used for defining boundaries on the Seismic Zone Map were established by the Seismology Committee of the Structural Engineers Association of California (Building Standards, September-October, 1986). The criteria they developed are as follows:

<table>
<thead>
<tr>
<th>Zone</th>
<th>Effective Peak Acceleration, % gravity (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>30% and greater</td>
</tr>
<tr>
<td>3</td>
<td>20% to less than 30%</td>
</tr>
<tr>
<td>2</td>
<td>10% to less than 20%</td>
</tr>
<tr>
<td>1</td>
<td>5% to less than 10%</td>
</tr>
<tr>
<td>0</td>
<td>less than 5%</td>
</tr>
</tbody>
</table>

The committee assumed that there was a 90% probability that the above values would not be exceeded in 50 years, or a 100% probability that the values would be exceeded in 475 to 500 years.

Sublette County is in Seismic Zones 1, 2, and 3 of the UBC. Since effective peak accelerations (90% chance of non-exceedance in 50 years) can range from 5%g-30%g in these zones, and there has been some significant historic seismicity in the county, it may be reasonable to assume that an average peak acceleration of 17%g could be applied to the design of a non-critical facility located in the county if only the UBC were used. Such acceleration, however, is significantly less than would be suggested through newer building codes.

Recently, the UBC has been replaced by the International Building Code (IBC). The IBC is based upon probabilistic analyses, which are described in a following section. Sublette County still uses the UBC, however, as do most Wyoming counties as of January 2003.

**Deterministic Analysis of Regional Active Faults with a Surficial Expression**

Deterministic analyses for twelve active fault systems are included for Sublette County (see Table 1 and Figure 2). The South Granite Mountain fault system is composed of several northwest-southeast trending fault segments in southeastern Fremont County and northwestern Sublette County. Geomatrix (1988b) divided the South Granite Mountain fault system into five segments. The segments, from east to west, are the Seminoe Mountains segment, the Ferris Mountains segment, the Muddy Gap segment, the Green Mountain segment, and the Crooks Mountain segment. Geomatrix (1988b) discovered evidence of late-Quaternary faulting on the Ferris Mountains and Green Mountain segments of the fault system. They concluded that the Ferris Mountains segment was capable of generating a maximum credible earthquake of magnitude 6.5 –
6.75 with a recurrence interval of 5,000 to 13,000 years. They also concluded that the Green Mountain segment was capable of generating a maximum credible earthquake of magnitude 6.75, with a recurrence interval of 2,000 to 6,000 years (1988b). Geomatrix (1988b) did not find evidence.

Figure 1. UBC Seismic Zone Map.
of late-Quaternary movement on the Seminoe Mountains, Muddy Gap, and Crooks Mountain fault segments. These segments, however, may be extensions of the known active faults in the South Granite Mountain fault system. They should therefore be considered to be potentially active. Geomatrix (1988b) estimated the length of the Seminoe Mountains segment to be 22.5 miles (36 km). Such a fault length would result in a magnitude 6.85 earthquake if the entire length ruptured (Wells and Coppersmith, 1994). The length of the Crooks Gap fault segment was estimated to be 21.25 miles (34 km) (Geomatrix, 1988b). This fault length could generate a magnitude 6.86 earthquake if the entire length ruptured (Wells and Coppersmith, 1994). The Muddy Gap fault system is approximately 14.4 miles (23 km) in length (Geomatrix, 1988b). If the entire fault ruptured, a magnitude 6.66 earthquake could be generated (Wells and Coppersmith, 1994).

Because only a rupture of the Crooks Gap fault segment of the South Granite Mountain fault system would affect Sublette County, only this segment will be discussed. A magnitude 6.86 earthquake could generate peak horizontal accelerations of approximately 1.9%g at Big Sandy. This acceleration would be roughly equivalent to an intensity IV earthquake, which should not cause any damage. The rest of the towns in Sublette County would be subjected to ground accelerations of less than 1.5%g and should not sustain any damage.

The Rock Creek fault system is a north-south-trending normal fault located approximately 15 miles west of Kemmerer, Wyoming, near Fossil Butte National Monument. McCalpin and Warren (1992) found evidence of late-Quaternary movement on this system. Based upon a surface rupture length of 24 miles (38 km) and Quaternary displacement amounts, it has been estimated that the Rock Creek fault is capable of generating a magnitude 6.9 to 7.2 earthquake with an approximate recurrence interval of 600-1500 years (Chambers, 1988; McCalpin, 1993). The most recent events on the Rock Creek fault, however, occurred approximately 3600±300 and 4600±200 years before present (McCalpin, 1993). This suggests that the recurrence interval for this fault system may be variable and an exact interval may be difficult to determine. A maximum magnitude 7.2 earthquake could generate peak horizontal accelerations of approximately 5.4%g at Big Piney, approximately 2.1%g at Big Sandy and Bondurant, approximately 2.4%g at Boulder, approximately 8.6%g at Calpet, approximately 2.6%g at Cora, approximately 3.3%g at Daniel, approximately 5.1%g at Marbleton, approximately 3.4%g at Merna, and approximately 2.5%g at Pinedale (Campbell, 1987). These accelerations are roughly equivalent to intensity V earthquakes at Big Piney and Calpet, and intensity IV earthquakes at Big Sandy, Bondurant, Boulder, Cora, Daniel, Marbleton, Merna, and Pinedale. Big Piney and Calpet could sustain very light damage, but no damage should occur at Big Sandy, Bondurant, Boulder, Cora, Daniel, Marbleton, Merna, or Pinedale.

The Grey’s River fault system is another active fault system located in Lincoln County on the western side of the Wyoming Range. Evidence of late-Holocene movement has also been identified on this north-south-trending normal fault (Jones and McCalpin, 1992; McCalpin, 1993). Based upon an estimated surface rupture length of 54 km, the Grey’s River fault system could
potentially generate a magnitude 7.1 earthquake with a recurrence interval of approximately 2970 – 3400 years (Jones, 1995; Jones and McCalpin, 1992). The most recent events on the fault occurred 1910-2110 and 5080-5310 years before present. However, because no movement occurred on the Grey’s River fault system between approximately 5000 and 15,000 years before present, this recurrence interval may be variable (Jones and McCalpin, 1992). A magnitude 7.1 earthquake could generate peak horizontal accelerations of approximately 8.2%g at Big Piney, approximately 2.8%g at Big Sandy, approximately 10.1%g at Bondurant, approximately 3.7%g at Boulder, approximately 8.4%g at Calpet, approximately 5.6%g at Cora, approximately 7.2%g at Daniel, approximately 7.8%g at Marbleton, approximately 10.3%g at Merna, and approximately 4.7%g at Pinedale (Campbell, 1987). These accelerations are roughly equivalent to intensity VI earthquakes at Bondurant and Merna, intensity V earthquakes at Big Piney, Calpet, Cora, Daniel, Marbleton, and Pinedale, and an intensity IV earthquake at Big Sandy. Light damage could occur at Bondurant and Merna, whereas Big Piney, Calpet, Cora, Daniel, Marbleton, and Pinedale could sustain very light damage. No damage should occur at Big Sandy.

The Star Valley fault system is also an active fault system in Lincoln County. This fault system, which has been subdivided into north and south segments, bounds the eastern edge of the Star Valley. Investigations of the Star Valley fault system determined that Holocene and late-Pleistocene offsets exist along the south fault segment (Piety et al., 1986; McCalpin et al., 1990; McCalpin, 1990). Several maximum magnitude earthquakes have been suggested for the Star Valley fault system. Piety and others (1986) proposed that the Star Valley fault system is capable of generating a maximum credible earthquake of magnitude 7.5 with a recurrence interval of 5,000 to 7,000 years. Based upon a surface rupture length of 27 miles, McCalpin and others (1990) determined that the Star Valley fault system could produce a maximum magnitude 7.2 earthquake. When McCalpin (1990) trenched a portion of the Star Valley fault near Afton, he determined that a magnitude 7.3 earthquake with a recurrence interval of 2550-6000 years is possible on this system. Approximately 5,500 years (radiocarbon age) has elapsed since the latest event on the fault system at the Afton locality. Based upon this evidence, the Star Valley fault system is near the maximum limit for the recurrence interval assigned to the system. Because of the extensive seismic activity associated with the area surrounding the Star Valley fault, and because of the close proximity of towns to this fault system, a maximum magnitude of 7.5 will be used for this analysis. It should also be noted that it has been approximately 5500 years since the last confirmed event on the Star Valley fault at Afton. This fault system is therefore nearing its recurrence interval limit. A magnitude 7.5 earthquake could generate peak horizontal accelerations of approximately 6.0%g at Big Piney, approximately 2.6%g at Big Sandy, approximately 9.4%g at Bondurant, approximately 3.6%g at Boulder, approximately 5.8%g at Calpet, approximately 5.2%g at Cora, approximately 6.0%g at Daniel, approximately 5.8%g at Marbleton, approximately 9.4%g at Merna, and approximately 4.4%g at Pinedale (Campbell, 1987). These accelerations are roughly equivalent to intensity VI earthquakes at Bondurant and Merna, intensity V earthquakes at Big Piney, Calpet, Cora, Daniel, Marbleton, and Pinedale, and an intensity IV earthquake at Big Sandy. Light damage could occur at Bondurant and Merna, whereas Big Piney, Calpet, Cora, Daniel, Marbleton, and Pinedale could sustain very light damage. No damage should occur at Big Sandy.
The Teton fault system is a series of northeast-southwest-trending normal faults located in Teton County on the eastern edge of the Teton Range near Jackson, Wyoming. While Quaternary/Holocene-aged fault scarps have been identified along the entire length of the fault (Smith et al., 1990a, Wong et al., 2000), much is still unresolved about the Teton fault system. Previous investigations have divided it into northern, central, and southern segments (Smith et al., 1990a; Susong et al., 1987). Other researchers prefer an unsegmented model of the Teton fault (Ostena et al., 1988, Byrd et al., 1994). In addition, questions still exist as to whether or not the Beula-Hering Lakes faults in Yellowstone National Park are a northern extension of the Teton fault (Wong et al., 2000). Based upon unsegmented surface rupture lengths (48 miles/77 km including Beula-Hering Lakes faults; 40miles/64km not including Beula-Hering Lakes faults), Wong and others (2000) estimate that the Teton fault is capable of generating a magnitude 6.9 to 7.5 earthquake. This agrees with other analyses, in which a maximum credible earthquake of magnitude 7.5 and a recurrence interval of 800-3600 years were suggested for the Teton fault (Doser and Smith, 1983; Gilbert et al., 1983). A trench on the Teton fault indicated that the fault most recently activated between 4800-7000 years ago (Smith et al., 1993). As a result, Case (1997a) suggests that the Teton fault may be overdue for a magnitude 7.5 earthquake. If a magnitude 7.5 earthquake did occur on the Teton fault, it could potentially generate peak horizontal accelerations of approximately 2.2%g at Big Piney, approximately 1.6%g at Big Sandy, approximately 9.0%g at Bondurant, approximately 2.2%g at Boulder, approximately 1.7%g at Calpet, approximately 3.5%g at Cora and Daniel, approximately 2.3%g at Marbleton, approximately 4.8%g at Merna, and approximately 2.9%g at Pinedale (Campbell, 1987). These accelerations are roughly equivalent to intensity V earthquakes at Bondurant and Merna, and intensity IV earthquakes at Big Piney, Big Sandy, Boulder, Calpet, Cora, Daniel, Marbleton, and Pinedale. Very light damage could occur at Bondurant and Merna, but no damage should occur at Big Sandy, Big Piney, Big Sandy, Boulder, Calpet, Cora, Daniel, Marbleton, or Pinedale.

The Baldy Mountain fault system is a series of short faults located approximately 21 miles (33 km) east of the Teton fault. Investigators at the U.S.G.S. identified areas where the faults offset Quaternary-aged glacial moraines. No maximum magnitude earthquake has been specifically postulated for the Baldy Mountain fault system. It is generally accepted that a magnitude 6.5 earthquake is required to produce ground surface rupture. While evidence of ground surface rupturing has been identified on the Baldy Mountain fault system, the ground surface rupture length is not consistent with a magnitude 6.5 event. In the interest of public safety, however, this report will model the Baldy Mountain fault system as being capable of generating a magnitude 6.5 earthquake with a recurrence interval of approximately 13,000-25,000 years (Machette et al., 2001; Pierce and Morgan, 1992). A magnitude 6.5 earthquake on this fault system could, in turn, generate peak horizontal accelerations of approximately 3.2%g at Bondurant, approximately 1.6%g at Cora, and approximately 1.8%g at Merna. These accelerations are roughly equivalent to intensity IV earthquakes, and should not cause any damage. The rest of the towns in Sublette County would be subjected to ground accelerations of less than 1.5%g and should also not sustain any damage.

The last active fault system in Teton County is the Togwotee Lodge fault system. This series of faults lie in the eastern part of the county, approximately 9 miles (15 km) west of Togwotee Pass. The U.S.G.S. found evidence that Quaternary-aged glacial deposits have been offset along the
fault traces, with a recurrence interval of approximately 16,000-23,000 years (Marchette et al., 2001). As with the Baldy Mountain fault system, the Togwotee Lodge faults have a shorter ground surface rupture length than would be produced by a magnitude 6.5 earthquake. The presence of any ruptured ground surface along these faults, however, suggests that they may be capable of producing at least a magnitude 6.5 earthquake. A magnitude 6.5 earthquake on the Togwotee Lodge fault system could generate peak horizontal accelerations of approximately 2.8%g at Bondurant, approximately 1.6%g at Cora, and approximately 1.7%g at Merna. These accelerations are roughly equivalent to intensity IV earthquakes, and should not cause any damage. The rest of the towns in Sublette County would be subjected to ground accelerations of less than 1.5%g and should also not sustain any damage.

Active fault systems present in the southern portion of Yellowstone National Park may also affect Sublette County. Love and Christiansen (1985) describe the Buffalo Fork fault as beginning on the western side of the South Arm of Yellowstone Lake and continuing south to Gravel Mountain in Teton National Forest. This normal fault that reactivated a reverse fault surface offsets the Quaternary Lava Creek Tuff near Channel Mountain (U.S.G.S., 1972). Based upon a maximum surface rupture length of 32 miles (51 km), a maximum credible earthquake of magnitude 7.1 has been postulated for this fault (Wong et al., 2000). No definite recurrence interval has been determined for the Buffalo Fork fault. The U.S.G.S. suggests a long recurrence interval of approximately 10,000 to 100,000 years (Marchette et al., 2001), since at least one event has occurred on the fault since the glaciers receded from the area. A magnitude 7.1 earthquake on the Buffalo Fork fault could potentially generate peak horizontal accelerations of approximately 3.5%g at Bondurant, approximately 2.0%g at Cora, approximately 1.8%g at Daniel, approximately 2.0%g at Merna, and approximately 1.7%g at Pinedale. These accelerations are roughly equivalent to intensity IV earthquakes, and should not cause any damage. The rest of the towns in Sublette County would be subjected to ground accelerations of less than 1.5%g and should also not sustain any damage.

The Beula-Hering Lakes faults are present east of Hering Lake and extend south into Teton County. They may even be an extension of the Teton fault system (Case, 1997a; Love, 1961; Love et al., 1992; Wong et al., 2000). For this analysis, however, they will be considered as a separate fault system. (See the first paragraph of this section for information related to including the Beula-Hering Lakes faults as part of the Teton fault) The Quaternary-aged Huckleberry Ridge Tuff and Lewis Canyon Rhyolite are displaced by the Beula-Hering Lakes faults. Based upon a maximum surface rupture length of 8 miles (13 km), Wong and others (2000) estimated that a maximum magnitude 6.7 earthquake could result from this fault system. A long recurrence interval is probable, as the most recent event is dated to less than 630,000 years before present (offset of the Lava Creek Tuff), but the 70,000 year old Pitchstone Plateau rhyolite flow is not disturbed by these faults (U.S.G.S., 1972; Marchette et al., 2001). A magnitude 6.7 earthquake on the Beula-Hering Lakes faults could generate a peak horizontal acceleration of approximately 1.8%g at Bondurant. This acceleration is roughly equivalent to an intensity IV earthquake, and should not cause any damage. The rest of the towns in Sublette County would be subjected to ground accelerations of less than 1.5%g and should also not sustain any damage.
The Mount Sheridan-Heart River fault system extends from the Heart Lake Geyer Basin southwest of Yellowstone Lake to near Bobcat Ridge in the Bridger-Teton National Forest. Quaternary-aged movement has been identified along these north-south-trending faults, as they offset the Huckleberry Ridge Tuff in several locations. Based upon a maximum surface rupture length of nearly 26 miles (41 km), a maximum magnitude 7.0 earthquake has been suggested for this fault system (Wong et al., 2000). The U.S.G.S. estimated that because this fault system has a high slip rate (1-5mm/yr), the recurrence interval for the Mount Sheridan-Heart River fault is less than 5,000 years. The age of the most recent events are not known, as no dating has been done on this fault system. A magnitude 7.0 earthquake on the Mount Sheridan-Heart River fault could generate peak horizontal accelerations of approximately 2.6%g at Bondurant and 1.6%g at Merna. These accelerations are roughly equivalent to intensity IV earthquakes, and should not cause any damage. The rest of the towns in Sublette County would be subjected to ground accelerations of less than 1.5%g and should also not sustain any damage.

The Yellowstone River Valley in the southeastern portion of Yellowstone National Park is bounded by several active normal faults. These faults displace Quaternary/Holocene deposits and alluvium along their trace. Based upon a maximum surface rupture length of 14 miles (22 km), these faults could generate a maximum magnitude 6.6 earthquake (Wong et al., 2000). No specific recurrence interval has been determined for these faults. A magnitude 6.6 earthquake on these faults could in turn generate a peak horizontal acceleration of approximately 1.5%g at Bondurant, or an intensity IV earthquake. No damage should occur at Bondurant. The rest of the towns in Sublette County would be subjected to ground accelerations of less than 1.5%g and should also not sustain any damage.

The Yellowstone Lake fault extends from Dot Island in Yellowstone Lake south to Overlook Mountain. The U.S.G.S. (1972) found evidence that this fault has disturbed Quaternary Lava Creek Tuff and Mount Jackson Rhyolite deposits, as well as lacustrine deposits from Yellowstone Lake. Based upon a maximum surface rupture length of 17.5 miles (28 km), Wong and others (2000) estimated that a maximum magnitude 6.8 earthquake could be generated by this fault. Preliminary investigations of the Yellowstone Lake fault suggest a recurrence interval of approximately 7,000 years for the middle section of the fault (Marchette et al., 2001; Locke et al., 1992). A magnitude 6.8 earthquake could produce peak horizontal accelerations of approximately 1.6%g at Bondurant. This acceleration is roughly equivalent to an intensity IV earthquake, and should not cause any damage. The rest of the towns in Sublette County would be subjected to ground accelerations of less than 1.5%g and should also not sustain any damage.

**Floating or Random Earthquake Sources**

Many federal regulations require an analysis of the earthquake potential in areas where active faults are not exposed, and where earthquakes are tied to buried faults with no surface expression. Regions with a uniform potential for the occurrence of such earthquakes are called tectonic provinces. Within a tectonic province, earthquakes associated with buried faults are assumed to occur randomly, and as a result can theoretically occur anywhere within that area of uniform earthquake potential. In reality, that random distribution may not be the case, as all earthquakes
are associated with specific faults. If all buried faults have not been identified, however, the
distribution has to be considered random. “Floating earthquakes” are earthquakes that are
considered to occur randomly in a tectonic province.

It is difficult to accurately define tectonic provinces when there is a limited historic earthquake
record. When there are no nearby seismic stations that can detect small-magnitude earthquakes,
which occur more frequently than larger events, the problem is compounded. Under these
conditions, it is common to delineate larger, rather than smaller, tectonic provinces.

The U.S. Geological Survey identified tectonic provinces in a report titled “Probabilistic Estimates
of Maximum Acceleration and Velocity in Rock in the Contiguous United States” (Agermissen
and others, 1982). In that report, Sublette County was classified as being in a tectonic province
with a “floating earthquake” maximum magnitude of 6.1. Geomatrix (1988b) suggested using a
more extensive regional tectonic province, called the “Wyoming Foreland Structural Province”,
which is approximately defined by the Idaho-Wyoming Thrust Belt on the west, 104° West
longitude on the east, 40° North latitude on the south, and 45° North latitude on the north.
Geomatrix (1988b) estimated that the largest “floating” earthquake in the “Wyoming Foreland
Structural Province” would have a magnitude in the 6.0 – 6.5 range, with an average value of
magnitude 6.25.

Federal or state regulations usually specify if a “floating earthquake” or tectonic province analysis
is required for a facility. Usually, those regulations also specify at what distance a floating
earthquake is to be placed from a facility. For example, for uranium mill tailings sites, the Nuclear
Regulatory Commission requires that a floating earthquake be placed 15 kilometers from the site.
That earthquake is then used to determine what horizontal accelerations may occur at the site. A
magnitude 6.25 “floating” earthquake, placed 15 kilometers from any structure in Sublette
County, would generate horizontal accelerations of approximately 15%g at the site. That
acceleration would be adequate for designing a uranium mill tailings site, but may be too large for
less critical sites, such as a landfill. Critical facilities, such as dams, usually require a more detailed
probabilistic analysis of random earthquakes. Based upon probabilistic analyses of random
earthquakes in an area distant from exposed active faults (Geomatrix, 1988b), however, placing a
magnitude 6.25 earthquake at 15 kilometers from a site will provide a fairly conservative estimate
of design ground accelerations.

Probabilistic Seismic Hazard Analyses

The U.S. Geological Survey (USGS) publishes probabilistic acceleration maps for 500-, 1000-
and 2,500-year time frames. The maps show what accelerations may be met or exceeded in those
time frames by expressing the probability that the accelerations will be met or exceeded in a
shorter time frame. For example, a 10% probability that acceleration may be met or exceeded in
50 years is roughly equivalent to a 100% probability of exceedance in 500 years.

The USGS has recently generated new probabilistic acceleration maps for Wyoming (Case, 2000).
Copies of the 500-year (10% probability of exceedance in 50 years), 1000-year (5% probability of
exceedance in 50 years), and 2,500-year (2% probability of exceedance in 50 years) maps are attached. Until recently, the 500-year map was often used for planning purposes for average structures, and was the basis of the most current Uniform Building Code. The new International Building Code, however, uses a 2,500-year map as the basis for building design. The maps reflect current perceptions on seismicity in Wyoming. In many areas of Wyoming, ground accelerations shown on the USGS maps can be increased due to local soil conditions. For example, if fairly soft, saturated sediments are present at the surface, and seismic waves are passed through them, surface ground accelerations will usually be greater than would be experienced if only bedrock was present. In this case, the ground accelerations shown on the USGS maps would underestimate the local hazard, as they are based upon accelerations that would be expected if firm soil or rock were present at the surface. Intensity values can be found in Table 2.

Based upon the 500-year map (10% probability of exceedance in 50 years) (Figure 3), the estimated peak horizontal acceleration in Sublette County ranges from approximately 7%g in the southeastern portion of the county to over 25%g in the northwestern corner of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9%g – 9.2%g), intensity VI earthquakes (9.2%g – 18%g), and intensity VII earthquakes (18%g – 34%g). Intensity V earthquakes can result in cracked plaster and broken dishes. Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Intensity VII earthquakes can result in slight to moderate damage in well-built ordinary structures, and considerable damage in poorly built or badly designed structures, such as unreinforced masonry. Chimneys may be broken. Big Piney and Pinedale would be subjected to accelerations of approximately 10%g (intensity VI) and 9%g (intensity V) respectively.

Based upon the 1000-year map (5% probability of exceedance in 50 years) (Figure 4), the estimated peak horizontal acceleration in Sublette County ranges from approximately 10%g in the eastern part of the county to nearly 40%g in the northwestern corner of the county. These accelerations are roughly comparable to intensity VI earthquakes (9.2%g – 18%g), intensity VII earthquakes (18%g – 34%g), and intensity VIII earthquakes (34%g – 65%g). Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Intensity VII earthquakes can result in slight to moderate damage in well-built ordinary structures, and considerable damage in poorly built or badly designed structures, such as unreinforced masonry. Chimneys may be broken. Intensity VIII earthquakes can result in considerable damage in ordinary buildings and great damage in poorly built structures. Panel walls may be thrown out of frames. Chimneys, walls, columns, factory stacks may fall. Heavy furniture may be overturned. Big Piney and Pinedale would be subjected to accelerations of approximately 10-15%g, or intensity VI.

Based upon the 2500-year map (2% probability of exceedance in 50 years) (Figure 5), the estimated peak horizontal acceleration in Sublette County ranges from approximately 17%g in the northeast and south-central parts of the county to over 60%g in the northwestern corner of the county. These accelerations are roughly comparable to intensity VI earthquakes (9.2%g – 18%g), intensity VII earthquakes (18%g – 34%g), and intensity VIII earthquakes (34%g – 65%g). Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Intensity VII earthquakes can result in slight to moderate damage in well-built ordinary structures, and considerable damage in poorly built or badly designed structures, such as unreinforced masonry.
Chimneys may be broken. Intensity VIII earthquakes can result in considerable damage in ordinary buildings and great damage in poorly built structures. Panel walls may be thrown out of frames. Chimneys, walls, columns, factory stacks may fall. Heavy furniture may be overturned. Big Piney and Pinedale would be subjected to accelerations of approximately 20%g, or intensity VII.

As the historic record is limited, it is nearly impossible to determine when a 2,500-year event last occurred in the county. Because of the uncertainty involved, and based upon the fact that the new International Building Code utilizes 2,500-year events for building design, it is suggested that the 2,500-year probabilistic maps be used for Sublette County analyses. This conservative approach is in the interest of public safety.

Table 2:

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<th>Acceleration (%g) (PGA)</th>
<th>Perceived Shaking</th>
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<td>9.2 – 18</td>
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Modified Mercalli Intensity and peak ground acceleration (PGA) (Wald, et al 1999).
Abridged Modified Mercalli Intensity Scale

Intensity value and description:

I  Not felt except by a very few under especially favorable circumstances.

II Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated.

IV During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably.

V Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight.

VII Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars.

VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed.


X Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks.


XII Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.
Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary
U.S. Geological Survey
National Seismic Hazard Mapping Project
Albers Conic Equal-Area Projection
Standard Parallels: 29.5

Figure 3. 500-year probabilistic acceleration map (10% probability of exceedance in 50 years).
Peak Acceleration (%g) with 5% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary
U.S. Geological Survey
National Seismic Hazard Mapping Project
Albers Conic Equal-Area Projection
Standard Parallels: 29.5

Figure 4. 1000-year probabilistic acceleration map (5% probability of exceedance in 50 years).
Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary

U.S. Geological Survey
National Seismic Hazard Mapping Project
Albers Conic Equal-Area Projection
Standard Parallels: 29.5

Figure 5. 2500-year probabilistic acceleration map (2% probability of exceedance in 50 years).
Summary

There have been numerous historic earthquakes with a magnitude greater than 2.0 recorded in or near Sublette County. Because of the limited historic record, it is possible to underestimate the seismic hazard in Sublette County if historic earthquakes are used as the sole basis for analysis. Earthquake and ground motion probability maps and specific fault analyses give a more reasonable estimate of damage potential in Sublette County.

Current earthquake probability maps that are used in the newest building codes suggest a scenario that would result in moderate to heavy damage to buildings and their contents, with damage increasing from the center and southeast to the northwest. More specifically, the probability-based or fault activation-based worst-case scenario could result in the following damage at points throughout the county:

**Intensity VIII Earthquake Areas**

**Bondurant**

Intensity VIII earthquakes can result in considerable damage in ordinary buildings and great damage in poorly built structures. Panel walls may be thrown out of frames. Chimneys, walls, columns, factory stacks may fall. Heavy furniture may be overturned.

**Intensity VII Earthquake Areas**

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In intensity VII earthquakes, damage is negligible in buildings of good design and construction, slight-to-moderate in well-built ordinary structures, considerable in poorly built or badly designed structures such as unreinforced masonry buildings. Some chimneys will be broken.
References


University of Utah Seismograph Station Epicenter Listings:
http://www.seis.utah.edu/HTML/EarthquakeCatalogAndInfo.html


Earthquakes > Magnitude 3.0 within 100 km Radius of Center of Study Area
Source: http://neic.usgs.gov/neis/epic

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Earthquake Hazards Program

Database Search

Complete Report for Grand Valley fault, Star Valley section (Class A) No. 726d

Brief Report || Partial Report


<table>
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<tr>
<th>Synopsis</th>
<th>General: This long fault extends from Idaho into Wyoming along the western base of the Snake and Salt River Ranges.</th>
</tr>
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<tr>
<td>Sections: This fault has 4 sections. Detailed mapping and limited trenching suggest that the fault has four segments and an additional poorly characterized part of the fault that suggest different rates of Quaternary displacement and apparently different paleoseismic histories. Those segments are herein considered as informally named sections in accordance with this compilation. From north to south they are the Swan Valley section [726a], the Grand Valley section [726b], the Prater Mountain section [726c], and the Star Valley section [726d]. The southernmost, the youngest and most active, records recurrent Holocene movement. The northern part of the fault is outside the Intermountain Seismic Belt and the southern part is within this active belt; furthermore, faulting on the northern part is clearly older and less frequent than to the south.</td>
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<table>
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<tr>
<th>Name comments</th>
<th>General: Name of fault and its sections are modified from Piety and others (1992 #538). Earlier workers in the area restricted the use of &quot;Grand Valley fault&quot; to the part of the structure in Idaho, the southern extension in Wyoming was known as the &quot;Star Valley fault.&quot; Preference for the single name as used by Piety and others (1992 #538) is given here. The Grand Valley fault extends from about 26 km southeast of Pocatello, Idaho, south to about 22 km south of Afton, Wyoming.</th>
</tr>
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<tbody>
<tr>
<td>Section: The section was defined by Piety and others (1992 #538) as extending from Prater Canyon south to 1 km north of the Salt River (as shown by Warren, 1992 #837). This part of the fault bounds two distinct structural and physiographic basins of</td>
<td></td>
</tr>
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</table>
approximately equal size (Piety and others, 1986 #55). Furthermore, the topographic high separating these two basins near "The Narrows" is coincident with a 4-km right step in the trace of the fault. The Star Valley section includes both parts of the Star Valley fault of Witkind (1975 #819) in Wyoming. Piety and others (1986 #55) suggested that the southern 27 km of the Grand Valley fault is characterized by similar faulting histories on either side of the echelon step.

**Fault ID Comments:**
Refers to number 22 (Grand Valley fault, Idaho) of Witkind (1975 #320) and numbers 20 and 21 (Star Valley fault, Wyoming) of Witkind (1975 #819).

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<th>County(s) and State(s)</th>
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<td>Preston</td>
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<td><strong>Physiographic province(s)</strong></td>
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<td><strong>Reliability of location</strong></td>
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<td>Compiled at 1:250,000 scale.</td>
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<td><strong>Comments:</strong></td>
<td>Fault location taken from 1:24,000-scale maps of Warren (1992 #837) and 1:275,000-scale map of Piety and others (1992 #538).</td>
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<tr>
<td><strong>Geologic setting</strong></td>
<td>Down-to-west range-front normal fault that extends from near the Snake River Plain southward along the western base of the Snake and Salt River Ranges. Basin fill is estimated to be 2 to 3 km thick based on seismic reflection data (Royse and others, 1975 #4391; Dixon, 1982 #4382).</td>
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<tr>
<td><strong>Length (km)</strong></td>
<td>This section is 52 km of a total fault length of 136 km.</td>
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<tr>
<td><strong>Average strike</strong></td>
<td>N8°W (for section) versus N22°W (for whole fault)</td>
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<td><strong>Sense of movement</strong></td>
<td>Normal</td>
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<td>Comments: (Piety and others, 1986 #55; Piety and others, 1992 #538)</td>
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<tr>
<td><strong>Dip</strong></td>
<td>10°-70° W.</td>
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<td></td>
<td>Comments: According to cross-section 1 of Webel (1987 #815), the fault dips 70° near the surface, but progressively flattens and merges with the Absaroka thrust fault (dip 10° W.) at a depth of about 12 km.</td>
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<tr>
<td><strong>Paleoseismology studies</strong></td>
<td>[726-1] Warren (1992 #837) trenched an 11-m-high scarp 0.8 km south of Swift Creek (the Afton trench site). The exposed stratigraphy suggests that three latest Quaternary earthquakes occurred at about 5,540±70 14C yr BP (3 m of slip), 8,090±80 14C yr BP (4 m of slip), and about 12-15 ka (4 m slip). McCalpin (1993 #796) reported that the earliest (third) event at the site</td>
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Isolated fault scarps are present on late Quaternary alluvial fans at the mouths of major valleys (Piety and others, 1992 #538). These scarps tend to fall into one of two size classes: 5-6 m high and 11-15 m high suggesting multiple times of movement on different age landscapes. Elsewhere, the fault is at the abrupt alluvial bedrock contact and few scarps exist beyond the mouths of the narrow channel valleys.

<table>
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<tr>
<th>Geomorphic expression</th>
<th>Holocene and late Pleistocene alluvial fans along the eastern margin of Star Valley.</th>
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<tr>
<td>Age of faulted surficial deposits</td>
<td>Latest Quaternary (&lt;15 ka)</td>
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<td>Most recent prehistoric deformation</td>
<td>&gt;5.5 k.y. (&lt;5.5 ka); 2.4-2.7 k.y. (5.5-8 ka); 4-7 k.y. (8 to 14.5-15 ka)</td>
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<tr>
<td>Recurrence interval</td>
<td>Between 0.2 and 1.0 mm/yr</td>
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suggest the slip rate during this period is probably less than the 1.1 mm/yr that Wong and others (2000 #4484) favored. Because most of the reported slip rates are less than 1 mm/yr (especially the younger ones), we assign the 0.2-1 mm/yr slip-rate category to this section of the Grand Valley fault.

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<td>James P. McCalpin, GEO-HAZ Consulting, Inc.</td>
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<tr>
<td>Michael N. Machette, U.S. Geological Survey</td>
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<td>Kathleen M. Haller, U.S. Geological Survey</td>
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Earthquake Hazards Program

Database Search

Complete Report for Greys River fault (Class A) No. 728

Brief Report || Partial Report


| **Synopsis** | Complex fault scarps in densely-forested terrain at the base of a steep range front. Data from three trenches at one location indicate that similar amounts of slip have characterized the past two faulting events; however, the history of faulting suggests highly variable recurrence intervals during the late Quaternary. |
| **Name comments** | Originally mapped but unnamed by Rubey (1973 #822). Name first used by Jones and McCalpin (1992 #813) and informally introduced by McCalpin (1993 #796). Fault extends from about 1 km south of Blind Trail Creek south to the East Fork of the Greys River as shown by Rubey (1973 #822) and Jones (1995 #3910). |
| **Fault ID Comments:** | Not shown on any previous compilation. |
| **County(s) and State(s)** | LINCOLN COUNTY, WYOMING |
| **AMS sheet(s)** | Preston |
| **Physiographic province(s)** | MIDDLE ROCKY MOUNTAINS |
| **Reliability of location** | Good Compiled at 1:250,000 scale. |

**Comments:** Fault location from 1:62,500-scale mapping of Rubey (1973 #822), supplemented by unpublished 1:24,000-scale mapping that was recompiled at 1:48,000 scale by Jones (1995 #3910). Although Rubey's mapping stopped at 43° N, the study by Jones (1995 #3910) supports a northern termination of the Quaternary fault at this same latitude. Fault traces were recompiled at 1:250,000 scale on a topographic base map. |
| **Geologic setting** | This high-angle down-to-west normal fault bounds the west side |
Fault probably soles into the Laramide-age Darby thrust fault. McCalpin (1993 #796) indicated that the throw of the fault may be 300-1000 m based on cross sections of Rubey (1973 #822).

| **Length (km)** | 50 km. |
| **Average strike** | N3°W |
| **Sense of movement** | Normal |
| **Dip** | 10°-70° W. |
| **Comments:** | Normal movement indicated by Rubey (1973 #822). |
| **Dip** | 10°-70° W. |
| **Comments:** | According to cross section 1 (fig. 14) of Webel (1987 #815), the fault dips 70° at the surface and joins the Laramide-age Darby thrust at depth of about 2 km, the latter of which flattens progressively to less than 10° at depth of 8.2 km. |
| **Paleoseismology studies** | Site 728-1. Jones and McCalpin (1992 #813) excavated three trenches across fault scarps on upper Pleistocene outwash deposits at Sheep Creek, a tributary to the Grey’s River. The trenches revealed evidence of one late and one middle Holocene earthquake; their timing is constrained by eight radiocarbon ages. No stratigraphic evidence for earlier earthquakes was present, even though the trenched deposits are thought to be about 15 ka. The most recent faulting event resulted in about 5 m of slip and the earlier event about 4.3 m of slip. |
| **Geomorphic expression** | Fault scarps generally are 3- to 11-m high (Jones and McCalpin, 1992 #813); along most of the range front, complex step faults are present in bedrock-cored colluvium. |
| **Age of faulted surficial deposits** | Upper Triassic and Jurassic bedrock is in fault contact with Permian-Pennsylvanian or lower Triassic bedrock along most of the length of the fault; locally Triassic bedrock is faulted as mapped by Rubey (1973 #822). |
| **Historic earthquake** | Latest Quaternary (<15 ka) |
| **Most recent prehistoric deformation** | Latest Quaternary (<15 ka) |
| **Recurrence interval** | 2,970-3,400 14C yr (about 2.0-5.2 ka) |
| **Comments:** | Recurrence interval from Jones and McCalpin (1992 #813) based on dated paleoeartquakes at 1,910-2,110 14C yr BP and 2,110±60 14C yr BP (Jones and McCalpin, 1992 #813; McCalpin, 1993 #796). This short recurrence interval suggests an earthquake cluster (two closely spaced events) that may not be characteristic of the longer late Quaternary history of the fault. However, no displacement occurred between about 5 ka and 15... |
ka. This 10-k.y. interval of quiescence implies considerable variability in recurrence times (McCalpin, 1993 #796).

**Slip-rate category**

**Between 0.2 and 1.0 mm/yr**

**Comments:** No slip rate is published, but the most recent displacement of 5 m occurred after an interval of 2970-3400 14C yrs suggests moderately high slip rates. This short recurrence interval suggests an earthquake cluster (two closely spaced events) that may not be characteristic of the longer late Quaternary slip rate of the fault. In fact, inferred late Quaternary slip rates are much lower because of the variability in the recurrence intervals. The previous 4.3 m of slip occurred over an interval of more than 10 k.y., which results in much lower possible slip rate that are consistent with the assigned slip-rate category. Wong and others (2000 #4484) suggested fault slip rates ranging from 0.04-1.9 mm/yr, each with separate weighting. These reported slip rates are based on data of McCalpin (1992 #813). They place a 60% weighting on a rate of 0.7 mm.yr, which we consider to be a maximum rate for the late Quaternary. Considering the above discussion and the evidence for an earthquake cluster in the middle Holocene, we categorize the Greys River fault in the 0.2-1.0 mm/yr bracket and recognize that it may have considerably faster slip rates over short intervals of geologic time (several thousand years). A similar treatment was afforded the nearby Rock Creek fault [729].

**Date and Compiler(s)**

1994
James P. McCalpin, GEO-HAZ Consulting, Inc.

**References**


008 20:11:08 UTC
Earthquake Hazards Program

Database Search

Brief Report for Rock Creek fault (Class A) No. 729

Partial Report || Complete Report


| **Synopsis** | The Rock Creek fault is a high-angle, down-to-west normal fault within the Tunp Range; it may sole into the Laramide-age Tunp thrust fault. Scarp{s} are present along much of the length of this fault. Morphologic studies of the scarps have been conducted and one trench that was excavated constrains the timing of the most recent movement at about 3.3 ka. |
| County(s) and State(s) | LINCOLN COUNTY, WYOMING |
| AMS sheet(s) | Ogden, Preston |
| Physiographic province(s) | MIDDLE ROCKY MOUNTAINS |
| Length (km) | 41 km |
| Average strike | N5°E |
| Sense of movement | Normal |
| Dip Direction | W |
| Historic earthquake | |
| Most recent prehistoric deformation | Latest Quaternary (<15 ka) |
| Slip-rate category | Between 0.2 and 1.0 mm/yr |
| Date and Compiler(s) | 1994, James P. McCalpin, GEO-HAZ Consulting, Inc. |
Appendix D

Environmental Permitting
TO: Matthew Bilodeau/US Army Corps of Engineers - Cheyenne
Kellie Roadifer/Bureau of Land Management - Pinedale
Brian T. Kelly/U.S. Fish and Wildlife Service - Cheyenne
Vern Stelter/Wyoming Game and Fish Department - Cheyenne

FROM: Doug Yadon/Project Manager

DATE: October 1, 2008

SEH NO: AWWDC0070400 FC

RE: Upper Green River Westside Storage Level II Study - Background, Preliminary Identification of Potential Environmental/Permitting Issues, and Description of Preferred Alternative Surface Water Storage and Water Supply Alternatives

Background

SEH is under contract to the Wyoming Water Development Commission (WWDC) to evaluate alternatives for new surface water reservoir storage and/or other water supply facilities within the Horse Creek, Cottonwood Creek, and Piney Creeks (North, Middle and South) subdrainage basins, all of which are tributary from the Wyoming Range to the west to the upper reaches of the Green River between Daniel/Pinedale and Marbleton/Big Piney (see Figure 1).

The overall objective of this project is to assess the technical feasibility and permissibility of storing (or otherwise providing) available flows in the subject subbasins to satisfy as much as possible of existing seasonal and dry-year irrigation shortages. Other potential benefits of water storage are to be identified and accommodated in reservoir siting and sizing to the extent practicable.

At this stage of the project a total of four preferred potential dam and reservoir sites have been identified and preliminarily characterized, together with a concept to pump directly from the Green River and convey irrigation water to the lower Piney Creek subbasins via pipeline and canal. These sites have been selected by screening a wide range of water storage/supply alternatives that included a total of more than 60 potential dam and reservoir sites and several major supply and delivery canal alignments (see Figure 2). The location of the preferred alternative dam and reservoir sites relative to existing irrigated lands is shown on Figure 3. Figure 4 shows the distribution of federal, state and private lands within the study area relative to the preferred sites/concepts. Each of the five preferred alternatives are further described in Table 1, and a map and accompanying fact sheet for each alternative are also provided following Table 1. Note that three of the four reservoir storage alternatives include proposed supply and/or delivery canals (and in one case, a small pumping station on North Cottonwood Creek).
Please note that the reservoir capacities shown in Table 1 and the fact sheets and the resultant reservoir surface areas shown on Figures 2 through 4 and the maps of the alternatives are preliminary and intended to be on the high side. Conceptual level reservoir operations modeling is in progress to further refine reservoir sizing.

**Environmental/Permitting Issues**

A preliminary environmental evaluation has been performed of the four preferred dam and reservoir sites (Alternatives 1 through 4) and the direct pumping concept (Alternative 5). The key known and potential issues identified to date are briefly identified as follows:

- Wetlands and riparian habitat
- Stream water quality
- Big game (crucial range, parturition areas, other seasonal use)
- Sage grouse (leks, habitat)
- Sensitive wildlife (bald eagle, western yellow-billed cuckoo, gray wolf, grizzly bear, Colorado cutthroat trout, other species)
- Sensitive plants (various species)
- Threatened, Endangered, Proposed and Candidate Species (Canada lynx, black-footed ferret, Kendall Warm Springs dace, downstream Colorado River fishes, Utes ladies’ tresses)
- Visual resources
- Historic trails (Emigrant Trail – Lander Cutoff)
- Other cultural resources

The results of the preliminary evaluations to date are summarized on Table 1 in the section titled “Environmental and Cultural Resources” (note that information from the Wyoming Natural Diversity Database is on order and will be included in the evaluations when received). These and any other key issues identified by input from relevant land management and permitting agencies will be addressed in the draft report for the project, together with a description of the permitting process (including NEPA) and potential mitigation measures for unavoidable potentially significant impacts.
Table 1
Characteristics of Water Storage/Supply Alternatives
Alternative #
SEH Site #

Element

South Dam

North Dam

1

2

3

4

5

SEH-15

15

SEH-10

SEH-12

SEH-36

North
North
Cottonwood
North Horse
Cottonwood Horse Creek
Creek
Creek Supply
Creek Supply Delivery Canal
Pumping
Canal
Canal
Station and
Delivery Canal

Site Name

Southeast
Dam

Haines Flat

Northeast
Dam

North Dam

South
Cottonwood
Creek Delivery
Canal

Dam

Whiskey
Creek

Mickelson Creek

Middle Piney
Creek Delivery
Canal

Dam

Pipeline and
Canal

Pumping from
Green River

Fish Creek

Location Information
Horse/Cottonwood

Basin
Tributary
Onstream / Offstream
Township
Range
Section
Latitude
Longitude
USGS Quadrangle

Cottonwood
South
Coittonwood
n/a
Creek
Onstream
Offstream
32
32
114
114

n/a

South Horse
Creek

Mickelson
Creek

Offstream
34
113

Onstream
34
113

Onstream
32
114

33

20

12,13

12

42.869
110.345

42.898
110.354

42.766
110.365

Merna

Merna

Halfway

Piney

Piney

Piney
North, Middle &
South Piney
Creek

North Piney
Creek

South Piney
Creek

Onstream
31
114

Onstream
29
114

29-30
111-112

12

24

2

Various

42.774
110.362

42.779
110.326

42.662
110.372

42.524
110.387

Halfway

Halfway

Meadow
Canyon

Springman
Creek

Big Piney East
& West

Basin Characteristics and Hydrology
Drainage Area (sq. miles)
Inflow Design Flood
Estimated Peak Discharge (cfs)
Estimated Runoff Volume (acre-feet)
Annual Peak Flow Characteristics
Region

35

47

60

81

44,000
11,000

52,000
14,000

62,000
31,000

74,000
42,000

Mountainous

Mountainous/High Desert

Mountainous

Mountainous

35
0
27.0
0.6
376
512
599
730
838
931
1,048
1,152
40

36
11
37.0
0.6
680
1,083
1,466
2,148
2,770
3,489
4,282
5,538
64

60
0
41.0
0.6
934
1,085
1,166
1,295
1,409
1,481
1,570
1,612
119

81
0
27.0
0.6
743
993
1,152
1,392
1,599
1,762
1,967
2,143
86

33,000
7,721
7,570
141
1.6
650
51

46,000
7,601
7,470
121
2.1
875
53

Mudslides,
Mudflows,
Block Slides
locally on
reservoir
slopes

Local
Mudslides,
Mudflows,
Debris Flows
on reservoir
slopes

Mountainous Area (acres)
High Desert Area (acres)
Average Annual Precipitation (in)
Geographic Factor
2-year Peak Flow (cfs)
5-year Peak Flow (cfs)
10-year Peak Flow (cfs)
25-year Peak Flow (cfs)
50-year Peak Flow (cfs)
100-year Peak Flow (cfs)
200-year Peak Flow (cfs)
500-year Peak Flow (cfs)
Mean Annual Flow (cfs)

Reservoir Characteristics and Operation
Normal High Water
Capacity (acre-feet)
Normal Pool Elevation (feet)
Minimum Reservoir Bottom Elevation (feet)
Maximum Reservoir Depth at NHWL (feet)
Reservoir Length (mi)
Surface Area (acres)
Average Water Depth (feet)

42,000
7,661
7,565
86

7,590
61

7,660
91

1.7
1,426
29

32,000
7,761
7,720
31
2.0
1,072
30

7,740
11

Site Geology
Geology and Geotechnics
Karst
Seepage
Structure (joints, fractures, shear zones)
Liquefaction Potential
Dispersive/Soluble Soils
Foundation Strength
Mudslides,
Mudflows,
Block Slides
locally on
canal
alignment

Landslide Deposits

Bedrock Geology Units

Wasatch
Wasatch
Formation
Formation
(mudstone;
(mudstone;
potentially
potentially
interbeds of
interbeds of
sandstone,
sandstone,
conglomerate conglomerate
and lesser oil and lesser oil
shale, lignite shale, lignite
and limestone) and limestone)

Surficial Geology Units

Alluvium,
alluvial terrace
and colluvium
deposits (in
order of
abundance)

Local
Local
Local
Local
Mudslide,
mudslide on mudslide on mudslide on
Mudflow,
reservoir slope reservoir slope reservoir slope Debris Flow
Complex

Local
MudslideMudflow

Wasatch
Wasatch
Wasatch
Wasatch
Wasatch
Wasatch
Wasatch
Wasatch
Wasatch
Wasatch
Wasatch
Formation
Formation
Formation
Formation
Formation
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potentially
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interbeds of
interbeds of
interbeds of
interbeds of
interbeds of
interbeds of
interbeds of
interbeds of
interbeds of
interbeds of
interbeds of
sandstone,
sandstone,
sandstone,
sandstone,
sandstone,
sandstone,
sandstone,
sandstone,
sandstone,
sandstone,
sandstone,
conglomerate conglomerate conglomerate conglomerate conglomerate conglomerate conglomerate conglomerate conglomerate conglomerate conglomerate
and lesser oil and lesser oil and lesser oil and lesser oil and lesser oil and lesser oil and lesser oil and lesser oil and lesser oil and lesser oil and lesser oil
shale, lignite shale, lignite shale, lignite shale, lignite shale, lignite shale, lignite shale, lignite shale, lignite shale, lignite shale, lignite shale, lignite
and limestone) and limestone) and limestone) and limestone) and limestone) and limestone) and limestone) and limestone) and limestone) and limestone) and limestone)

Wasatch
Formation
(mudstone;
potentially
interbeds of
sandstone,
conglomerate
and lesser oil
shale, lignite
and limestone)

Alluvium,
Alluvium,
Alluvium,
Alluvium,
Alluvium,
Alluvium,
Colluvium,
Colluvium,
alluvial terrace alluvial terrace alluvial terrace
alluvial terrace alluvial terrace
alluvial terrace alluvial terrace
Alluvial terrace
Alluvial terrace Alluvium and
alluvial terrace Colluvium and Alluvial terrace
and colluvium and colluvium and colluvium
and colluvium and colluvium
and colluvium and alluvium
deposits and
and alluvium alluvial terrace
and minor minor alluvium and alluvium
deposits (in
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deposits (in
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deposits
minor alluvium
deposits
deposits
alluvium
deposits
order of
order of
order of
order of
order of
order of
order of
deposits
abundance)
abundance)
abundance)
abundance)
abundance)
abundance)
abundance)

Seismotectonics
Potentially Active and Active Faults
Historic Seismicity
Estimated Peak Horizontal Ground Acceleration (PH

0.35

0.35

0.35

0.35

0.28

0.32

0.32

0.30

0.28

0.28

0.25g

Borrow
Relative apparent availability
Relative apparent quality

Mineral and Energy Resources
Mineral Resources

Mineral Ownership and Federal Leases

Private Mineral Ownership;
some Federal Mineral
Ownership and Leased
Federal Minerals

Coal Potential
Sulfur Potential
Uranium
Gypsum
Phosphorus Potential
Bentonite
Energy Resources

Oil and Gas Leasing Category (applies only to
portion of affected lands unless noted otherwise)

Oil and Gas Management Areas (applies only to
portion of affected lands unless noted otherwise)

Private
Private
Private
Mineral
Mineral
Mineral
Ownership;
Ownership;
Ownership;
some Federal some Federal some Federal
Mineral
Mineral
Mineral
Ownership
Ownership
Ownership
and Leased
and Leased
and Leased
Federal
Federal
Federal
Minerals
Minerals
Minerals

Private
Mineral
Ownership
and some
Federal
Mineral
Ownership

Private Mineral Ownership; some Federal
Mineral Ownership and Leased Federal
Minerals

Private
Mineral
Ownership

Private
Private
Private
Mineral
Mineral
Mineral
Ownership;
Ownership;
Ownership;
some Federal some Federal some Federal
Private Mineral
Mineral
Mineral
Mineral
Ownership
Ownership
Ownership
Ownership
and Leased
and Leased
and Leased
Federal
Federal
Federal
Minerals
Minerals
Minerals

Low
Low

Low
Low

Low
Low

Low
Low

Low
Low

Low
Low

Low
Low

Low
Moderate

Low
Moderate

Low
Moderate

Low
Low

Low

Low

Low

Low

Low

Low

Low

Low

Low

Low

Low

No Surface Occupancy

No Surface
Occupancy

No Surface
Occupancy

No Surface
Occupancy;
Seasonal
Limitations

No Surface
Occupancy;
Seasonal
Limitations

No Surface
Occupancy;
Controlled
Surface Use;
Seasonal
Limitations

No Surface
Occupancy;
Controlled
Surface Use;
Seasonal
Limitations

1/2 mi. NSO buffer; Leased
Federal Minerals

No Surface Occupancy

1/2 mi. NSO 1/2 mi. NSO 1/2 mi. NSO
buffer; Leased buffer; Leased buffer; Leased
Federal
Federal
Federal
Minerals
Minerals
Minerals

1/2 mi. NSO
buffer;
Traditional
Traditional
Traditional Leasing Area; Leasing Area;
Leasing Area;
Leased
Leased
Leased
Federal
Federal
Federal
Minerals
Minerals
Minerals

1/2 mi. NSO buffer; Leased Federal Minerals

Major Oil and Gas Field Locations

Conventional Gas Development Potential

Coal Bed Natural Gas Development Potential

Riley Ridge

Riley Ridge

Big PineyLaBarge CAP

Low (<20 wells per township)

Low (<20
wells per
township)

Low (<20
wells per
township)

Low (<20
wells per
township)

Moderate (20100 wells per
township)

Moderate (20- Moderate (20- Moderate (20- Moderate (20- Moderate (20100 wells per 100 wells per 100 wells per 100 wells per 100 wells per
township)
township)
township)
township)
township)
Moderate to
Moderate to
Moderate (20Very Low to
Very low (<2
High (20-500 High (20-500
100 additional
Moderate
wells per
additional
additional
wells per
(<100 wells per
township)
wells per
wells per
township)
township)
township)
township)

Moderate (20-100 wells per township)

Low (<20 additional wells per
township)

Low (<20
additional
wells per
township)

Low (<20
additional
wells per
township)

Low (<20
additional
wells per
township)

Very low (<2
wells per
township)

Very low (<2 additional wells per township)

699

<1

5

14

9

612

11

280

407

10

39

163

<1

<1

5

<1

181

<1

159

158

<1

<1

Very Low (only
at pumping
station
diversion, one
draw and
Kilpecker
Creek)

Moderate to High (mostly irrigated lands;
floodplain high)

Very Low
(possibly
some local
riverine
wetlands)

Very Low
(possibly
some local
riverine
wetlands)

Very Low (only
in lower Muddy
Creek and at
South Piney
Creek
crossing)

2AB

2AB

Environmental and Cultural Resources
Environmental Issues
Wetlands
NWI Wetlands (acres)
NWI Wetlands minus overlapping irrigated
acreage (acres)

Relative Wetlands Impacts

WDEQ/WGFD Stream Classification

Sage Grouse Leks

Sage Grouse Habitat
Big Game Habitat - Crucial Range (acres for
reservoir, miles for canals/pipelins)
Antelope
Elk
Moose
Mule Deer
Rocky Mountain Goat
White Tail Deer
Big Game Habitat - Other Season Use (acres for
reservoir, miles for canals/pipelins)
Antelope
Elk
Moose
Mule Deer
Rocky Mountain Goat
White Tail Deer
Big Game Habitat - Parturition (birthing) (acres for
reservoir, miles for canals/pipelins)
Antelope

Moderate to Very Low (only Very Low (only
Low (only in
Low (mostly
High (some
narrow
narrow
North Horse
irrigated
irrigated lands;
riverine
riverine
Creek
lands)
floodplain
wetlands in
wetlands in
floodplain)
high)
some draws) some draws)

2AB

2AB

2AB

2AB

2AB

2AB (2C Kilpecker
Creek)

None (>3 mi. None (>3 mi. None (>3 mi. None (>3 mi. None (>3 mi. None (2 mi. to
to closest lek) to closest lek) to closest lek) to closest lek) to closest lek) closest lek)

2AB

2AB

None (two leks at 1.4 mi.)

Moderate to
Moderate to
High (some
High (some
irrigated lands; irrigated lands;
floodplain
floodplain
high)
high)

2AB

None (one lek
at 1.4 mi.)

2AB

None (>3 mi. None (one lek None (+/- 3 mi.
to closest lek) at 1.4 mi.)
to closest lek)
Minor portions
Portions of
of reservoir
reservoir rim
rim

Portions of reservoir rim

>3/4 of
alignment

>3/4 of
alignment

<1/3 of
alignment

+/- 1/2 of
alignment

Portions of reservoir area

+/- 1/2 of
alignment

0
0
250
11
0
0

0.0
0.0
2.3
0.0
0.0
0.0

0.0
0.0
0.0
0.0
0.0
0.0

0.0
0.0
4.0
0.0
0.0
0.0

0.0
0.0
1.2
0.0
0.0
0.0

0
0
430
0
0
0

0.0
0.0
3.0
0.0
0.0
0.0

0
0
660
0
0
0

0
0
270
0
0
0

0.0
0.0
2.8
0.0
0.0
0.0

0.0
0.0
0.4
0.0
0.0
0.0

0.0
0.0
1.9
0.0
0.0
0.0

0.0
0.0
2.4
0.0
0.0
0.0

0
0
610
0
0
0

0.0
0.0
2.5
0.0
0.0
0.0

0

0.0

0.0

0.0

0.0

0

0.0

+/- 1/2 of
alignment

None

0
520
770
0
0
0

0.0
0.0
1.6
0.0
0.0
0.0

1.7
0.0
2.5
0.3
0.0
0.0

0
0
0
890
0
0

0
0
170
231
0
0

0.0
0.0
1.1
3.5
0.0
0.0

0.0
0.0
5.4
0.0
0.0
0.0

0

0

0.0

0.0


## Table 1
Characteristics of Water Storage/Supply Alternatives

<table>
<thead>
<tr>
<th>Alternative #</th>
<th>SDHI Site #</th>
<th>Site Name</th>
<th>North Horse Creek Supply Canal</th>
<th>South Horse Creek Supply Canal</th>
<th>Middle Piney Creek</th>
<th>Other Roads</th>
<th>Highways</th>
<th>Residences/Facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SEH-15</td>
<td>Horse Pass</td>
<td>2.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>SEH-15</td>
<td>Haines Flat</td>
<td>2.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>SEH-15</td>
<td>Mickelson Creek</td>
<td>2.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

### Elements
- **Supply and Delivery Facilities**
  - Dam and Hydraulic Structures
  - Infrastructure/Ownership
- **Grazing Allotments**
- **Access**
  - Pipelines
  - Delivery Canals
  - Supply Canals
  - Emergency Spillway
  - Outlet Works
- **Service Spillway**
- **Storage Efficiency**
  - Design Capacity (cfs)
  - Terrain
  - Length (miles)
  - Cut Volume (cy/1000)
  - Approximate Length (feet)
  - Design Capacity (cfs)
- **Proposed Type**
  - Outlet Elevation (feet)
  - Proposed Type
  - Approximate Width (feet)
  - Design Capacity (cfs)
- **Total Earthwork Fill Volume**
  - Above Ground Earthwork Volume (1000 cy)
  - Maximum Dam Height (feet)
  - Crest Width (ft)
  - Total Crest Length (feet)
  - Crest Length @ Water Surface (feet)
  - Crest Elevation (feet)
  - Freeboard/Head on Spillway (ft)
  - Federal
  - State
  - Private

### Infrastructure/Utilities Conflicts
- **Cultural Resources**
- **Other roads**
- **Highways**
- **Canals/Ditches**
- **Irrigated Lands Inundated**
- **Communication Lines**
- **Residences/Facilities**
- **Roads**

### Other
- **Power Lines**
- **Pipelines**
- **Railroads**
- **Residences/Facilities**
- **Roads**

### Visual Resources
- **Historic Trail Viewsheds**
- **Historic Trails**
- **Historic Trail Vacantlands**

### Other Species
- **Sensitive Plants**
- **Sensitive Wildlife**
- **Raptor Nesting Area**
- **Sensitive TLP & Small Watershed**
- **Sensitive Bird & Bird Habitat**
- **Sensitive Fish & Fish Habitat**

### Species
- **Grizzly Bear**
- **Gray Wolf**
- **Western Yellow-Billed Cuckoo**
- **Bald Eagle**
- **Bighorn Sheep**
- **Moose**
- **Elk**
- **Rocky Mountain Goat**
- **Mule Deer**

### Observations
- **Possible fatal flaw**
- **Unfavorable**
- **Marginal**
- **Favorable**
- **Very Favorable**
### Alternative 1 – Horse Creek/Cottonwood Creek Storage

#### Major Elements

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
</table>
| Haines Flat Reservoir (SEH-15) | One dam on South Horse Creek – 60 ft. high  
One dam offstream to North Cottonwood Creek – 110 ft. high  
Reservoir capacity – 42,000 ac.-ft.  
Reservoir surface area – 2.2 sq. mi. |
| North Horse Creek Supply Canal | Canal length – 6.0 mi.  
Capacity – up to 400 cfs  
Period of operation – non-winter months, primarily May-June |
| North Cottonwood Creek Supply Canal | Canal length – 6.1 mi.  
Capacity – 200 cfs  
Period of operation – non-winter months, primarily May-June |
| Horse Creek Delivery Canal | Canal length – 6.3 mi.  
Capacity – 80 cfs  
Period of operation – irrigation season  
Delivery area – lower 2/3 of North Horse Creek |
| North Cottonwood Creek Pumping Station/Delivery Canal to South Cottonwood Creek | Canal length – 4.3 mi.  
Pumping station lift – 60 ft.  
Pumping/canal capacity – 30 cfs  
Delivery area – lower 1/3 of South Cottonwood Creek |

#### Function/Operation

| Source(s) of Supply | North Cottonwood Creek – 25,000 ac.-ft. physical inflow  
South Horse Creek – 12,000 ac.-ft. physical inflow  
North Horse Creek – 48,000 ac.-ft. physical inflow (as needed) |
|---------------------|-------------------------------------------------------------------|
| Irrigated Lands Served | Gravity release from storage:  
Lower 2/3 of North Cottonwood Creek – 5,000 ac./up to 3,800 ac.-ft. shortage  
South Horse Creek – 800 ac./up to 1,000 ac.-ft. shortage  
Horse Creek – 1,500 ac./up to 3,000 ac.-ft. shortage  
Exchange:  
Exchange from Cottonwood Creek to upper 1/3 of North Cottonwood Creek as necessary and appropriate |

#### Key Assumptions/Comments

- Evaluate advantages of North Horse Creek Delivery Canal vs. larger carryover storage in Haines Flat Reservoir relative to meeting shortages
- Evaluate ability to satisfy South Cottonwood Creek shortages from Mickelson Reservoir only, without pump station/delivery canal from North Cottonwood Creek
- Supply canals assumed to operate only March through October (check implications of one-fill rule)
- Evaluate exchange potential to satisfy shortages in approximately upper 1/3 of North Horse Creek
## Alternative 2 – South Cottonwood Creek Storage

<table>
<thead>
<tr>
<th><strong>Major Elements</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mickelson Creek Reservoir (Site15)</strong></td>
</tr>
<tr>
<td>Dam on South Cottonwood Creek – 100 ft. high</td>
</tr>
<tr>
<td>Reservoir capacity – 32,000 ac.-ft.</td>
</tr>
<tr>
<td>Reservoir surface area – 1.7 sq. mi.</td>
</tr>
<tr>
<td><strong>South Cottonwood Creek Supply Canal</strong></td>
</tr>
<tr>
<td>Canal length – 6.0 mi.</td>
</tr>
<tr>
<td>Capacity – 65 cfs</td>
</tr>
<tr>
<td>Delivery area – middle 1/2 of South Cottonwood Creek</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Function/Operation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source(s) of Supply</strong></td>
</tr>
<tr>
<td>South Cottonwood Creek – 22,000 ac.-ft. physical inflow</td>
</tr>
<tr>
<td><strong>Irrigated Lands Served</strong></td>
</tr>
<tr>
<td>Gravity release from storage:</td>
</tr>
<tr>
<td>Middle 1/2 of South Cottonwood Creek – 4,000 ac./up to 10,000 ac.-ft. shortage</td>
</tr>
<tr>
<td><strong>Exchange:</strong></td>
</tr>
<tr>
<td>Exchange from lower South Cottonwood Creek and/or Cottonwood Creek to upper 1/4 of South Cottonwood Creek as necessary and appropriate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Key Assumptions/Comments</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluate ability to satisfy South Cottonwood Creek shortages from Mickelson Creek Reservoir only, without pump station/canal from North Cottonwood Creek delivering release from Haines Flat Reservoir (Alternative 1)</td>
</tr>
<tr>
<td>Evaluate exchange potential to satisfy shortages in approximately upper 1/4 of South Cottonwood Creek</td>
</tr>
</tbody>
</table>
Alternative 3 (SEH-10): Whiskey Creek Reservoir

North Piney Creek
### Alternative 3 – North Piney Creek Storage

<table>
<thead>
<tr>
<th>Major Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whiskey Creek Reservoir (SEH-10)</td>
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<tr>
<td></td>
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<tr>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Function/Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source(s) of Supply</td>
</tr>
<tr>
<td>Irrigated Lands Served</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
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</tbody>
</table>

### Key Assumptions/Comments
- Coordinate gravity release operation/exchange potential with pumping/canal from mainstem Green River (Alternative 5) to best serve all of North Piney Creek
### Alternative 4 – South/Middle Piney Creek Storage

<table>
<thead>
<tr>
<th>Major Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fish Creek Reservoir (SEH-12)</strong></td>
</tr>
<tr>
<td>Dam on South Piney Creek and Fish Creek – 80 ft. high</td>
</tr>
<tr>
<td>Reservoir capacity – 46,000 ac.-ft.</td>
</tr>
<tr>
<td>Reservoir surface area – 1.9 sq. mi.</td>
</tr>
<tr>
<td><strong>Middle Piney Creek Delivery Canal</strong></td>
</tr>
<tr>
<td>Canal Length – 4.5 mi.</td>
</tr>
<tr>
<td>Canal Capacity – 50 cfs</td>
</tr>
<tr>
<td>Delivery area – middle 1/2 of Middle Piney Creek</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function/Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source(s) of Supply</strong></td>
</tr>
<tr>
<td>South Piney Creek – 20,000 ac.-ft. physical inflow</td>
</tr>
<tr>
<td>Fish Creek - 11,000 ac.-ft. physical inflow</td>
</tr>
<tr>
<td>Middle Piney Creek - 12,500 ac.-ft. physical inflow if needed</td>
</tr>
<tr>
<td><strong>Irrigated Lands Served</strong></td>
</tr>
<tr>
<td>Gravity release from storage:</td>
</tr>
<tr>
<td>Upper 3/4 of South Piney Creek and middle 1/2 of Middle Piney Creek – 12,000 ac./up to 20,000 ac.-ft. shortage</td>
</tr>
<tr>
<td>Exchange:</td>
</tr>
<tr>
<td>Exchange from lower South and/or Middle Piney Creek(s) as necessary and appropriate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key Assumptions/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Modeling required to check for inflow (supply) limitation on reservoir sizing/operations</td>
</tr>
<tr>
<td>▪ Evaluate need/feasibility to capture available flows (up to 4,400 ac.-ft.) on Middle Piney Creek, including existing Middle Piney Reservoir</td>
</tr>
<tr>
<td>▪ Coordinate gravity release operation/exchange potential with pumping/canal from mainstem Green River (Alternative 5) to best serve all of South and Middle Piney Creeks</td>
</tr>
</tbody>
</table>
Alternative 5: Pumping from Green River
### Alternative 5 – Pumping to Lower Piney Creek Subbasins from Green River

<table>
<thead>
<tr>
<th>Major Elements</th>
<th></th>
</tr>
</thead>
</table>
| **Pumping Station** | Location – Green River (2.4 mi. ESE of Big Piney)  
Pumping station lift – 180 ft. |
| **Pipeline (from pumping station to delivery canal)** | Pipeline length – 4.4 mi. |
| **Lower Piney Creeks Delivery Canal** | Canal length – 8.3 mi.  
Capacity – up to 75 cfs  
Period of operation – irrigation season  
Delivery area – lower portions of North, Middle and South Piney Creeks |

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<thead>
<tr>
<th>Function/Operation</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Source(s) of Supply</strong></td>
<td>Green River</td>
</tr>
</tbody>
</table>
| **Irrigated Lands Served** | Direct service by pumping:  
Lower portions of North, Middle and South Piney Creek subbasins – 5,000 ac.  
Exchange:  
Pumping to lower subbasins allows exchange of up to 15,000 ac.-ft. to address shortages higher in subbasins |

<table>
<thead>
<tr>
<th>Key Assumptions/Comments</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumed that water is available from mainstem Green River in the amount and at the time needed during the irrigation season</td>
<td></td>
</tr>
<tr>
<td>Coordinate gravity release operation/exchange potential under Alternatives 3 and 4 (North Piney Creek Storage and South/Middle Piney Creek Storage, respectively) with pumping from mainstem Green River to best serve all of Piney Creeks shortages</td>
<td></td>
</tr>
</tbody>
</table>
BLM initial list of issues to address in consideration of the Westside Storage Level II Study

Cultural Resources

The Environmental/Permitting Issues paragraphs are inadequate. Native American concerns aren’t included and archaeological resources are relegated to a status of “other cultural resources”. Since dam building requires Corps of Engineer 404 compliance, full and complete cultural resources inventory, evaluation and mitigation studies are required of all project elements. All proposals are high in known or suspected cultural resources, including sites considered sacred, sensitive or of importance to known Native American groups. Mitigation of proposed adverse effects could represent a significant expense.

Project 4, called Fish Creek, would adversely affect a Congressionally-designated National Historic Trail (NHT), and would destroy several miles of NHT. It also would inundate several known or suspected Emigrant graves along the Trail, a CCC camp and other known cultural resources that are eligible for National Register inclusion.

Tribal consultation
Alternative 2 would inundate an historic ranch/homestead
Coordination of the WWDC with SHPO and State Archaeologist
The North Piney Creek proposal would impact a known Native American burial. This significant impact would need to be assessed and mitigated.

Effects to Indian Trails
Table 1 completely ignores known or suspected archaeological resources, which would be potentially adversely affected by all of the proposals, and is thus inaccurate.
Impact to cultural and other resources due to construction of the various supply and delivery canals, ancillary facilities, pumping stations and the like are not addressed.

Riparian and watershed impacts

Existing water rights
Changes to groundwater (Quality, Quantity, Location)
Inundation of public lands by backed up water
Fluctuation of water levels within the reservoirs
Creation of new springs downstream of dams
Loss or creation of wetlands/riparian areas at and below the dams
The impact of upstream or downstream river channel disruption, erosion, down-cutting, displacement and restructuring; stream channel impacts upstream due to water level fluctuations within the dams
Effects to stream disruption and flow during filling

Livestock grazing

Changes in grazing (Are these reservoirs going to be fenced? How will that impact the use of private lands and BLM-administered grazing allotments?)
Changes in how livestock use the lands and location of fences (aside from those directly impacted by the impounded water)

**Recreation impacts**

Public access to the National Forest though South Piney Canyon
Changes in existing roads
Fishing access

**Wildlife habitat impacts**

Loss or creation of amphibian habitat (sensitive species included)
CRCT habitats and habitat connectivity
Will there be a conservation pool (with WGFD) for fisheries?
Impact of the North Piney Creek proposal on the North Piney Creek elk feed ground and elk movement in and through the area.
Effects to migration corridors
Impacts on trees in the areas of the reservoirs; eagle and other raptor nest sites?
Inundation of sage-grouse habitats
October 30, 2008

Wyoming Regulatory Office

Lawrence M. Besson, P.E.
Deputy Director
Wyoming Water Development Office
Dam and Reservoir Section
6920 Yellowtail Road
Cheyenne, Wyoming 82002

Dear Mr. Besson:

This letter is in response to a request we received from Short Elliott Hendrickson, Inc. (SEH) for comments on the Upper Green River Westside Storage Study. SEH is completing a Level II Study and is interested in identifying issues related to future permit requirements that should be considered in the analysis of water supply alternatives. The study area includes the Horse Creek, Cottonwood Creek, and Piney Creek watersheds between Daniel and Big Piney in Sublette County, Wyoming.

A Technical Memorandum (TM) provided by SEH summarizes the results of previous study efforts. The TM suggests that the project purpose is to provide additional water supply for irrigation of existing fields. Approximately 60 reservoir sites and several major canals were considered. The Level II Study will include more detailed evaluations of four preferred reservoir sites and related canals. The water storage sites are Haines Flat Reservoir, Mickelson Reservoir, Whiskey Creek Reservoir, and Fish Creek Reservoir. Another alternative under consideration is to pump water from the Green River and deliver it directly to properties in the lower Piney Creek watershed with no water storage component.

Several activities related to these five alternatives could require Department of the Army authorization pursuant to Section 404 of the Clean Water Act (33 U.S.C. 1344). Determining whether an activity is subject to regulation relies on our definition of "waters of the United States", which establishes geographic limits of our jurisdiction. In the March 28, 2000, edition of the Federal Register (Vol. 65, No. 60), our Headquarters in Washington D.C. (HQUSACE) announced new regulations at 33 CFR Part 331 implementing an administrative appeals process for “approved” jurisdictional determinations. This procedure became more complicated on June 5, 2007, when HQUSACE implemented guidance that requires extensive data collection, evaluation, and an administrative coordination procedure with the U.S. Environmental Protection Agency before exerting jurisdiction over many streams and wetlands. Therefore, processing jurisdictional determinations for aquatic resources at proposed water storage sites during a subsequent Level II Phase III study would be beneficial by completing the administrative processes early and establishing locations and boundaries of waters of the U.S.

Identifying locations and boundaries of wetlands using the National Wetlands Inventory (NWI) or other off-site mapping techniques is unreliable and often misleading when defining the limits of waters of the U.S. For example, the preamble to our regulations at 33 CFR Part 328.3 states that “Artificially irrigated areas which would revert to upland if the irrigation ceased” are generally not considered to be waters of the U.S. yet these areas are often mapped as wetland for the NWI. Therefore, we recognize that conducting formal wetland delineations for an entire project area covering several square miles could be unreasonable if a significant portion of the area would not be classified as waters of the U.S. Requesting approved jurisdictional determinations that establish outer limits of wetlands adjacent to other waters of the U.S. based on specific site conditions such as topography or hydrology criteria prior to conducting wetland delineations would be appropriate in areas where wetland characteristics arise due solely to historic irrigation practices.

Processing permits for water storage projects is challenging because it requires a comprehensive evaluation of the project purpose and need along with alternatives that satisfy the project purpose. We recognize that identification and detailed evaluation of the best opportunities to achieve multiple uses and benefits from one or more reservoirs is an important result of Level II studies. It’s also important to recognize that our federal action requires us to evaluate a range of “reasonable alternatives” under the National Environmental Policy Act (NEPA)(40 CFR 1502.14) and a range of “practicable alternatives” under the Section 404(b)(1) guidelines (40 CFR Part 230.10(a)). Reasonable and practicable alternatives are not necessarily synonymous and water supply alternatives are not limited to surface water storage only. Other alternatives may include conservation techniques, ground water utilization, and land management activities that affect water supply.

Conducting the alternatives analysis based on a watershed approach is much more valuable from our perspective because it does not artificially constrain the analysis. We recommend more detailed evaluations of irrigation system improvements, groundwater development, and land use management in addition to surface water storage throughout each of the three watersheds. That information would be valuable because it would expedite our consideration of alternatives when evaluating applications for surface water storage projects.

Detailed information on other environmental factors is also valuable when we evaluate the affected environment under NEPA and during our public interest review (33 CFR Part 320.4). Some of those factors are property ownership, land uses, recreation, transportation, food and fiber production, energy consumption and development, minerals and mining, fish and wildlife resources, cultural resources, water quality, flood plains, and stream channel stability. Other factors that we must consider are prime and unique farmland, air quality, aesthetics, public safety, Indian Tribes and treaties, and minority or low income populations. It is our
understanding that prior studies addressed several of these factors and more detailed evaluations
during a subsequent Level II Phase III study would be very beneficial.

We appreciate this opportunity to comment on the Upper Green River Westside Storage Study and are available for further discussions on these topics. Please contact Mr. Thomas Johnson in our office at (307) 772-2300 and reference file NWO-2008-02752 if you have any questions about these comments.

Sincerely,

Matthew A. Bilodeau
Program Manager
Wyoming Regulatory Office

Copy Furnished:

Douglas Yadon, P.E.
Short Elliott Hendrickson, Inc.
2637 Midpoint Drive, Suite E
Fort Collins, Colorado 80525
October 31, 2008

WER 11844
Short Elliott Hendrickson Inc.
Upper Green Westside Storage
Level II Study

Doug Yadon
Short Elliott Hendrickson Inc.
2637 Midpoint Drive, Suite E
Fort Collins, CO 80525-4432

Dear Mr. Yadon:

The staff of the Wyoming Game and Fish Department has reviewed the Upper Green Westside Storage Level II Study. We offer the following comments for your consideration.

Terrestrial Considerations:

Significance of Impacts

We recommend that the Wyoming Water Development Commission evaluate the significance of impacts to wildlife and habitat that may result from this proposed project. The scale and magnitude of constructing these reservoirs, and the wildlife species that depend on these areas for food and shelter, warrant detailed analysis of impacts. Additionally, we recommend that current and potential cumulative effects be identified and addressed.

Sage Grouse

We have significant concerns about potential impacts to important sage grouse habitats that may result from this project. The proposed project area provides important habitat for sage grouse. Sage grouse use the area for breeding, nesting, and brood rearing. It is important that the proposed reservoir developments do not impact the area’s ability to support and maintain sage grouse at or above their current population levels.

We recommend that sage grouse inventories be completed and analyzed prior to initiating this project. Sage grouse lek locations, nesting habitats, brood rearing areas, and wintering locations should be identified and plotted for detailed analysis of potential impacts. These areas should be strongly considered during the planning process.
Big Game and Trophy Game Seasonal Ranges, Migratory Corridors, and Bottlenecks

The project area is located in areas designated as winter/yearlong range for the Wyoming Range mule deer herd; spring/summer/fall range for the Sublette mule deer herd; crucial winter and winter/yearlong range for the Piney elk herd; crucial winter and winter/yearlong range for the Sublette moose herd; and spring/summer/fall range for the Sublette pronghorn herd. The area is also contains big game parturition habitat. In addition, the area is used for important daily big game movement as well as migration corridors to seasonal ranges.

Approximately 50-75% of the Sublette moose herd occupies the east slope of the Wyoming Range. The percentage of moose counted annually along the east slope of the Wyoming Range are observed in the following drainages:

- Piney Creeks: 32% (n=152-238 moose)
- Cottonwood Creeks: 24% (n=114-178 moose)
- Horse Creeks: 18% (n=85-134 moose)
- Beaver Creeks: 6% (n=28-45 moose)
- Green River from Warren Bridge to Cottonwood Creek: 20% (n=95-149 moose)

A thorough assessment of potential impacts to the Sublette moose herd should be completed prior to the final site selection of potential reservoirs. The loss of willow habitat in designated moose crucial winter range could result in significant impacts to this herd.

The area is also occupied by black bears and mountain lions during the spring, summer and fall. Black bears are suspected to build winter dens on the steep, heavily timbered north exposures of the project area.

Seasonal Stipulations

If development of the proposed water storage facilities occurs, we recommend that the following seasonal stipulations be applied in applicable portions of the project area.

- Avoid human activity in designated big game crucial range from November 15 – April 30
- Avoid human activity in designated big game parturition areas from May 1 – June 30
- Avoid human activity within ¼ mile of occupied leks from March 1 – May 15
- Avoid surface disturbing activity within 2 miles of an occupied lek or within identified nesting and early brood-rearing habitat from March 15 – June 30.
- Avoid human activity within designated sage-grouse winter habitat from November 15 – March 14

Sensitive, Threatened and Endangered Species, and Nongame Wildlife Issues

The proposed project area is used by many species of nongame birds and mammals. Some of these species may be designated as Sensitive, Threatened, Endangered, or Designated Candidate Species for potential listing under the Threatened and Endangered Species Act. Consequently, all surface-disturbance activities associated with the proposed water storage
project should adhere to the appropriate timing and acreage restrictions regarding raptor nest sites and riparian habitat. If necessary, consultation should occur with appropriate federal agencies regarding activities that may affect Threatened and Endangered Species.

We recommend that surveys be conducted on forested north-facing slopes for nesting avian species, with an emphasis on USFS Sensitive Species that include: northern goshawk, great gray owl, boreal owl, flammulated owl, and northern three-toed woodpecker. We recommend that the analysis identify sensitive and nongame wildlife habitat parameters within the project areas, and develop measures to maintain, and where possible, enhance habitat for species of concern.

**Canada lynx**

The most significant breeding population of Canadian lynx in Wyoming has historically occupied habitats in Townships 30 - 35 and Ranges 114-115. We have also identifies this habitat as most important for potential recovery of the species in Wyoming. We have studied a breeding pair of lynx in the in these Townships 1996 – 2001. Radio telemetry documented home ranges during the breeding season, and dens with kittens were located in T36N, R114, Sec33 and T35, R114, Sec4. In addition, reintroduced lynx in Colorado have also dispersed to Wyoming and occupy habitats in a pattern similar to Wyoming lynx we studied prior to Colorado’s reintroduction effort. Habitats in this and adjacent sections are valuable for population egress and ingress.

The potential impacts of open roads on Canada lynx were identified as a significant issue in the development of the lynx conservation strategy. The Wyoming Range may be the most important recovery area for this species in the future, provided that adequate habitat can be maintained, especially winter foraging habitat.

**Potential Impacts to Hunting Opportunity**

There is potential for significant impacts to big game hunting if high intensity development occurs throughout the entire project area. Additional roads will likely increase motorized access and expose big game animals to higher levels of stress throughout the year. The most significant impacts will likely occur to localized sub-populations of the Wyoming Range and Sublette mule deer herds, Sublette moose herd, and Piney elk herd, which occupy the east slope of the Wyoming Range. The proposed reservoir sites and any associated roads should be designed in a manner that will not cause big game to be displaced from their important seasonal ranges. Moose population numbers and distribution will likely be impacted by the development and upgrade of roads in the area. We recommend a comprehensive analysis of road design and placement. Roads should not be developed in or adjacent to crucial riparian willow habitats in order to minimize displacement of moose and the potential for increased illegal hunting.

**Wyoming BLM Standard Mitigation Guidelines for Surface-Disturbing Activities**

The Pinedale Resource Management Plan (RMP) provides specific guidance on what activities may warrant standard mitigation. In order to comply with the Pinedale RMP, "Surface
Disturbance Mitigation Guidelines and Wildlife Mitigation Guidelines (pages 58 and 59) should be thoroughly evaluated in cooperation with USFS, BLM, and WGFD personnel to determine their relevance to the proposed reservoir developments. In addition, we recommend that during the analysis a “Mitigation Proposals” section be included in the document that proposes and analyzes a series of mitigation actions in order to offset potential impacts to crucial wildlife habitats.

**Control and Spread of Noxious Weeds**

We recommend that preventive measures to control the establishment and spread of noxious plants be considered. Measures should be identified to prevent their establishment and aggressively treat invasive species that may result from the proposed development.

**Department Involvement**

We would like to be active participants and cooperators in the analysis of this potential development. Our personnel stationed in the our Pinedale Regional Office have the expertise to address wildlife and habitat related issues as they may pertain to this water storage proposal. Please do not hesitate to contact Wildlife Management Coordinator – Scott Smith at 307-367-4353 to coordinate any requests for information.

**Aquatic Considerations:**

Based on what we presently know of the five alternative dam sites and their potential operation, none of these potential reservoirs are a high priority to us in terms of additional reservoir fishing opportunities to Wyoming for nonnative trout species. However with further review of the project, an alternative site may be beneficial to native fish restoration and the creation of a native sport fish reservoir. At this time, we have not conducted any detailed analyses or quantified the project’s overall effects to the aquatic resources in the affected areas of the project. As a consequence all of the comments provided here should be viewed as preliminary assessments and may change as additional project information becomes available. Note also that these comments may not represent a complete listing of potential project issues and effects.

**BACKGROUND INFORMATION**

The alternative reservoir sites are located from the Horse Creek watershed south to the South Piney watershed in the Wyoming Range. The impacted areas also include those watersheds where water will be supplied or pumped. For ease with commenting on this draft proposal, we will discuss the native species present throughout the Wyoming Range and the concerns and issues that may be related to all alternatives instead of focusing on each individual site.

The native amphibians, reptiles, and fish present within the Wyoming Range area include northern leopard frog, tiger salamander, boreal chorus frog, boreal toad, spotted frog, mottled sculpins, mountain suckers, flannelmouth suckers, bluehead suckers, roundtail chub, speckled
dace, mountain whitefish, and Colorado River cutthroat trout. Of those listed species all amphibians except boreal chorus frogs are species of concern and of the fish species this includes Colorado River cutthroat trout, flannelmouth suckers, bluehead suckers, and roundtail chub. Even though the other fish species are not listed as species of concern at this time, impacts to their habitats and migration are still a concern. Electrofishing surveys have been completed in each of the proposed drainages. However most trend surveys were located on Forest lands instead of private lands. In 2005 – 2006 a crew was hired to complete a one time only assessment of native fish species present on private lands.

We have identified a list of native species within their historic range that are considered a species of concern. The basic Native Species Status (NSS) matrix provides a conceptual tool for explaining the basic principals of the NSS classifications and fish biologists within the state to determine each native species ranking used this matrix. Currently, limiting factors include habitat, human activity levels, genetics, invasive species, disease, environmental contaminants and climate change. Additional limiting factors may be identified in the future. Species listed within our matrix are identified within a certain NSS category. Those species that fall in the NSS 1, NSS 2, and NSS 3 categories are considered species of greatest conservation need (SGCN).

The amphibian species of concern include boreal toad (NSS 1), northern leopard frog (NSS 3) and columbia spotted frog (NSS 3). Native fish species include roundtail chub (NSS 1), bluehead sucker (NSS 1), flannelmouth sucker (NSS 1), and Colorado River cutthroat trout (NSS 2).

Roundtail chub, bluehead sucker and flannelmouth sucker populations are greatly restricted in numbers and distribution and extirpation is possible. Habitat reduction is the main factor limiting roundtail chub populations. For suckers the main limiting factor is introgression with nonnative sucker species. However habitat alterations have played a significant part in the decline of these species also. Due to the declines, state and federal agencies, have joined together and developed a range-wide conservation agreement and strategy for the three species in the states of Wyoming, Utah, New Mexico, Arizona, and Colorado (Utah Department of Natural Resources 2006). The goal is to ensure the persistence of these species throughout their historic range. Each state has developed their own management plan that will address the overall objectives stated in the CAS.

Roundtail chubs typically inhabit pool-riffle habitat in flowing water. Adults favor slow moving deep pools with access to cover with water temperatures ranging from 0 to 32 C (Bezzerides and Bestgen 2000). Long distance migrations have not been recorded but roundtail chub are known to move some distance during spawning season. Unique populations of roundtail chub reside in some of the Finger Lakes located around Pinedale, WY in Sublette County. In flowing water, spawning usually occurs in deep pools or runs. The impacts of the disruption of access to diverse stream habitats by the creation of in-channel barriers of any kind (physical, chemical or thermal) and the replacement of flowing water habitat with standing water habitat such as a reservoir on roundtail chub is unknown.

Flannelmouth suckers typically inhabit pools and deeper runs in flowing water systems. They are occasionally found in lakes such as the Finger Lakes located in Pinedale, WY. This
species uses a wide variety of habitat types and seem to prefer hard substrate rather than sand or silt (Bezzerides and Bestgen 2000). Long distance migrations are not common however they may be important for maintaining smaller isolated headwater populations. Spawning occurs from March to June depending on the system. Water temperatures of 6 to 19°C are desired.

Bluehead suckers are found in small or large streams. Adults prefer deep water and commonly seek out area with cover. Fast current and rocky substrate are necessary habitats for bluehead sucker. Research indicates that they are infrequently found in lakes and prefer large, cool streams with water temperatures less than 20°C (Bezzerides and Bestgen 2000). Water temperature during spawning is typically around 15 to 25°C.

Colorado River cutthroat trout (NSS2 species) populations are also physically isolated in much of their historic range and overall are not stable. Invasive species and habitat degradation have impacted the persistence of this species and has prompted biologists in the states of Colorado, Utah and Wyoming to develop a conservation agreement and a strategy for this subspecies. Implementation of the Agreement and its associated Conservation Strategy will reduce or eliminate habitat issues and hybridization issues (CRCT Conservation Team 2006). It should be noted that Colorado River cutthroat trout have been petitioned for listing as an endangered species under the U.S. Fish and Wildlife Service (USFWS) Endangered Species Act several times and undoubtedly will be petitioned for listing again in the near future.

Colorado River cutthroat trout evolved in flowing water though populations do persist in some reservoir environments where there is adequate habitat for them to complete their entire life history. Cutthroat trout require cold water (preferably less than 65°F) for all life stages. Spawning and rearing streams tend to be cold and nutrient poor. Colorado River cutthroat trout seek out gravel substrate in riffles and pool crests for spawning and they require substrate relatively clean of fine sediment.

Northern leopard frogs, boreal toads, and columbia spotted frogs have been located in the Wyoming Range. These species are typically found in moist habitat located in the foothills and mountains of Wyoming (Baxter and Stone 1980). Small ponds are necessary for breeding and rearing. Little is known about their distribution within the proposed dam sites.

POTENTIAL PROJECT-RELATED EFFECTS:

All reservoirs cause significant changes in the natural characteristics of flowing streams. Specifically, dams and the water released from reservoirs is known to affect hydrologic patterns (intra- and inter-annual flow variability patterns that many aquatic organisms are adapted to), stream connectivity (up and downstream passage for aquatic organisms, nutrients, and bedload materials), geomorphology (the physical form and function of stream channels including erosion processes and stream bank stability), biology (the number and kinds of organisms that occur within the reservoir footprint and downstream channel – including fish, terrestrial wildlife, and riparian vegetation), and water quality (temperature, chemistry, and suspended sediments). A good source of information about these effects and supporting documentation can be found in Annear et al. (2004). Should any of these dams be built we anticipate all of these kinds of effects, though some may be of more significance than others depending on the location.
Likewise, some effects may be more easily mitigated than others. Detailed, site-specific studies that may take several years to complete will be required to quantify project-related effects and develop appropriate mitigation strategies. Some but not all of the specific effects that might occur are noted below.

Water temperature in the reservoir may reach unsuitable temperatures for trout and could limit or preclude angling opportunities for cold-water species. Water temperature may not be an issue in the short term but with on-going climate changes and retention of sediments, water may reach temperatures not tolerant to cold-water fish. Water temperatures in the streams below the proposed reservoir sites (and resultant decreased flow in the river) could impact trout populations. The temperature of releases during the winter could also be a concern. The water in reservoirs typically stratifies according to thermal properties during the winter (and summer). In the winter, relatively warm water is found at the bottom of reservoirs, but the release of this water disrupts natural ice forming processes in the stream below the dam. Such changes can affect habitat and survival of aquatic species below the dam (Annear et al. 2002). To avoid or minimize these undesirable consequences, releases should be made from the surface of the reservoir where water temperatures are closer to the temperature of water flowing into the reservoir. Detailed stream temperature simulation studies should be done to address all of these concerns.

Nonnative trout species are present in the project areas and are a concern to the persistence of the native fish species (especially Colorado River cutthroat trout and native suckers). Removal of all nonnative species from all tributaries within the desired project area could be a benefit to the status of Colorado River cutthroat trout and native suckers and possibly preclude the likelihood of these species being listed as threatened or endangered in the future. We encourage the project sponsor to include this feature in the final project and coordinate closely with us on the details of conducting this work.

Existing information suggests that the timing, duration and magnitude of flows associated with reservoir releases in any of the alternative sites may change significantly. Should this occur it is highly likely that such change in the hydrologic regime will alter geomorphological processes (erosion and deposition) and change the channel shape as well as water quality. More specifically, accelerated stream bank and streambed erosion is possible and the channel would either widen or deepen depending on what sediments are mobilized (bank or bed) and where they are deposited. As a consequence, we encourage the project sponsor to conduct a thorough geomorphological analysis of how future flow releases will affect the stream channel below the dam.

A main issue for off- or on-channel sites will be spring spawning. For successful spawning below the dam site it will be important to not release too much water to early in the year yet be sure to leave enough water for channel maintenance below the diversion. On-channel sites we'll have somewhat similar concerns as well as ensuring enough properly timed flow to maintain in channel and riparian processes.

There is no mention in the report of issues associated with riverine connectivity (passage or entrainment) for fish or other aquatic organisms. This is common to all alternatives. The loss
of fish species in canals has been documented in the Pinedale Region and in other areas. The increased number of water diversion structures associated with this project would likely increase loss of fish and inhibit upstream movement of all fish. Reduced flows in the river resulting from increased water diversion would further reduce opportunities for upstream movement during critical periods.

Aquatic nuisance species is a growing concern and these unwanted species can spread in many ways. To help prevent the spread of unwanted species it would be recommended that water from whirling disease positive streams not be delivered to non-positive waters. Increase recreational use in the area would also increase the likelihood of spreading other aquatic nuisance species.

The quantity and quality (including species diversity) of riparian vegetation and habitats has a direct effect on the form and function of in-channel stream features as well as the terrestrial wildlife that reside in riparian areas. We anticipate potential riparian effects caused not only by inundation of existing habitats by a new reservoir but also as a consequence of the altered hydrologic regime of reservoir releases. We do not anticipate riparian vegetation to develop along the reservoir shoreline that will offset existing stream riparian habitats because the annual fluctuation patterns of the new reservoir will not support such growth. Likewise, the loss of overbank flooding along the stream below the dam will preclude the maintenance and development of riparian habitats over an extended length of stream. Wetland habitats associated with the existing riparian corridor will also be lost with the inundation of the project area and potential loss of overbank flooding below the dam. Wetland communities do not typically develop in the shoreline around irrigation reservoirs. As a consequence, riparian and wetland habitats within the project area (including up and downstream stream segments) should be quantified and a mitigation plan developed to offset those losses.

ISSUES

The following need to be included in the environmental issue list and evaluated in detail for each alternative. This issue list is subject to change as the project develops and certainly may not be a complete list. Issues listed may not necessarily be of concern for all the alternatives.

- Impacts to wetlands and riparian habitat inundated by the reservoir and the habitat downstream.
- Changes in flow regimes and its impacts on riparian habitat, streambanks, spawning habitat and other issues related to channel function
- Transfer of aquatic nuisance species with the delivery of water across divides and with the potential increased use if the storage area was managed as a recreational reservoir.
- Impacts to habitat and life history of species of greatest conservation needs. This includes boreal toads, northern leopard frog, columbia spotted frog, flannelmouth sucker, bluehead sucker, roundtail chub, and Colorado River cutthroat trout.
- Inundation of roads that provide public access recreational areas above the reservoirs.
• Issues associated with riverine connectivity (passage or entrainment) for fish and other aquatic organisms.
• Potential increase in water temperatures and associated impacts to aquatic organisms and recreational opportunities.
• Fish passage and entrainment issues for all fish species.
• Address instream flow, or minimum flow, for each potential site. Discuss a seasonally appropriate instream flow regime for each alternative (Annear et al. 2004). Our agency has considerable expertise in this field and we encourage the project sponsor to work closely with our staff on this project feature.
• Address the need for a maximum depth of the reservoir for each alternative. For this project to achieve one of its potential purposes as a recreational fishery, a minimum fishery pool will be needed to ensure protection of this public value. We encourage the project sponsor to note that a guaranteed minimum fishery pool will be provided. Our agency has considerable expertise in quantifying minimum fishery pool trade-offs and we encourage the project sponsor to work closely with our staff on this project feature.
• Outlet structure: To address downstream temperature concerns as described above, the outlet should include multiple penstocks to allow maximum flexibility to manage temperature of releases at all times of year. Target temperatures for summer will probably depend on a variety of factors and fishery management goals. The temperature of releases in the winter, if any, should approximate natural winter stream temperatures as closely as possible.
• Return irrigation flows (quantity and quality) may have significant effects on fishery resources in any of the potential streams. We encourage the project sponsor to conduct a detailed study to address the potential effects of return flows on fishery resources in receiving water bodies.

PRELIMINARY MITIGATION AND FISHERY ENHANCEMENT RECOMMENDATIONS – MAY NOT BE COMMON TO ALL ALTERNATIVES

Fish screens should be installed and maintained on all canals to prevent fish loss from any of the watersheds. Fish passage should not be inhibited on any of the drainages. If the proposed project proceeds, mitigation of these concerns (e.g. fish screen, fish ladders, and minimum flows at critical times) should be part of the plan.

Chemical treatments of the drainages to remove non-native trout and restore a genetically pure population of native trout and other native fish species would be a project benefit. If included, this effort should occur prior to construction of the proposed reservoir and may take up to 3 years or more to plan and complete. Our agency has considerable expertise in this area and we recommend the project sponsor work closely with our staff to plan and conduct this work. This work should be a project expense.
As part of the above fishery renovation effort, planning and funding should also be included to salvage native fish species from renovated stream segments or collect them in other streams and reintroduce them into these restored stream habitats once non-native fish have been removed.

The project should include a minimum fishery pool to maximize public benefits. The precise size of the pool cannot be determined at this time but for planning purposes, the project sponsor may use a figure of 30% of the storage at the maximum pool elevation.

Provide fish passage from the stream to the reservoir. A fish ladder at the reservoir and a minimum flow in the streams at critical times needs to be part of the plan.

An instream flow requirement for each alternative site should be a part of the overall mitigation plan but the present number being used by the project planners should be re-evaluated. In similar situations, it takes 12 to 18 months to plan a project, conduct field studies, analyze data, and generate recommendations for instream flow regimes. We encourage project planners to work closely with our staff to develop this project feature.

To ensure fish have adequate habitat for spawning and rearing, mitigation measures for the tributaries entering the reservoir are necessary. Instream channel habitat improvements upstream of the proposed reservoir would improve spawning and rearing habitat for all native species. Upland habitat improvements may also be appropriate to restore, maintain or enhance riverine habitat conditions for native fish species.

An appropriate quantity and quality of wetland and riparian habitats should be created and maintained for the life of the project. Among other species, this project feature is important for all life stages of northern leopard frog, boreal toad, and columbia spotted frog.

Thank you for the opportunity to comment.

Sincerely,

[Signature]

JOHN EMMERICH
DEPUTY DIRECTOR

JE:VS:gtb

cc: USFWS
Thank you for your letter, dated October 1, 2008 and received in our office on October 6, regarding the Upper Green Westside Storage Level II Study (Project). SEH is under contract to the Wyoming Water Development Commission to assess the feasibility and permitability of surface water reservoir storage and/or other water supply facilities. Four Project alternatives include siting dam(s) and a reservoir in Horse Creek, Cottonwood Creek, or Piney Creeks (North, Middle, and South) subdrainage basins between Daniel and Big Piney, in Sublette County, Wyoming. Three of the four alternatives include supply and/or delivery canals. A fifth alternative involves pumping water directly from the Green River to convey irrigation water to the lower Piney Creek subbasin via pipeline and canal.


You have already identified potential environmental issues that may include wetlands/riparian areas and threatened, endangered, candidate, and sensitive species which may occur in the Project area. In addition to those issues, we have concerns that migratory birds and important wildlife habitat could be affected by the project as discussed below.

Also your information listed gray wolf (Canis lupus) as a sensitive species. On July 18, 2008, a Federal District Court issued a preliminary injunction that immediately reinstated the Act’s protections for wolves in the northern Rocky Mountains. In September 2008, the Service requested the court vacate and remand the final delisting rule back to the Service. The court granted the Service’s request on October 13, 2008. The Service recently reopened the public comment period on its proposal to delist the gray wolf in the northern Rocky Mountains and intends to make a new final listing determination. At this time, the Act’s provisions currently in
effect are the same ones in effect before wolves were delisted on March 28, 2008. All wolves within Wyoming are now considered part of the nonessential experimental population. The Act provisions reinstated by the court are the same ones that were in effect before wolves were delisted on March 28, 2008. Although wolves in Wyoming currently remain listed and protected under the Act, additional flexibility is provided for their management under the provisions of the special regulations promulgated for the nonessential experimental population on January 6, 2005 (70 FR 1286) and January 28, 2008 (73 FR 4720). The Service recommends assessing potential effects to wolves in the vicinity that may be affected by the Project.

**Migratory Birds:** The MBTA, enacted in 1918, prohibits the taking of any migratory birds, their parts, nests, or eggs except as permitted by regulations and does not require intent to be proven. Section 703 of the MBTA states, "Unless and except as permitted by regulations ... it shall be unlawful at any time, by any means or in any manner, to ... take, capture, kill, attempt to take, capture, or kill, or possess ... any migratory bird, any part, nest, or eggs of any such bird..." The BGEPA, prohibits knowingly taking, or taking with wanton disregard for the consequences of an activity, any bald or golden eagles or their body parts, nests, or eggs, which includes collection, molestation, disturbance, or killing.

Work that could lead to the take of a migratory bird including an eagle, their young, eggs, or nests (for example, if you are going to construct new power lines in the vicinity of a nest), should be coordinated with our office before any actions are taken. Removal or destruction of such nests, or causing abandonment of a nest could constitute violation of one or both of the above statutes. Removal of any active migratory bird nest or nest tree is prohibited. For golden eagles, inactive nest permits are limited to activities involving resource extraction or human health and safety. Mitigation, as determined by the local Service field office, may be required for loss of these nests. No permits will be issued for an active nest of any migratory bird species, unless removal of an active nest is necessary for reasons of human health and safety. Therefore, if nesting migratory birds are present on, or near the project area, timing is a significant consideration and needs to be addressed in project planning.

If nest manipulation is proposed for this project, the project proponent should contact the Service’s Migratory Bird Office in Denver at 303-236-8171 to see if a permit can be issued for this project. No nest manipulation is allowed without a permit. If a permit cannot be issued, the project may need to be modified to ensure take of a migratory bird or eagle, their young, eggs or nest will not occur.

**Greater sage-grouse:** The Service is currently conducting a review to determine if the greater sage-grouse (*Centrocercus urophasianus*) warrants listing. Greater sage-grouse are dependent on sagebrush habitats year-round. Habitat loss and degradation, as well as loss of population connectivity have been identified as important factors contributing to the decline of greater sage-grouse populations rangewide (Braun 1998, Wisdom *et al.* 2002). Therefore, any activities that result in loss or degradation of sagebrush habitats that are important to this species should be closely evaluated for their impacts to sage-grouse. If important breeding habitat (leks, nesting, or brood rearing habitat) is present in the project area, the Service recommends no project-related disturbance March 1 through June 30, annually. Minimization of disturbance during lek activity, nesting, and brood rearing is critical to sage-grouse persistence within these areas. Likewise, if important winter habitats are present (Doherty *et al.* 2008), we recommend no project-related
We recommend you contact the Wyoming Game and Fish Department to identify important
greater sage-grouse habitats within the project area, and appropriate mitigative measures to
minimize potential impacts from the proposed project. The Service recommends surveys and
mapping of important greater sage-grouse habitats where local information is not available. The
results of these surveys should be used in project planning, to minimize potential impacts to this
species. No project activities that may exacerbate habitat loss or degradation should be
permitted in important habitats. Additionally, unless site-specific information is available,
greater sage-grouse habitat should be managed following the guidelines by Connelly et al. 2000
(also known as the WAFWA guidelines).

**Mountain plover:** The Service has withdrawn the proposal to list the mountain plover
(*Charadrius montanus*) and we will no longer be reviewing project impacts to this species under
the Act. We do, however, encourage providing continued protection for this species as it
remains protected under the MBTA. Measures to protect the mountain plover from further
decline may include (1) avoidance of suitable habitat during the plover nesting season (April 10
through July 10), (2) prohibition of ground disturbing activities in prairie dog towns, and (3)
prohibition of any permanent above ground structures that may provide perches for avian
predators or deter plovers from using preferred habitat. Suitable habitat for nesting mountain
plovers includes grasslands, mixed grassland areas and short-grass prairie, shrub-steppe, plains,
alkali flats, agricultural lands, cultivated lands, sod farms, and prairie dog towns.

**Colorado River water depletions:** Formal consultation is required for projects that may lead to
depletions of water to the Colorado River system. Federal agency actions resulting in water
depletions to the Colorado River system may affect the endangered Bonytail (*Gila elegans*),
Colorado pikeminnow (*Ptychocheilus lucius*), Humpback chub (*Gila cypha*), and Razorback
sucker (*Xyrauchen texanus*) downstream in the Green and Colorado River systems. In addition,
depletions may contribute to the destruction or adverse modification of designated critical habitat
for these four species.

In general, depletions include evaporative losses and/or consumptive use of surface or
groundwater within the affected basin, often characterized as diversions less return flows.
Project elements that could be associated with depletions include, but are not limited to, ponds
(detention/recreation/irrigation storage/stock watering), lakes (recreation/irrigation
storage/municipal storage/power generation), reservoirs (recreation/irrigation storage/municipal
storage/power generation), hydrostatic testing of pipelines, wells, dust abatement, diversion
structures, and water treatment facilities. Any actions that may result in a water depletion should
be identified. The document should include: an estimate of the amount and timing of average
annual water use (both historic and new uses) and methods of arriving at such estimates; location
of where water use or diversion occurs as specifically as possible; if and when the water will be
returned to the system; and what the water is being used for. Note that depending upon the
specific details of the project the Service may have more specific questions regarding the
potential consumptive use of water within the Colorado River system.

**Water Quality:** The NEPA analysis for the Upper Green River Westside Storage Level II study
should include an assessment of naturally-occurring trace element contamination (*e.g.* selenium)
from geologic formations upstream of the proposed reservoir sites. The Blind Bull, Aspen Shale, and Bear River geologic formations occur on the upper reaches of the Horse Creek, Cottonwood Creek, and Piney Creeks (North, Middle and South) watersheds. We could not find any site specific data for selenium for these formations; however, Case and Cannia (1988) identified these formations as having significant selenium present in localized areas.

Waterborne selenium concentrations greater than 2 μg/L could result in impacts to fish and aquatic birds inhabiting downstream receiving waters. Fish also can bioaccumulate selenium directly from the water as well as from their diet. Top level consumers in aquatic systems, such as waterfowl, can readily accumulate selenium to concentrations that lead to low reproduction, embryonic deformities and increased mortality (Ohlendorf et al. 1988). The current aquatic chronic criterion of 5 μg/L selenium is not adequate for preventing adverse effects on fish and aquatic birds. To protect fish, waterfowl, shorebirds, and other wildlife from adverse effects, waterborne selenium concentrations should be 2 μg/L or less (Skorupa and Ohlendorf 1991; Lemly 1993; Hamilton 2002). Furthermore, selenium bioaccumulates in aquatic vegetation and invertebrates. Aquatic invertebrates can contain concentrations 2 to 6 times those found in aquatic plants. Selenium can concentrate in the food chain up to 300,000 times the concentration in the water (Besser et al. 1993).

The NEPA analysis should also evaluate water quality impacts resulting from oil and gas development in the Upper Green River Westside Storage Level II study area and possible
discharge of oilfield produced water into the streams flowing into the proposed reservoirs. The U.S. Bureau of Land Management’s 2008 Pinedale Draft Resource Management Plan Revision and Environmental Impact Statement shows “intensively developed” oil and gas fields within the Upper Green River Westside Storage Level II study area.

Figure 2. Potential Oil & Gas development areas in the Upper Green River Westside Storage Level II study area.
Thank you for your efforts to ensure the conservation of threatened, endangered, and other species in Wyoming. If you have further questions regarding this letter, please contact our office at the letterhead address or phone Ann Belleman at (307) 578-5116.

Sincerely,

Brian T. Kelly
Field Supervisor
Wyoming Field Office

cc: WGFD, Non-game Coordinator, Lander, WY (B. Oakleaf)
    WGFD, Statewide Habitat Protection Coordinator, Cheyenne, WY (V. Stelter)

References


Appendix E
Technical Modeling Memo
Planning Model Development and Application for the Wyoming State Water Plan

May 2, 2008

Project No. 17132.00-0001
# Table of Contents

Section 1  Introduction....................................................................................................................1  
  1.1 Introduction .....................................................................................................................1  
  1.2 Purpose of this Memorandum .........................................................................................1  
  1.3 Memorandum Organization ............................................................................................2  
Section 2  Modeling Concepts ........................................................................................................4  
  2.1 Baseflows ........................................................................................................................4  
  2.2 Consumptive Use and Consumptive Irrigation Requirement ..........................................6  
  2.3 System Efficiency ............................................................................................................7  
  2.4 Demand ...........................................................................................................................8  
  2.5 Diversion Constraints ......................................................................................................9  
  2.6 Study Period ....................................................................................................................9  
  2.7 Summary of Key Points ................................................................................................10  
Section 3  Wyoming Planning and Models...................................................................................11  
  3.1 WWDO Level I Study ...................................................................................................11  
  3.2 WWDO Level II Phase I Study .....................................................................................13  
  3.3 WWDO Level II Phase II Study ....................................................................................15  
  3.4 WWDO Level II Phase III Study ..................................................................................16  
  3.5 Subsequent Rounds of Basin Plans ...............................................................................16  
  3.6 Wyoming State Engineer’s Office Studies ....................................................................17  
Section 4  Spreadsheet Model Compared with Simulation Model (Green River).......................18  
  4.1 Green River Basin Plan Round 1 Spreadsheet Model ...................................................18  
  4.2 StateMod Model of Upper Green ..................................................................................19  
  4.3 Summary Comparison Table .........................................................................................20  
Section 5  Moving From Spreadsheets to Simulation Models.....................................................26  
  5.1 Raw Input Data ..............................................................................................................26  
  5.2 Choice of Model Based on Available Data ...................................................................31  
  5.3 Estimated Input Data .....................................................................................................32  
  5.4 Recommendations on Data Collection .........................................................................35  
Section 6  Documentation Guidelines ..........................................................................................40  
Section 7  Model Update, Maintenance, and Storage .................................................................44
Appendix

APPENDIX A - Methodology to Convert Basin Spreadsheet Model Inputs to Simulation Model Inputs

APPENDIX B – CDSS Planning Model User Manual Table of Contents
Section 1

Introduction

1.1 Introduction

Computer models have been appropriated by scientists, engineers, and planners to address all types of questions related to water resources. This discussion is limited to models that focus on the distribution of the natural water supply with respect to both space and time; and the imposition of human management on the water supply. We use these models to make decisions about where to build projects that put water to beneficial use, how to size components of the project, and whether the impact of the project on the remaining supply is acceptable.

The State of Wyoming has invested, through its basin planning process, in spreadsheet models of the major rivers of the state. The purpose of the spreadsheets was to develop a general understanding of the availability of water for new projects to meet Wyoming’s water needs. The State recognizes that to analyze feasibility of project alternatives, and confidently identify the most appropriate one, a more detailed understanding of local hydrology and beneficiary needs is required.

1.2 Purpose of this Memorandum

The objective of this memorandum is to support development of more detailed models in the State, beginning with the Green River basin where there is recent specific experience with simulation modeling. The Green River experience provides a case study from which general guidelines or protocol can be drawn, having applicability in other basins. Thus one purpose of this memorandum is to suggest methods and approaches for dealing with the typical challenges that modelers face, such as how to deal with missing data, or how to estimate historical consumptive use. The memorandum also describes the broader, programmatic aspects related to simulation model development, such as expectations for model documentation, maintenance, and improvement of models over time, and information technology resources required.
A second purpose of this memorandum is to educate the audience that expects to either use the models themselves, or use the results delivered by the models. Models, however simple or complex, serve the purpose of integrating the complex interplay of hydrology, with its natural variability, users’ needs, which also vary over time, and the institutional environment. The latter includes Wyoming’s water rights, exchange agreements and practices, reservoir operating rules, and so on. While a model’s purpose is to render a complex system or situation understandable, it is important to view model results with respect for the underlying complexity. If the underlying system were not complicated, a model would not be required. Users of model output need to familiarize themselves with modeling methods and simplifying assumptions, to understand the applicability of the model results to the question at hand. For this reason, parts of this technical memorandum are devoted to educating those interested in understanding how to use the information that can be developed by river basin models.

A third topic addressed by this memorandum is the applicability of computer models to the sequence of studies required for water development projects sponsored by the Wyoming Water Development Office (WWDO) as set forth in Operating Criteria of the Wyoming Water Development Process. Similarly, modeling needs of the State Engineer’s Office will be described.

Finally, the State recognizes that model development will be constrained somewhat by the availability of data. For instance the USGS has discontinued stream gaging at an estimated 21 sites throughout Wyoming in the last several years. Historical diversion data is sparse in the Green River basin, which impacts our ability to estimate water-supply limited consumptive use. This memorandum offers a list of data needs in this basin, and discusses their contributions to accuracy of any model to be developed.

1.3 Memorandum Organization

The following is a “road map” for the remainder of this memorandum:

Section 2 Modeling Concepts provides general information on water allocation modeling and modeling terms, in fulfillment of the education objective described above.
Planning Model Development and Application for the Wyoming State Water Plan

Section 3 Wyoming Planning and Models addresses modeling needs in terms of WWDO’s Level I through Level II Phase III study process, and describes SEO applications for planning models.

Section 4 Spreadsheet Model Compared with Simulation Model describes, compares, and contrasts the spreadsheet model and the StateMod models that were developed in the Green River basin. This case study illustrates with examples some of the concepts introduced in Sections 2 and 3.

Section 5 Moving from Spreadsheets to Simulation Models suggests approaches for developing a StateMod model from a spreadsheet developed in the first round of basin water plans. The recommendations are general and could apply to any basin, but comments specific to the Green River are also included. In particular, forthcoming work by the State Engineer’s Office to delineate irrigated lands throughout the basin and determine service areas for diversion structures and water rights is expected to be available for the Green River effort. The section recommends, in general, how essential data may be gathered in the future and which parameters are of greatest importance.

Section 6 Documentation Guidelines describes the documentation needs that should accompany model development.

Section 7 Model Update, Maintenance, and Storage is devoted to a general description of the ongoing warehousing and maintenance of basin models and data.
Section 2

Modeling Concepts

In this section, certain modeling concepts are presented in terms independent of the particular code or tool adopted for analysis, to provide common understandings of both specific terms and general concepts encountered in the modeling environment. This section is not a comprehensive treatment of water allocation modeling. Instead it highlights specific topics that we believe may be at the root of some confusion or misunderstanding on the subject. A clear understanding of these concepts will help users of model results appreciate their meanings, and facilitate conversation and interpretation.

The hydrologic models described here are not physically based. That is, they are not mathematical representations of the physical processes of interception, infiltration, overland flow, and so on, that govern surface streamflows. They focus on human operations and influences on the hydrologic system, as revealed by the occurrence of runoff in the past. And they can be used to test new operations and influences (e.g., new storage) because they allocate water to users in accordance with the rights, rules, and operating policies that govern in the real world.

2.1 Baseflows

The modeler’s job is to first recreate what a stream system would have looked like if there were no diversions, no reservoirs, and no uses. This is variously termed “naturalized flow”, “virgin flow”, or “baseflow” by different modelers, but “baseflow” will be used here. Baseflows represent the water supply to be allocated to the modeled uses.

Baseflow is not computed based on precipitation and rainfall-runoff relationships. Instead, the estimation starts with the outcome – the historical gaged flow ($Q_{gage}$) -- wherever that is available. Whatever was historically taken out of the system above the gaged point during the model’s time step (typically monthly, weekly, or daily) is added to the gage value. Historical
reductions to the stream include exports from the basin, diversions to consumptive beneficial use or storage, and evaporation losses. Flows that would not have been there during the time step, except for human influences, are subtracted from the gage value. Historical additions to the stream include imports delivered into the basin, releases from reservoir storage, and delayed return flows from irrigation. In summary:

\[ Q_{\text{base}} = Q_{\text{gage}} + \text{Diversions} - \text{Return Flows} - \text{Imports} + \Delta \text{Storage} + \text{Evaporation} \]

Where exports from the basin are included in Diversions; both the consumptive and nonconsumptive portion of diversions are included in Diversions; Return Flows refers to all return flows that are measured in the gage within the time step, and may be attributable to previous time steps’ diversions (i.e., delayed, or lagged return flows); \( \Delta \text{Storage} \) is the change in reservoir contents, and can be positive or negative; Evaporation refers to reservoir evaporation. Thus an ideal data set for computing baseflow at a gaged site would include complete time series of these parameters:

- Historical gaged flow
- All historical diversions above the gage
- Consumptive fraction of historical diversions above the gage
- Timing and location of return of non-consumed fraction of diversions above the gage
- Reservoir contents at the end of each time step, for all reservoirs above the gage
- Imports to or exports from the basin above the gage

Of course, all this information is never completely available or even measurable. Fortunately, influences that are difficult to quantify can legitimately be ignored in the baseflow estimation. However, a component that is ignored (“left in the gage”) cannot be manipulated in any “what if” scenarios. The baseflow estimate reflects the ignored effect, which means that when you simulate some new condition, you are assuming that the effect is persisting in the background. For example, if you have no historical end-of-month reservoir content information, you can leave the reservoir storage term out of your baseflow estimate. But you can’t operate the reservoir in a “what if” scenario. And the supply that the model “has” to allocate to users other than the
reservoir reflects the reservoir doing exactly what it did historically. Similarly, if the second cfs diversions are a component of the hydrology that you anticipate storing in the future, they must be explicitly accounted for in the baseflow estimate.

In some cases, the modeler can “live with” a reasonable estimate of a component of hydrology in the baseflow estimation. For instance, Return Flows are not directly measurable in general, and Diversions are not measured in much of Wyoming. A common practice is to replace the two terms, Diversions and Return Flows, with a single term representing the consumptive use, or the net result of diversions and returns. Various crop consumptive use models are available that can reasonably estimate water use for given crop type and weather conditions, assuming the crop has a full water supply. The limitation of this approach is that late in the irrigation season, crop consumption is below the theoretical maximum because there is not enough water to support maximum growth and uptake. Diversion records are necessary to determining when this condition exists, and estimating actual consumptive use.

The above discussion touches on the essential contribution of diversion records to water allocation modeling. They need to be included explicitly in the baseflow estimate if the modeler wants to analyze changes in diversions in the future. Secondly, they are important to estimating crop consumptive use, which, on a long term basis, accounts for most of the difference between gaged flow and baseflow.

### 2.2 Consumptive Use and Consumptive Irrigation Requirement

Consumptive use (CU), in general, is the amount of water taken up by crops and lost to surface and/or groundwater system due to evapotranspiration. “Potential CU” refers to the consumptive use that occurs when a crop is fully supplied with water. Where irrigation is practiced, precipitation provides some of the water needed for evapotranspiration, and the balance is provided by the irrigation supply. Thus we refer to the portion of the potential CU that cannot be met by precipitation as the Consumptive Irrigation Requirement (CIR). Mathematical CU methods such as Blaney-Criddle or Penman-Monteith estimate potential CU and CIR from climate data and crop parameters that reflect crop type and stage of growth. Since both of these types of parameters change over a season and from year to year, CU and CIR are time series.
Another useful term is “supply-limited CU”, the CU supported by irrigation that occurs when crops are not receiving an optimal, ideal water supply. Supply limitations on CU during at least some part of the irrigation season are typical in Wyoming. Thus, “historical CU”, the CU that actually occurred during a study period, is generally supply-limited to some extent. The time series of historical CU reflects not only climate and crop, but also water supply. Historical CU is generally determined as the minimum of CIR and water applied to the crop. However, methods for estimating historical CU using Landsat thermal imagery are becoming available. The University of Wyoming’s WYGISC Remote Sensing Ream, under a contract with the SEO’s Colorado River Compact Administration Program, is currently developing estimates of historical CU for the 2007 growing season, and will repeat the effort for the 2008 growing season.

2.3 System Efficiency

System efficiency has nuanced meaning depending on the context in which it is used. Very generally, it reflects differences in the amount of water diverted from the stream and the amount that gets used by the crop. Factors that affect efficiency include ditch losses between river headgate and fields, and the necessary surcharge required to deliver water from the farm headgate to the full extent of the fields. As such, system efficiency is sometimes thought of as an attribute of a ditch system, regardless of water supply conditions.

In a water allocation modeling context, efficiency reflects losses to the stream system associated with irrigation. It is efficiency from the perspective of the stream, because the model’s focus is on allocating the stream supply, accounting for removal and addition of water throughout the stream. Efficiency is typically calculated as CIR divided by diversion, but capped at a maximum representing the upper limit that can practically be achieved by the irrigation method. This maximum efficiency corresponds to the system efficiency described in the preceding paragraph.

Thus, historical system efficiency is a time series that reflects not only CIR and diversions (both time series) but also the state parameter maximum efficiency, an attribute of the irrigation system and practice. Two systems with similar ditch lengths, soil types, slopes, and all the other characteristics that determine maximum efficiency, but different priorities, will have different historical efficiencies. The senior diverter will have more water available to it, and can operate at
a lower efficiency, than his more junior neighbor. An irrigator’s efficiency varies from month to month and year to year, just as his supply varies.

2.3.1 Use of system efficiency in modeling

One way to model consumptive use by irrigation is to specify monthly efficiencies for the diversion structures, presumably based on typical or historical efficiencies. The consumed portion of the diversion is calculated as the diverted amount times the monthly efficiency for the structure; the balance of the diversion is returned to the stream on some lagged schedule. A more detailed approach is to input a time series of CIR, and calculate consumption as the smaller of CIR and the product of maximum efficiency and the diverted amount.

Diversion demand, described below, is sometimes calculated from CIR and some estimate of system efficiency. Choice of system efficiency to use depends on the objectives. For instance, if you are trying to simulate historical conditions but you don’t have diversion records, you could base demand on an efficiency believed to reflect historical practices, based on interviews, anecdotal information, or other evidence. If you are simulating a future condition in which efficiencies will change because of the project (e.g., canals lined, supplemental rights foregone, or by disallowing historical “free river” diversions), the efficiency could be a hypothetical value.

2.4 Demand

Demand refers to the amount of water a user needs, and a model will typically “try” to deliver the demanded amount to a user, but not exceed it. Demand can be represented differently in different applications of the same model, depending on the simulation objective. For example, when calibrating a model, demand should be set to historical levels. Calibrating a model is the process of adjusting estimated values so that, with all input as close to historical as can be known, the allocation results in responses that are similar to historical. That is, modeled diversions, gages, and reservoir levels resemble their real world prototypes. If an analysis is seeking to estimate irrigators’ ability to divert the standard Wyoming duty of water of 1 cfs per 70 acres, the demand should be calculated accordingly. If the purpose is to estimate water available for storage if irrigators divert enough to fully satisfy their crops, demand should be
Planning Model Development and Application for the Wyoming State Water Plan

based on CIR and system efficiency. If the objective is a depiction of water supply 30 years into the future, an estimated future demand should be used.

2.5 Diversion Constraints

In a water allocation model, demand is a diversion constraint, since it provides an upper limit on the diversion. Other diversion constraints that come into play include the physical limitations of the diversion and conveyances (e.g., ditch capacity), operating characteristics, and water rights.

The water rights information supplied to the model includes a flow amount for the right, and a priority relative to other rights in the model. The simulated diversion reflects the minimum (most constraining) of demand, water right, diversion and/or conveyance capacity, and available water supply.

In the real world, diverters typically divert more than their water right when the river is “free”. If this needs to be simulated in a model, it can be addressed by assigning a very junior water right to the diversion. This provides the diversion the opportunity to be allocated water if all other uses have been addressed.

2.6 Study Period

Historically based water allocation models have a “study period” associated with them. This is the sequence of years from which data were drawn to create the model. Ideally, a model’s study period covers a range of hydrologic conditions, including extremes of wet and dry supply. The longer the study period, the more likely it will capture the spectrum of hydrologic possibilities. When establishing the study period, the modeler must consider availability of data, and may reject years in which too much data is missing. Data limitations thus impact the model’s ability to portray a wide range of historical conditions, undermining its effectiveness in illuminating system responses, reliability, and sensitivities. Key to developing an accurate simulation model is to establish a more complete stream gaging and diversion record database, which will likely require installation of additional measuring and recording devices.

Simulation models step through the study period, one month, day, or other time step, at a time. With this approach, the 30-year (for instance) simulation does not represent a project operating
over a planning horizon. In other words, the model is not representing, for example, 2008 conditions at the beginning of the simulation period, and 2038 conditions at the end. Instead it represents the demands and operations that correspond to a snapshot in time, either current or future. By imposing those conditions on thirty years of hydrology, one learns how water rights and projects perform given the natural variability of water supply. The modeler or water resources professional infers reliability, yield, or sensitivity of a project under the universe of hydrologic possibilities by looking at the 30-year sample.

2.7 Summary of Key Points

- A water allocation model demonstrates how a water supply was managed historically, and helps us explore future management approaches. That is, it shows what can be done with a baseflow supply, and does not determine what the baseflow supply is.

- Diversion records are a key component for determining water supply or baseflow.

- Demand is the amount of water the modeled user “wants” to get, and is an upper limit on his diversion.

- Demand is a key element of the “what if” scenario, and can legitimately be estimated differently, depending on the modeling objective.

- System efficiency is not static, but changes with system management and supply.

- System efficiency can legitimately be estimated differently, depending on the modeling objective.

- Modeling a study period is an exercise in testing allocation rules against a sample of hydrologic conditions.
Section 3

Wyoming Planning and Models

This section describes Wyoming’s planning needs that could be served by water allocation models and levels of model detail appropriate to each.

The WWDO’s water development program is described in Operating Criteria of the Wyoming Water Development Program (December, 2006). The document describes a process through which the WWDO explores new projects and advances their evaluation and design prior to construction. The various planning levels are described below, along with a discussion of appropriate levels of hydrologic evaluation. Some flexibility in applying these “Level” designations to projects and their hydrology investigations should be maintained, because the process differs depending on the type and size of project. For example, a small reservoir that provides a few hundred acre-feet (af) of late summer supply on a tributary where there is currently no storage is probably more constrained in terms of alternatives, and involves less complex decision-making, than a medium-sized irrigation supply reservoir providing carryover storage for a large district. For the latter project, more complex tools should be introduced earlier in the process.

3.1 WWDO Level I Study

This is a preliminary/reconnaissance level analysis of project alternatives to economically develop water for Wyoming’s use and benefit. The study compares project options based on physical and legal water availability, technical, economic, legal, and environmental considerations. Factors that could prohibit development of options are identified.

The Basin Plan spreadsheets, exemplified by the spreadsheet assembled in the Green River basin, are appropriate tools for this level of study. Hydrologic supply and demand are averaged over historical Wet, Dry, and Normal years. Demand at a structure is set to averaged historical diversions, if they are available. If diversion records are not available, the
Planning Model Development and Application for the Wyoming State Water Plan

demand is set to an estimate of the consumptive portion of the diversion. The CU can be estimated reasonably, and shows the net impact of diversions and return flows on the stream. The CU demand is calculated as CIR for the amount of irrigated land at a node, for the portion of the month in which irrigation is generally practiced under Wet, Dry, and Normal conditions. For instance, if irrigation generally ceases in mid-July, then the July demand is set to half the July CIR for Normal years. Duration of irrigation is based on practices at nearby structures that do have diversion records, as well as the hydrographer’s description of the basin. (For a more complete description of the spreadsheet model, refer to the Task 3B memorandum in any of the Wyoming basin plans.) Accordingly, the spreadsheet model indicates whether an available supply exists and very generally, a probability percentile for the supply.

Furthermore, the basin plan spreadsheet can show that from a water supply perspective, one site is probably more favorable than another. A limitation of the spreadsheets is that they reflect historical use patterns and don’t reveal anything about supply that results from potential changes in operations and behaviors. For example, irrigators who participate in a storage project may be motivated to refrain from diverting excessively early in the year, if they know the water can be put into storage and released later in the summer for their district’s benefit. The spreadsheet can’t estimate that component of supply, but assuming this behavior-based “bump” in yield is similar at two different sites, it will show which site probably has more storable water in it. In other words, the absolute numbers coming from the spreadsheet model may be less important than relative numbers for different sites. Since the objective of Level I is to identify a potential project or projects that may be pursued, the spreadsheet tool is adequate for making recommendations regarding future studies/investigations.

One limitation of the basin plan spreadsheets is that they are not detailed in the tributaries and headwaters. If the new project alternatives are sited outside the spreadsheet model area, it could be appropriate to extend the existing spreadsheet model in the Level I study.
During the Level I Watershed Study, the modeler should recommend for future, regular easement, diversions that would provide additional data needed to either extend a spreadsheet model or convert from a spreadsheet to a “simulation” model. The Water Development Office Project Manager, in negotiations with the Project Engineer, should determine whether “force account” expenditures for measuring diversions is appropriate at this level of study.

3.2 WWDO Level II Phase I Study

This level of investigation is termed a “feasibility” determination. A Level II Phase I study is required to present “a reasonable quantification” of the amount of water that can physically and legally be developed, and a determination of water needs that could be served. Other requirements relate to the physical configuration of the project, opinions of cost, a “preliminary operating plan”, and an assessment of safety and technical feasibility. Institutional problems and possible solutions are identified.

At this level, the project’s complexity has bearing on the selection of a tool for hydrologic evaluation. A reasonable quantification of the available water supply probably requires more information than that available by way of the spreadsheet model, with respect to both time and space. Month-by-month, i.e., time series modeling should be considered, because average monthly values mask extremes, variability, and skew. Local hydrology needs to be understood, and a reasonable quantification of supply probably requires more site specific information than that represented in the spreadsheet.

At Level II Phase I, it may be adequate to analyze both supply and need in terms of consumptive demand, which makes it possible to move forward without explicit diversion and efficiency information. Irrigated acreage information is essential, however, in order to estimate the consumptive demand. And some evidence or estimate of historical supply limited consumptive use is needed. This information is a piece of the baseflow estimate, and the estimate of pre-project shortages (i.e., the amount of unsatisfied irrigation demand). If the model is run with consumptive demand only, there will be error related to the fact that the unconsumed/return flow portion of diversions is being ignored. But the model will show the overall mass balance between storable supply and consumptive demand, on a time series
Planning Model Development and Application for the Wyoming State Water Plan

basis. If a project is not feasible for lack of supply under this analysis, it should be dropped from consideration. In other words, the approach will not erroneously eliminate projects that make sense.

If the purpose of the project is to mitigate pre-project shortages, the shortages represent need for the project, and the model will show to what extent the project can meet the need. Note that the model does not reveal existing shortages; the existing shortages are embedded in the model input, specifically, in the baseflow estimates. What the model shows is the ability of the project to meet the need.

While the Round 1 basin plan spreadsheet may not provide enough information for a Level II Phase I analysis, a basin-wide simulation model may not be an appropriate tool either. For instance, if the project is in a headwater tributary and supplying local demand, conditions, and operations distant from the project may not be relevant. The important thing is to understand local hydrology. In this case, a month-by-month spreadsheet that works out the hydrology and demand may be adequate. The Project Consulting Engineer modeler shall consult with the Wyoming Water Development Office project manager to determine whether application of a monthly spreadsheet model or simulation model is more appropriate.

Including the diversion demand, as opposed to consumptive demand, in whatever type of model is used would be acceptable at this level of investigation. A diversion demand based on current service area, based on aerial imagery, and 1 cfs per 70 acres would be simple to produce and reasonably accurate.

Some things that influence the choice of modeling approach include:

- Degree of local appropriation and use – the “tighter” the water supply, the more refined information you need to discriminate whether the project is viable. “Refined” refers to resolution of the information: time series analyses are more refined than analyses of averages, and structure specific model nodes are more refined than aggregated nodes.
Planning Model Development and Application for the Wyoming State Water Plan

- Variability of supply – similarly, the “flashier” the system, the more refined information you need to discriminate whether the project is viable.

- Influence of downstream call – if the project is on a tributary which, although small, connects to a large main stem river, you need a less expansive tool than if the project is likely to experience legal constraints stemming from distant water rights.

- Operational complexity – if large reservoir projects control movement of water through the basin, and these operations influence availability of supply, you may need to begin simulation modeling early in the planning process.

During the Level II, Phase I Feasibility Study, the modeler should review existing diversion records to recommend installation of additional measuring devices to provide the “explicit” data needed to either improve the existing spreadsheet model or convert to a “simulation” model. The Project Engineer/Modeler, in consultation with the Wyoming Water Development Office Project Manager, may then determine whether “force account” expenditures for measuring diversions are appropriate at this level of study.

### 3.3 WWDO Level II Phase II Study

The second phase of Level II study refines every aspect of the first phase feasibility study. With respect to water availability and allocation, the WWDO operating criteria description for Level II Phase II studies calls for “hydrological investigations” and an operating plan.

The discussion above for Level II Phase I is applicable to the second phase of Level II planning, except that it can be said more definitively that the Round 1 basin spreadsheet models are inadequate once planning has advanced to this stage. If a spreadsheet model was used during the Level II, Phase I Study, it is time to refine. The modeler should review existing diversion records and recommend installation of additional measuring devices to provide additional data needed to convert from a spreadsheet to a “simulation” model. The Water Development Office Project Manager, in consultation with the Project
Planning Model Development and Application for the Wyoming State Water Plan

Engineer/Modeler, may determine whether “force account” expenditures, in addition to any amounts already budgeted for measuring diversions, are appropriate at this level of study.

3.4 WWDO Level II Phase III Study

Storage projects that enlarge existing reservoirs by at least 1,000 af, or new projects with a capacity of 2,000 af or more, are eligible for Water Account III, Level II Phase III support. This phase is the final engineering design of the project, and/or preparation of NEPA-required documents.

It’s difficult to imagine a storage project at this level that would not require step-by-step simulation modeling, and demands that reflect real world practices. The yield of a reservoir at a given size is determined by the interaction of the time series of supply and the time series of demand on the project. Although pre-computer age graphical methods exist for evaluating the size and yield aspects of a proposed reservoir, given pre-determined supply and demand time series, a simulation model can help to determine those series in a dynamic way. Subject to site limitations, the simulation model can help the engineer refine the estimate of reservoir size.

Demand in this model should reflect the practices anticipated when the project is in place. If historical practices are expected to persist, then a diversion demand calculated from crop irrigation requirement and historical monthly system efficiencies could be used. If higher efficiencies are likely to occur because of the project, a target or ideal efficiency could be used in the calculation of diversion demand.

An allocation model that fully simulates hydrology, demand, and operations will also show the changes in stream conditions attributable to a project, which is a key element of environmental assessments and impact statements. If the project constitutes a federal action, this level of modeling is likely to be expected if not required.

3.5 Subsequent Rounds of Basin Plans

Whether a spreadsheet or a simulation is utilized in subsequent river basin planning efforts, will depend upon the number of explicit structures and cost for installation of additional stream
gaging or diversion gaging devices to reach a reasonable level of data availability for the basin. Costs may dictate that the second round of basin planning use a combination of both spreadsheet and simulation models, e.g. for those reaches that have a sufficient number of explicit gages a simulation model may be appropriate, while a spreadsheet model may continue to be employed in river reaches or in individual watersheds within the river basin that lack sufficient data. The State should consider adding diversion measurements throughout the State in 2008 and 2009, so that by the time each basin is “up” for a second round of planning, a small amount of history will be available.

3.6 Wyoming State Engineer’s Office Studies

A fully developed water allocation model could support the State Engineer’s mission of protecting Wyoming’s water supply in the face of compact administration. For instance, a StateMod implementation of the Green River would be particularly valuable in investigating the State’s pool in Fontenelle, and its ability not only to make a specified level of compact delivery, but recover in subsequent years. This sort of “big picture” question can effectively be addressed even if detailed headwater sub-basin hydrology is not modeled, especially if upstream depletions occur under senior rights.

If and when all Green River depletions and water rights are represented in the model, the SEO could use the model to test curtailment scenarios associated with a compact call, in a planning environment. That is, the model is not envisioned as a tool for daily or weekly administration, but it could be used to explore generally the impacts of potential policies and operations. With enough detail regarding individual water users and rights included, the model could be used to estimate the amount of water deliverable to the compact call, under a specified level of curtailment. This type of application requires more data than are currently available, but with water right attribution to individual structures and development of system efficiencies throughout the basin, estimates of curtailment effects would be possible.
Section 4
Spreadsheet Model Compared with Simulation Model (Green River)

4.1 Green River Basin Plan Round 1 Spreadsheet Model

The Green River basin spreadsheet model was a product of the “first round” of the Green River Basin Plan. Aware that certain hydrologic and use data were in short supply, the authors of the reconnaissance study for the basin plans envisioned models that were useful but also compatible with the data limitations. The model actually consists of three models reflecting each of three hydrologic conditions: dry, normal, and wet year water supply. The spreadsheets show representative flow conditions at discrete locations throughout the basin for each month of each year type.

One rationale for this type of a model was that missing historical time series for river flows, diversions, and climate parameters did not have to be completely filled in. All of the parameters generally represented by time series are based in the model on the period 1971 through 1998. Each of these 28 years was designated as Normal, Wet, or Dry, based on rankings of flow at selected gages, and approximate identification of the 20th percentile of flows at the upper (Wet) and lower (Dry) ends of the spectrum. Gage records were filled using linear regression models based on nearby gages, to the extent that satisfactory correlations could be found. But where no strong correlation could be found, and for missing diversion data, for instance, an average value for the measurement could be computed from the years for which there were data.

Besides addressing gaps in data time series, the basin plan spreadsheets accommodated limitations related to structure specific information. One important part of the basin plan was the development of GIS coverages of irrigated lands based on aerial photography. These coverages documented irrigated areas throughout the basin as a whole, but no information was available identifying the ditch or ditches that serve a particular parcel of land. The irrigated acreage data
Planning Model Development and Application for the Wyoming State Water Plan

was essential to determining crop irrigation requirement under ideal conditions, that is, ignoring water supply limitations, which was also an important product of the plan.

Water right permit data were collected, and it was generally possible to determine the rights associated with a given ditch, but without an association to specific lands, it was not possible to estimate headgate demand. The water rights information provided a tentative check on the irrigated lands mapping. For instance, if permitted water rights believed to serve a tributary sub-basin added up to too much or too little water, based on 1 cfs per 70 acres, it was cause to review the mapping. As often as not, the mapping appeared to be correct and the active permits simply didn’t reflect the current irrigation practice. Occasionally, mapping issues were uncovered and resolved in this way.

Another important product of the first round plan was a set of “operating memos” documenting history, structural, and operating information for select large ditches (“explicit structures”). Ditch company personnel and users were contacted, and a memo was written up describing the type of headgate structure, water rights permits according to the ditch organization, and general operating information like typical length of season, conveyance losses, and so on. If available, diversion records were included. All of this information was extremely important to the modeling. But it required cooperation of the ditch owner, including interviews and in some cases site visits. Because of the costs involved, these operating memos were developed for only a small percentage of the ditches in the basin.

4.2 StateMod Model of Upper Green

The State of Colorado’s Stream Simulation Model (StateMod) is a generic water allocation and accounting model capable of making comparative analyses on a monthly or daily basis for the assessment of historic and future water management policies in a river basin. It is designed to be applied to any river basin through appropriate input data preparation. The StateMod model data operates to meet input demands (e.g., diversion, storage, instream flow) with available flows, in priority based on the Prior Appropriation Doctrine – “first in time, first in right”. The StateMod model is publicly available and is maintained by the Colorado Division of Water Resources (CDWR). The State of Colorado’s Consumptive Use model (StateCU), and associated data
management interface (DMI) software that are used to develop StateMod model input files are also publicly available from CDWR. (http://cdss.state.co.us/DNN/Products/tabid/63/Default.aspx)

Version 12_16 of the StateMod model has a set of 49 general operating rules that simulate operations to divert water to an off-channel reservoir via a carrier structure, release water from a reservoir for river diversion, transfer storage water among reservoir accounts or between reservoirs, etc.

The StateMod data set developed for the Upper Green River Basin was a product of the Upper Green River Basin Level II Study. The Level II Study used the information collected for the GRBP model as the basis for the StateMod representation. The main focus of the Level II Study was to better characterize the monthly and annual variability of streamflows and demands, compared to the GRBP model, and represent and operate water permits for all nodes, thereby developing better estimates of flows available for irrigation and for storage in new reservoir sites. The StateMod model data set developed in the Level II Study is being further refined and used to estimate prospective reservoir sites as part of the Upper Green River Westside Storage Level II Study.

4.3 Summary Comparison Table

Table 1 describes how key elements of the models were handled. The table is arranged to allow side-by-side comparisons.
Table 1 Comparison of Green River Spreadsheet and StateMod Models

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<tr>
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<th>Spreadsheet</th>
<th>StateMod</th>
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<tr>
<td><strong>Spatial Resolution</strong></td>
<td>The river system is represented as a network of individual nodes, representing diversions, reservoirs, tributary confluences, gages, or other significant water resources features. The network links between nodes represent the stream. The ability to uniquely characterize a diversion, based on available data, was what determined the amount of irrigated land represented by a node. Where there were no diversion records, for instance, irrigated lands were lumped together in “aggregated nodes”. Often, the delineation between aggregations reflected the configuration of sub-tributaries. For example, it may have been clear from topographic maps that a group of lands were served by a stream in a reach between two tributary confluences. By grouping the lands together as one diversion, we avoided dealing with headgate locations and stream order. In some cases, because the irrigated lands were physically isolated, it was possible to determine irrigated acreage for a single ditch. If diversion records were available (per the operating memos described above) for that sort of ditch, the node represented a single diversion structure, and was referred to as an “explicit” node.</td>
<td>The stream gages, explicit diversion nodes, and aggregate diversion nodes that made up the river network in the GRBP model were duplicated for the StateMod model network. The proposed reservoirs identified in the first Level II Study were added to the model network. The Colorado Decision Support System’s (CDSS’s) StateDMI graphical user interface is used to create and revise the model network.</td>
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<td><strong>System Efficiency</strong></td>
<td>System efficiencies were required for explicit nodes only. To develop these values, monthly historical diversions for the study period years of each hydrologic type were averaged to determine, for instance, the average June Wet year diversion for the ditch. This diverted amount was divided by CIR for the irrigated area associated with the ditch, for the same month and hydrologic condition, to get the month’s system efficiency. However, efficiency was capped at 55 percent because there is a practical upper limit to the efficiency that can be achieved with flood irrigation.</td>
<td>System efficiencies were estimated for explicit nodes based on historical CIR and historical diversions, limited by a maximum farm efficiency to put a cap on the amount of farm deliveries that can be consumed. System efficiencies for aggregate nodes were estimated based on efficiencies of explicit nodes on the same tributary, or explicit nodes on nearby tributaries with similar base hydrology. System efficiencies were used to develop future demands for all structures, and used to develop historical diversions for aggregated nodes.</td>
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<td><strong>Historical Consumptive Use</strong></td>
<td>Demand for aggregate nodes was set to historical consumptive use. In much of the Green River basin, consumptive use is water supply limited. While the crop irrigation requirement can be determined from irrigated acreage and climate data, one cannot determine actual consumptive use without knowing how much water was applied to the crop. For aggregated nodes, for which there were no diversion records, the estimated consumption is the result of analysis and educated guesswork outside of the spreadsheet, and reliance on information available for explicit structures. Basically, though, consumptive use early in the irrigation season was estimated to be equal to crop irrigation requirement, that is, it was assumed that water supply was adequate. In the last two months of the irrigation season, it was assumed</td>
<td>The StateMod model operates on a river demand basis for all nodes, and therefore requires input of monthly historical river diversions, rather than consumptive use. The model calculates consumptive use by multiplying the simulated river diversion by the input system efficiency. Historical consumptive use came into play in estimating system efficiencies, as described above.</td>
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that irrigators operated for only part of the month, and at an efficiency of 55 percent – a practical upper limit for flood irrigation. The number of irrigation days in the month was selected based on conversations with the hydrographers, available daily diversion records from ditches in the vicinity, and/or an inferred number of irrigation days for representative, nearby ditches with monthly diversion records. In the last case, it was assumed that the representative ditch ceased diverting after the number of days required to operate at a system efficiency of 0.55. For example, if September’s irrigation requirement was 100 af and monthly diversion records showed that 27.5 af were diverted, we inferred that irrigation was practiced for half the month. This piece of information was then one “data point” considered in selecting the number of irrigation days for the aggregated structures. Accordingly, the historical consumptive use reflected, as well as could be estimated, water supply limitations and operating practices.

**Baseflow**

In the spreadsheet model documentation, this component is referred to as the “Reach Gain/Loss”. It is baseflow as described in Section 2, but since the term reflects every change in streamflow between two gages that is not captured by the spreadsheet computations (e.g., delayed return flows, conveyance losses, etc.), “reach gain/loss” seemed more appropriate. The term is calculated by taking the difference in gaged flows at the top and bottom of the reach and adding to it 1) the estimated historical consumptive use by aggregated diversion nodes between the gages, 2) full diversions by explicitly modeled structures (historical diversion records available), and 3) additions to storage between the gages, if a reservoir is represented by a node in the model. Then, the following are subtracted from the result: 1) estimated return flows attributable to explicitly modeled structures, in the month when they reach the stream, and 2) releases from storage between the gages, if a reservoir is represented by a node in the model. The gain/loss term reflects ungaged tributaries, groundwater/surface water interactions, the unconsumed portion of diversions at aggregated structures, lagged return flows associated with aggregated structures, unmodeled reservoir operations, or any other process not explicitly or perfectly modeled.

A modeled reach gain/loss could be negative in what is a naturally gaining stream. For instance, in the real world, when every user is diverting as much water as he is legally and physically able to, the downstream gage may record less flow than the upstream gage. That is, diversions out of the stream reach exceed natural gain within the stream reach. In the

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<td>spreadsheet model, only the estimated historical consumptive use for most</td>
<td>Water rights included in the State's previous WIRSOS modeling efforts of</td>
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<td>diversions is added to the gage difference, because the majority of use is</td>
<td>the Upper Green River basin were assigned to the associated model nodes.</td>
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<td>represented at aggregated nodes. The effect of the unmeasured and</td>
<td>Priorities were assigned to the water rights based on the Permit dates.</td>
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<td>unmodeled inefficient portion of the diversion is forced into the reach</td>
<td>Separate water right entries were input for the second cfs of pre-1945</td>
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<td>gain/loss term. The gain (loss in this case) is negative because the</td>
<td>and pre-1985 permits. These water rights were assigned 1945 priorities or</td>
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<td>computation is dominated by the negative</td>
<td>1985 priorities in the same relative order of the senior water rights.</td>
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<td>( (Q_{\text{dstreamgage}} - Q_{\text{upstreamgage}}) ) term.</td>
<td>Model runs to date simulate the second cfs diversion, in priority, to meet</td>
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<td>irrigation river demands not satisfied by the original permit. Free river</td>
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<td>rights (999 cfs with most junior priority in model input files) were added</td>
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<td>meet historical diversions are not limited to permitted rights without the</td>
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<td></td>
<td>free river right. Having the rights separated in the input files allows</td>
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<td></td>
<td></td>
<td>users the flexibility to turn the second cfs or free river right off if those</td>
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<td></td>
<td></td>
<td>diversions are not envisioned for a particular analysis.</td>
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<td></td>
<td></td>
<td>As noted above, diversions to meet river demands are simulated by priority.</td>
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<td></td>
<td></td>
<td>Therefore, all demand nodes must be assigned specific priorities.</td>
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<tr>
<td></td>
<td></td>
<td>Although not carried out for the StateMod data set, due to budget</td>
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<td></td>
<td></td>
<td>constraints at the time of model development, water permits for all</td>
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<tr>
<td></td>
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<td>structures should be checked against the SEO Water Permits Database.</td>
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<tr>
<td>Water Rights</td>
<td>Water rights are not simulated in the spreadsheet model. Water is diverted</td>
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<td>to explicit users as it was historically, and consumptive use is permitted</td>
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<tr>
<td></td>
<td>to occur at aggregated nodes as we estimate it occurred historically. The</td>
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<tr>
<td></td>
<td>historical amount of diversion or consumption presumably reflects a system</td>
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<td></td>
<td>that was operating under Wyoming water law.</td>
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</table>
Table 1 Comparison of Green River Spreadsheet and StateMod Models

<table>
<thead>
<tr>
<th>Demands</th>
<th>Spreadsheet</th>
<th>StateMod</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demand was represented in the Round 1 spreadsheet as either the historical diversion (explicit structures) or a depletion demand (aggregate structures). Because both of these reflect historical practices, the demand is water supply limited in some months of some years.</td>
<td>Irrigation demands are input as river headgate based on monthly CIR divided by average monthly efficiency. The demands in the Upper Green StateMod data set are based on the Pochop recommendation of a May 1 to September 15 irrigation season, every year. These demands may not truly represent irrigation practices where irrigation ceases after the first cut, and may result in higher-than-actual shortages reported by the model. Changes to the input demands for specific nodes, all the nodes on a tributary, or all the nodes in the basin can easily be done. As noted in Appendix A, more information on irrigation practices in a basin should be gathered at the onset of developing a basin simulation model to best represent the actual demands in the basin.</td>
</tr>
<tr>
<td>Shortages</td>
<td>The spreadsheet models do not calculate shortages. To determine shortages, one would have to compare the historical diversions in the model with calculated ideal demands.</td>
<td>Shortages are defined in the StateMod model as river demands not satisfied by simulated in-priority diversions. These shortages represent the amount of unmet river demand that may be met from other sources (e.g., reservoir releases).</td>
</tr>
<tr>
<td>What User Can and Cannot Do</td>
<td>The user can estimate water availability for a new project, with the understanding that all users are behaving as they have historically, and using an additional availability spreadsheet that was produced as part of the Green River Basin Plan. The second spreadsheet took into account the needs of downstream users. The water availability is determined in the model at a limited number of points in the basin, reflecting the spatial detail of the model. The user can compare available supply at different parts of the basin, and understand very generally whether water would be available in wet years only, or in wet and normal years. Since “normal” represented the average of the middle years, it may reflect available supply, very generally, about 50 percent of the time. The user should be aware of changes in the basin since 1998, which could affect availability today. The user can add a diversion or storage node to the model and see how the downstream flows are affected, in a very general way.</td>
<td>Model outputs include the legally available flow below each model node for each month of the study period. The legally available flow represents the water available to a junior water right. Therefore, the model can compare the monthly and annual availability of supply, in priority, at different sites over the historical study period. Longer study periods, different hydrologic periods (e.g., based on tree rings, climate change scenarios, etc.) can be input to see how the demands can be met under different scenarios, or how a future reservoir’s operations may change under various hydrologic conditions. The simulation model output, therefore, can help determine water availability for a new project. A calibrated model is the ultimate goal of model development, and is the model that will likely be needed to define purpose and need of a proposed project as part of Level II Phase III studies. A calibrated model provides the best representation of the physical system and responses to changes in operations, irrigation practices, etc. A model cannot be calibrated until sufficient information on streamflows, historical river diversions, acreage irrigated by specific ditches and permits, and estimates of...</td>
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</tbody>
</table>
Table 1 Comparison of Green River Spreadsheet and StateMod Models

<table>
<thead>
<tr>
<th>Spreadsheet</th>
<th>StateMod</th>
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<tbody>
<tr>
<td>The user <strong>can</strong> estimate shortages if he defines full or ideal supply, and replaces modeled demands with the ideal demands. The user <strong>cannot</strong> look at streamflow at every site in the basin – only at the discrete nodes that are modeled. Some aggregations are fairly large (for example, on Black’s Fork) because information to characterize smaller units of diversion and use were not available. Headwater basins above gages were not included if use was relatively small. The user <strong>cannot</strong> evaluate use of a new source of supply that accrues to the river and would be allocated on the basis of water rights, as opposed to being shepherded to specific beneficiaries. This is true because the model does not operate water rights.</td>
<td>return flow locations and timing from irrigated acreage have been gathered. The Upper Green River StateMod data set <strong>cannot</strong> be calibrated until more information is gathered to provide a one-to-one correspondence between river headgates, irrigated acreage, and water permits serving the irrigated lands. Priorities of data collection to meet this objective are discussed in Section 5.</td>
</tr>
<tr>
<td>The user <strong>cannot</strong> evaluate performance of a specifically-sized storage project over time, and estimate yield, because averages don’t show variability of supply.</td>
<td>Simulation model can be used to run numerous “what if” scenarios. A few example scenarios follow:</td>
</tr>
<tr>
<td>• Ability of a reservoir to store and release water to meet irrigation shortages</td>
<td>• Benefit to filling the reservoir with a junior water right from reservoir carrier ditches on two tributaries (more physically available flow), versus one tributary</td>
</tr>
<tr>
<td></td>
<td>• Double (or halve) the size of the reservoir to see the incremental benefit to reducing irrigation shortages</td>
</tr>
<tr>
<td></td>
<td>• Modification of reservoir release rules from a future reservoir to understand relative benefits from various operational scenarios</td>
</tr>
<tr>
<td></td>
<td>• Effect of an instream flow right on basin operations</td>
</tr>
<tr>
<td></td>
<td>• Use of second cfs for storage, rather than irrigation, with late-summer storage releases to irrigators that forgo their second cfs during the spring runoff</td>
</tr>
</tbody>
</table>
Section 5
Moving From Spreadsheets to Simulation Models

Various basin operations data were gathered and summarized for Round 1 of the Wyoming State Water Plan. These initial planning efforts, and any associated models, should serve as the basis of efforts to develop the next generation models for use by WWDO and SEO. The availability of data will help define what kind of model should or can be developed (refined spreadsheet model, “skeletal” simulation model, or fully developed simulation model), and then identify what data should be gathered in order to prioritize future data collection efforts in the basin. A general protocol for identifying available data, organizing the data, and identifying data needs is presented below in the context of the input data required for spreadsheet models and simulation models. Additional details regarding the more data-intensive simulation models are discussed in Appendix A.

5.1 Raw Input Data

Data from the Basin Plans as well as other data available from WWDO, SEO, and previous studies and modeling efforts, should be gathered and reviewed for amount, and quality, of data available for future modeling efforts. To facilitate model development for a basin, subsequent basin modeling efforts, and development of a centralized Wyoming water database, all of the data should be gathered, digitized or scanned (if possible), and summarized in short technical memoranda so that other users will know the sources, availability, past uses, etc. for the various basin input data. The information will eventually be incorporated in the model documentation, as discussed in Section 6.

Raw input data regarding streamflows, diversion nodes, and irrigated acreage should initially be organized around the development of a river network, which will represent the various uses in the basin.
Planning Model Development and Application for the Wyoming State Water Plan

- Stream gages – Streamflows represent the cornerstone of physical flows available for future operations. The primary sources of these data are the USGS and WY SEO. Collection of all available data will help modelers develop approaches for using the data in models and distributing flows to ungaged basins and along the river main stem.

Some of the Water Divisions have collected seasonal data (usually in the summer months) for certain tributaries over a number of years, or possibly for a year or two for a certain project. These efforts provide more localized representation of river reaches. Compilation of all available data in one place will also help the development of a centralized database, as discussed in Section 7.

A memorandum should be developed summarizing the stream gage IDs, locations, sources of data, periods of record, completeness of data, entity responsible for upkeep of gages or projects/studies for which gage data were collected, etc.

- Diversions and Irrigated Acreage – Headgate locations and irrigated lands mapping that is available from the Basin Plans or other efforts will first be used to locate the various basin irrigation uses with respect to one another. The general locations of acreage are used to develop the stream order between nodes and will be used in the development of a model network for the spreadsheet model or simulation model. If a spreadsheet model has already been developed for the basin, the relative locations of uses should be reviewed based on the available irrigated lands mapping.

- Irrigated acreage coverage in the basin should be assigned to either individual explicit nodes, or to aggregates on tributaries and the river main stem. Aggregates should be defined by location within certain sections of tributaries; above or below stream gages, towns, other tributaries, etc. In general, the finer the resolution on the aggregates the better. A general rule is that each node (explicit or aggregate) should have a location on the river from which the diversion will be modeled, and a location(s) on the river or to other irrigated fields where the irrigation return flows from the node will accrue. For simulation models, the permits will also need to be associated with the acreage.
The SEO is developing/assigning unique identifiers for all diversion structures in the state. The irrigated acreage should be assigned to these unique river node IDs. Diversion data, water rights, and other information associated with the river headgate location and irrigated acreage will also be tied to the river node ID. The unique identifiers for the structure will be the basis of the Wyoming water database, the data “keys” for structure information.

- Information regarding tributary and river main stem uses can be used to identify structures to be modeled explicitly (if it has identifiable acreage and associated permits). Ditch operating memos were compiled in Round 1 (at least in some basins), and these should be reviewed and updated if available. Diversion records in the Hydrographer’s Records should be reviewed, gathered electronically or digitized, if necessary, and summarized by month and by structure. Diversion data for specific nodes with identified acreage will allow for development of good system efficiencies for that node. The permits assigned to the acreage can be used in a simulation model to represent the ability to get water to those lands, by priority.

Questions regarding what lands are served by a specific ditch, or irrigated by water from a specific tributary, etc. should be summarized and discussed with Water Division personnel and possibly the irrigators to help with clarifying node selections, locations, and representation in the stream network.

A memorandum should be developed cataloguing the available GIS or other mapping data gathered for the basin, along with summary maps of acreage and node IDs, summary of discussions with Water Division personnel, irrigators, and others, and other pertinent data related to organization of river network around irrigated acreage and diversion data.

- Reservoirs – The locations of existing reservoirs in the basin should be identified with respect to stream gages and diversion nodes, for development of the river network. Proposed reservoirs that have been identified in other studies should be similarly located.
Information regarding the reservoirs should be gathered and added to the model development files. This information might include recorded historical storage contents, locations on quad maps, storage capacity-area-elevation curves, release capacities, method of operating, seepage estimates, etc. These data will be used for some of the inputs for the models. The storage contents data should be digitized, since this time series is important for the calculation of baseflows and will ultimately be incorporated into the Wyoming water database.

The StateMod model represents net evaporation losses based on an input area-capacity curve. The climate data needed for this operation is described further below.

- Municipal and industrial (M&I) uses – M&I demands should be input based on user information or historical records of use. River diversions will be considered as instantaneous impacts on the river system. Well diversions for these, and other uses, can be modeled to impact the river under a specified delay pattern that reflects the timing of groundwater movement. Efficiencies for M&I uses (i.e., the portion of river diversions that is consumed) and locations of return flows from the M&I uses are other inputs to the model. From a priority perspective, municipal and industrial water rights should be handled similarly to agricultural rights.

- Instream flows – The effects of instream flow rights or demands on basin operations can also be represented in a planning model. This water use is more likely to be used in a simulation model versus a spreadsheet model, since modelers can see the streamflow available for permitted or planned instream flows. The StateMod model can represent instream flows at a single point on the river, or over a reach of the river, with specified minimum flow rates to be in the instream reach by a certain priority. Minimum lake levels to preserve reservoir storage contents for environmental, fishing or other purposes can also be represented in the StateMod model. Since instream flows and minimum lake levels are non-consumptive uses, the model simulates to ensure the flows stay within the instream flow reach or minimum storage contents stay in the reservoir without the water
being used or diverted by water rights junior to the instream flow or minimum lake level priority.

- Water Rights – Water rights consisting of an amount of water (cfs for diversions or instream flows, ac-ft for reservoirs) to which the owner is entitled, and a priority, are required if the model is to simulate Wyoming’s water administration. A significant programming effort would be required to carry out the water right allocation in a spreadsheet environment. If the intention is to replicate water distribution in accordance with Wyoming water law, then a simulation model is generally required. In fact, this capability is important to fully characterize any planning scenario that involves a new or changed supply to river. For example, a new reservoir would permit late season diversions that didn’t occur historically. While the reservoir supply itself may be “shepherded” to the reservoir owners, their lagged return flows accrue generally to the river, and would be allocated according to the priority system.

- Climate data – Climate data are used to estimate CIR and to model evaporation losses from reservoir storage. Temperature and precipitation data are typically available for at least one climate station in the basin being modeled. (Fully automated stations measuring all standard parameters are scheduled to be installed in the Green River basin in 2008 and 2009.) If not available at all, or if some of the data are missing from the climate station records, the data can be filled using various methods, as discussed in Appendix A. Reservoir storage losses are caused by gross evaporation losses that are offset by precipitation. If not already identified for the basin, average annual gross evaporation values can be pulled from the NOAA NWS-33 report. The gross evaporation must be distributed monthly and then compared to average monthly precipitation to estimate monthly net evaporation model inputs. The method for distributing annual gross evaporation on a monthly basis may be available from previous basin studies, university research efforts, and possibly other sources.
Planning Model Development and Application for the Wyoming State Water Plan

5.2 Choice of Model Based on Available Data

The extent to which data are available for each of the data types listed above, and for each of the nodes in the model network, will influence the choice of an appropriate model. A general approach for the choice of model is presented below. These concepts should be compared to the models required for the WWDO planning study levels discussed in Section 3. Keep in mind that there can be no hard and fast rules for the amount of data required to justify a given level of modeling. In a consistently water short basin where return flows are essential to sustaining irrigation and the water supply is highly managed, the need for detail is more acute than in a basin with more plentiful supply and fewer complex operations like exchanges.

- A basin with a few explicit structures defined, sparse streamflow data, and limited understanding of the acreage irrigated from specific tributaries illustrates a worst-case scenario. This scenario would be best served with starting with a spreadsheet model and making estimates of the various other input data necessary for the spreadsheet model. An option to consider under this circumstance is a month-by-month spreadsheet model over a relatively short period such as ten years. However, if reconnaissance Level I Study efforts indicate that water development opportunities exist within data short reaches or watersheds, the State of Wyoming should invest in establishing additional explicit structures to describe system hydrology and to either extend an existing spreadsheet to improve estimates or convert from a spreadsheet to a simulation model.

- Basins where there is more historical diversion data, better mapping of irrigated lands, and explicit structures representing at least approximately 15 to 25 percent of the total nodes or identified acreage in the basin, may be ready for creation of a simulation model. This scenario is similar to what existed in the Upper Green River and was used in development of the StateMod model representation of the basin. Meaningful output is available from the simulation model results. Although there is not complete enough data to provide a meaningful model calibration, the structure of the model has been established. Any new data that is gathered over time can be incorporated into the model.
input files relatively easily. The data that does exist can be used to develop recommendations for further data collection, as discussed below.

- Basins for which even more, and better, data are available can move directly to simulation models that can provide even more useful output. The amount of available raw input data determines how far along that basin is toward being able to develop a calibrated simulation model that can be used to identify purpose and need in a Level II Phase III Study. Similarly, the amount of raw input data has a direct effect on the data that must be estimated to develop model inputs, as discussed below.

5.3 Estimated Input Data

Various data inputs need to be developed for spreadsheet models and simulation models both because there is always missing data regarding water uses, and because the models need to estimate CIR and other future demands that may be different from the available data representing historical operations (e.g., trying to meet a full crop demand because a new reservoir has come online, whereas previously the crops may have been deficit irrigated due to more limited supplies).

The available raw input data forms the backbone of the model and has a direct effect on filling the missing data, the various estimated data inputs, ability to calibrate models, and the quality of the model results. The estimated input data are described below, including discussions of the sensitivity of model results to the various raw input data, followed by recommendations to help the State prioritize its data collection efforts. Specifics regarding filling methods and various approaches to be used for the different data sets are included in Appendix A. The approaches described in Appendix B can be used in most model environments, even though Appendix A focuses on the transfer of a spreadsheet model into a StateMod data set.

- Crop Irrigation Requirement (CIR) – Crop demand or CIR is a significant input in determining future demands on the river basin and for estimating system efficiencies based on historical operations. Estimates of CIR rely first, and foremost, on the amounts of irrigated acreage and crop types irrigated by the various diversion nodes. As noted in
Section 4, the GRBP and Upper Green StateMod data set includes estimated Average, Wet, and Dry CIR based on CIR values developed to support a University of Wyoming (UW) report (Pochop et al., WWRC-92-06). The representative irrigation demands are appropriate for a spreadsheet model used in Level I and, possibly, Level II Phase I studies, but do not provide the monthly and annual variability needed for a simulation model.

The Pochop study reports the means and extremes of monthly crop demand values for crops grown locally near 67 weather stations spread throughout Wyoming. The sophisticated model used in the WWRC-92-06 study has not been maintained, according to Dr. Pochop, who is retired. Therefore, another approach is necessary to estimate crop demands for a simulation model. For the Upper Green River StateMod data set, the modified Blaney-Criddle method was calibrated to the Pochop study data, as discussed in Appendix A.

Although the approach used in the Upper Green River Level II Studies may be appropriate for other basin models, development of the next round of basin simulation models would benefit from a more complete search of available crop demand estimation techniques either currently, or historically, used for irrigated crops in Wyoming. University personnel, basin groups, and state and government offices should be contacted for help in identifying what data and CIR models are available. The available output from these models (and possibly the model themselves), published studies, interview notes, and other information should be summarized in a memorandum along with an electronic file(s) with the data that was collected. Identification of which models are maintained would be helpful for future model development.

Although it would be nice to have a standard approach to use in all of the basin models (e.g., development of calibrated Blaney-Criddle crop coefficients), the best approach may differ for each basin depending on what kind of information is available in that basin. The CDSS StateCU model is one tool that has been extensively tested and can be used to calculate CIR using various estimation methods.
Efficiencies – System efficiencies represent both ditch losses and farm losses associated with irrigation. System efficiencies are typically estimated based on historical CIR and historical diversions. Implicit in the estimate is a maximum farm efficiency to put a cap on the amount of farm deliveries that can be consumed. Measurable data on these two portions of system efficiency is not likely available.

Ditch loss estimates are often based on ditch lengths and seepage properties of underlying soils. Estimates of maximum efficiency are often based on the type of irrigation practice. Typical values used include 60 percent maximum farm efficiency for flood irrigation, and 80 percent maximum farm efficiency for sprinkler irrigation. The GRBP and the Upper Green StateMod data set used a maximum system efficiency of 55 percent, reflecting both conveyance and on-farm efficiency.

The system efficiency represents the portion of water diverted from the river that is consumed by the crops. The portion of the river diversions that are not consumed by the crops returns to the river over time. As discussed further below, the timing and location of return flows is important in the calibration of simulation models. Determining the amount of unconsumed water is therefore also important in model calibration. In addition to having a good handle on CIR, the most important part of calculating system efficiencies is completeness of record of river diversions.

Return flow locations and timing – The return flow locations are used to represent where all, or a portion, of the unused water from a node’s irrigated lands return to the river. This might be to the headgate or lands for the next downstream node; it might be to a neighboring tributary; a stream gage; or a reservoir. The timing of returns is used to represent the immediate surface returns that occur during the month water is applied to the fields, and to accounted for the lagged effects of subsurface returns.

Reasonable estimates for these inputs can be developed if the acreage associated with the various diversion nodes has been mapped or can be identified. The return flow inputs are
Planning Model Development and Application for the Wyoming State Water Plan

relatively easy to develop based on this information and should be calculated, or original calculations revisited, for all future modeling efforts.

• Demands – The spreadsheet models have typically modeled the CU depletion of the irrigation rather than the dynamics of river diversions and return flows. In these scenarios, the consumptive use is set equal to the CIR, and potentially limited based on estimated days in priority to divert water, and possibly on future operations.

5.4 Recommendations on Data Collection

Different input data are necessary for model development, and much of these data have a direct effect on the other inputs that are calculated, and ultimately for calibration of a simulation model. Listed below are various data that can be collected, their influence on model output, and the level of effort anticipated to collect these data. Specific recommendations are provided for the Upper Green River basin, based on the recent modeling efforts.

• Study data – This information can be collected from or developed based on information from previous studies, USGS databases and quad maps, NOAA databases, Wyoming water permits database, and aerial photos. These data are not considered to be particularly expensive to gather or require much ongoing expense.

➢ Streamflows – Available streamflow data from the USGS, SEO, university studies, and sources should be collected and reviewed to identify gaps in spatial or temporal representation of flows in the basins throughout the state. Gaps in understanding should be filled through gaging efforts discussed under Field data below.

➢ Irrigated acreage – Correlation of irrigated acreage to ditch headgates should be first reviewed in the office based on legal descriptions in water permits and review of aerial photos (and possibly satellite photos) of the locations of irrigated acreage and ditch layouts to trace these irrigated areas back to specific diversion points on the river. Assignment of irrigated acreage to specific ditches and water
permits should be confirmed through interviews, as discussed under Interview data below.

At the beginning of any modeling effort, and especially in the development of a simulation model, previous studies should be gathered to determine what approaches have been used to estimate CIR in the basin of interest. Monthly output for about 12 weather stations from the Pochop et al. study was collected and used as part of the GRBP effort. These data included estimates of CIR for various years between 1956 and 1990. The data were provided for climate stations only within the Green River basin, although they did contain stations located both above and below Fontenelle Reservoir. The data for the remaining stations should be collected and potentially used to develop calibrated monthly crop coefficients for other river basins for use with the Blaney-Criddle model.

- Diversion – During the Round 1 GRBP, some ditch diversion records were collected and compiled in ditch “operating memos”. These should be extended using diversion records available from the Hydrographers Records, and ditch company records if available. They should be collected and assigned to specific river headgates. Similar to streamflows, gaps in spatial and temporal representation of diversion in the basins should be filled through diversion recording efforts discussed under Field data below.

- Reservoirs – Information regarding existing and proposed reservoirs should be collected from reservoir operators and previous studies, respectively. Evaporation pan data, if available at the reservoir, should be collected.

- Water rights – Water permits on lands should be identified against water permits available in the SEO Water Permits Database. These permits could be checked against the representation of water permits to WIRSOS model nodes, which might identify inconsistencies that should be further investigated. The water permits
should be checked through interviews with SEO personnel and users to identify those which are, and are not, active.

- Climate data - Available precipitation and temperature data from NOAA, SEO, university studies, and sources should be collected. Daily climate data that may be used in daily combination method equations that used to estimate CIR (e.g., solar radiation, relative humidity, wind speed) should be noted for either future use modeling efforts or comparison to CIR estimated through simpler methods such as the Blaney-Criddle method.

- Field data – Streamflows, diversion records, locations of river headgates, irrigated acreage tied to river headgates, crops irrigated, and water permits assigned to irrigated lands.

- Stream gages should be installed and streamflows recorded throughout the state for areas where there are big spatial gaps in available data, specifically tributaries identified for future storage projects. These data should be collected for at least two or three years, and preferably for longer periods, to provide the best information for model development, identification of available flows, and model calibration. Stateline gages are specifically recommended to better understand Wyoming basin effects on state line flows on river systems subject to interstate compact obligations.

- Diversion data – Diversion records in the Hydrographers records collected and used in the Upper Green River model are typically recorded only a few times during the irrigation season. More frequent recording of diversions would help improve the monthly variability of diversion practices for irrigation. Measuring flumes, rating of existing diversion canals, and other methods should be established to record diversions throughout the state for areas where there are big spatial gaps in available data, specifically tributaries identified for future storage projects. These data should be collected for at least two or three years, and
preferably for longer periods, to provide the best information for model development and calibration. Diversion information is particularly helpful in the calculation of ditch system efficiencies and gains and losses in river reaches. Project Engineer/Modelers should attempt to replicate existing irrigation practices, including a more accurate characterization of the irrigation season. For instance, many appropriators quit irrigating much earlier than the September 15 end of season date for the Green River Basin published by Pochop et al.

- Interview data – This information can be collected from basin meetings, on-the-ground and telephone interviews with irrigators and Water Division personnel.

  - Irrigated acreage and Water permits – As noted above, Water Division personnel, and irrigators should be interviewed to clarify information gathered and reviewed regarding the correspondence of river headgates, irrigated lands, and associated water permits.

  - Irrigation practices – At the beginning of upcoming modeling efforts, it is recommended that interviews, surveys, or other efforts be conducted to understand how irrigation is carried out in specific basins and tributaries, and understanding of basin users would change these practices if more water were available, or to make more water available (e.g., through construction of a new reservoir). This is specifically aimed at understanding the seasonal extent of current irrigation practices. For instance, if irrigators use water through late September for either irrigation or wetting up feed for winter feed, as modeled by Pochop et al., or stopping water use in late-July to hay and cease irrigation for the season. Future practices of extending the irrigation season by foregoing the second cfs in the spring for storage, which would accommodate late-summer releases, should also be investigated to better represent historical and future water uses in the basin.
Planning Model Development and Application for the Wyoming State Water Plan

- Specific recommendations – The following data collection efforts are recommended for the Upper Green River modeling effort, and possible extension of the model to other parts of the Green River basin:

  - Diversion data – Increase frequency of record keeping at existing structures to provide better estimates of monthly variability of diversions. Install flumes or recorders, as necessary, on as many ditches as possible on the Cottonwood Creek, Horse Creek, and Piney Creek system that is the focus of the Westside Storage Level II Study. This will provide tributary-specific information that will be used to develop baseflows and system efficiencies.
Section 6

Documentation Guidelines

In order for simulation models produced as part of the basin planning process to become a tool of choice, they must be well documented. Those who have little familiarity with the data sets must be able to understand sources of data, have insight into their relative accuracy, and for calculated input parameters, understand how the values were created. For a model as extensive as the Green River basin model, for instance, the documentation effort can be significant.

Two levels of documentation are described and recommended here. The first is documentation on a “metadata” level. Fortunately, StateMod allows for “self-documented” input files. That means that information on the source of data can be embedded in the input file itself. The Colorado Decision Support System (CDSS), of which StateMod is the planning model component, includes data management interface (DMI) software. This software is the link between databases and the model; it generates most of the StateMod input files, following a list of commands created by the modeler. The commands are powerful, and can include data manipulation functions (e.g., fill missing months in time series A using time series B). The DMI generates text in the file it creates, stating what database the information came from, how the data was processed, and so forth. With this information, plus the database metadata, a user can gather all he needs to know about the data.

Currently, Wyoming cannot take full advantage of the CDSS DMI’s because Wyoming’s databases are not compatible with them. However, the description is included because it could serve as a model for future development. Databases could eventually be created that are compatible with the CDSS DMI’s, or, Wyoming could develop interface software compatible with their own data, and include this self-documenting feature.
In the near term, however, the model developers can supply text, which StateMod ignores, within the input files. There is no limitation on the number of lines devoted to these comments. The kinds of information that should be placed in the file could include:

- Source of information (e.g., on-line database, report, basin plan ditch operating information)
- How missing data were filled
- Derivation techniques for calculated input, or citations for techniques
- Assumptions underlying derivations
- Date the file was developed, developer name

The effectiveness of this level of documentation depends on the diligence of the individual model developer, and requires a budget that recognizes and supports this important aspect of modeling.

The second level of documentation is a user manual for the model. The Table of Contents for the CDSS Yampa River planning model user manual is included as Appendix B. The full document can be viewed or downloaded by going to [http://cdss.state.co.us](http://cdss.state.co.us) and clicking “Surface Water Model” in the pull-down menu under “Products”. This manual could be used as a template for Wyoming’s model documentation, as it is the product of several iterations under CDSS with respect to documentation, and has been well-received.

Each section of the documentation is described below. Some sections are transportable from basin to basin. Once the section was written for the first basin it could be used with minor variation for subsequently developed basin models. Other sections are unique:

**Section 2**

What’s in this Document – explains the layout of the user manual and describes other useful CDSS documentation, such as the StateMod user manual and technical papers that describe literature searches, sensitivity studies, and pilot projects through which the modeling approach was derived. This section is similar in every basin model user’s manual.
### Planning Model Development and Application for the Wyoming State Water Plan

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>The Yampa River Basin – describes briefly the basin physical and human geography; very basin specific.</td>
</tr>
<tr>
<td>4</td>
<td>Modeling Approach – provides an overview of methods and techniques used in the model, addressing an array of typical modeling issues such as aerial extent, study period, and data filling. Much of this section is applicable to other basin models. Once written the first time, it can be “customized” for a particular basin fairly easily.</td>
</tr>
<tr>
<td>5</td>
<td>Baseline Data Set – describes the input data set, file by file. This data set represents current demands imposed on historical hydrology. Content, source of data, and implementation issues are covered in detail. Many file descriptions begin with the default approach taken for the majority of rights, structures, or time series, as applicable to the file. All special cases are then described in particular detail. This section is very basin specific and requires the greatest effort.</td>
</tr>
<tr>
<td>6</td>
<td>Baseline Results – presents summarized results of the baseline simulation. It consists mostly of graphs of simulated total flow and simulated available flow at key gages. Historical gage flow is shown for reference, but the purpose is not to show how closely the model simulates the real world. It shows how current use of the water resource results in a different outcome, compared to historical conditions.</td>
</tr>
<tr>
<td>7</td>
<td>Calibration – describes the calibration process and demonstrates the model’s ability to replicate historical conditions under historical demand and operations. Comparisons of historical and simulated values for streamflow, diversions, and reservoir levels are presented.</td>
</tr>
<tr>
<td>8</td>
<td>Daily Baseline Results – the Yampa CDSS basin model includes a daily implementation, which this section describes. It presents summarized results of the daily baseline simulation. Daily modeling is not envisioned in the immediate future in Wyoming.</td>
</tr>
<tr>
<td>Appendices</td>
<td>A through D – these are technical memoranda that support model input calculations. They tend to be basin specific, as more general technical memos as noted in Section 2, are available on the CDSS website.</td>
</tr>
</tbody>
</table>

Wyoming could choose to produce a less extensive user manual, but Sections 4 and 5 are essential. Section 7 is also essential once sufficient data have been collected to allow for model calibration. If a dataset is available, the user can produce the information in Section 6 by him or
herself. We recommend that a “Baseline Results” section be included because it is good reference information. The effort to produce the section is minor relative to effort for other sections.

User documentation should not be overlooked in budgeting for model development. Documentation could require on the order of 160 hours or more of labor, depending on how detailed the model is. One of the benefits of documenting the input files in specific detail is that it creates one final check on all aspects of input. Thus resources allocated to documentation also accomplish quality control.
Section 7

Model Update, Maintenance, and Storage

Important efforts in model development that are often overlooked include the storage of collected data and maintenance and updating of the models. Consideration of these elements is important to ensure that when the present modeling effort is completed, subsequent efforts can easily find the information from the model and not need to recreate the wheel. This will save time and money when the completed model is refined, when model simulations of additional “what if” scenarios are run, and when additional data are collected for structures in the basin (e.g., diversion records, storage contents).

As noted previously, a unique identifier for all structures (i.e., nodes) is necessary to allow for easy access of data associated with a particular structure. Irrigated acreage is being associated to the diversion structure (and the diversion structure’s identifier) that serves the land, as part of the SEO’s effort to develop a geohydrodatabase for the Upper Green River in Wyoming. The structure identifiers are also tied back to the SEO Water Permits Database. The centralized database being developed by the SEO will ultimately allow structure identifiers to be associated with time series of diversions, storage contents, and irrigated acreage, along with state variables like ditch capacity, storage capacity-area-elevation curves, etc.

The storage protocol for all modeling efforts should start with a meeting with the SEO’s IT Initiative Team to coordinate model data collection efforts with the Team’s database management and development efforts.

Model maintenance should include identifying a central location for all completed models to reside. This would include all of the working files developed by consultants related to data gathering, decision making regarding developing necessary model input data that may be missing, etc. The internal memos developed as part of the protocol, as described in Section 5, will be collected and presented in the model documentation, as described in Section 6. The
model documentation will include information related to these work products, describe how data were gathered and manipulated, how the model was set up, and information regarding the model outputs from various input scenarios. The documentation and the centrally-located models can then serve as a starting point to future model runs or model refinements.
APPENDIX
APPENDIX A

Methodology to Convert Basin Spreadsheet Model Inputs to Simulation Model Inputs

The following efforts are recommended to upgrade spreadsheet model representation of a basin into the information needed for simulation model efforts. The information presented is intended to apply to all river basins, but builds on the approach and lessons learned in the development of the StateMod model data set in the Upper Green Level II Study, subsequent refinements in the Upper Green Westside Storage Level II Study, and other recommendations based on previous modeling efforts in other river basins using the StateMod model.

Model network – A visual representation of model nodes in upstream to downstream order on the river main stem and tributaries should be created using the StateDMI software. Model nodes include stream gages, irrigation and municipal diversion nodes, reservoirs, and instream flow reaches. The general approach is to maintain organization and designation of nodes included in spreadsheet model.

- Include explicit structures from spreadsheet model as explicit structures in the StateMod model network.
- Include aggregate structures from spreadsheet model as aggregate structures in the StateMod model network.
- “Break” aggregates into explicit structures if new data are available.
- Include instream flow nodes for which permits have been issued or that are being considered. These reaches are generally represented by a pair of nodes representing the top and bottom of the instream flow reach (e.g., headwaters of Cottonwood Creek down to Cottonwood Creek-Green River confluence).
- Include existing and projected reservoirs.
- Other nodes can be included in the model network as more information becomes available.

Irrigated acreage – Acreage is a key input to the model and is used, along with crop types and local weather station data, as basis for crop demands. Different approaches can be used to develop acreage.
- We recommend that model efforts begin with using the acreage identified in the spreadsheet models as the baseline representation of irrigated acreage in the river basin.

- Other approaches can be employed to refine irrigated acreage in the river basin that reflect the basin-specific water operations:
  - Acreage can be further refined by reducing the decreed areas by overlaying actual irrigated areas as determined by satellite imagery interpretation.
  - The baseline acreage can be modified based on previous studies summarizing total irrigated acreage in the river basin, conversations with local irrigators, etc.

Return flows – Return flow locations can be initially assigned to the next node downstream below each structure or as in the GRBP spreadsheet, if explicit. Return flow timing should be initially assigned as occurring in the month of diversion. Modifications to these inputs should be made based on the following efforts:

- Irrigated acreage mapping should be reviewed with respect to sub-basin boundaries (i.e., USGS County-HUCs) in order to identify return flow locations and timing of river diversions to irrigation. Development of these model input data are used to improve the baseflow calculation, which relies on estimates of how much, and in what timing, irrigation return flows occur above each stream gage and confluence in the river network. The better these return patterns are understood, the better the calculated baseflows.
  - Centroids of irrigated acreage assigned to the nodes, as discussed above, should be estimated in order to represent the ‘average’ response of water diverted to irrigation for that node.
  - Using irrigated acreage with centroids overlaid on topographic maps, return flow pathways should be identified for the irrigation nodes. Estimates should be made on the pro-rata amount of acreage tributary to the next down gradient acreage or location on the river, if irrigated lands are not located down gradient. This information should be used to estimate the location(s) of return flows and percentage of the total return flow going to each of the return flow locations.
Refinements to return flow locations should be incorporated as additional information becomes available (e.g., conversations with irrigators, conversations with Water Commissioners and irrigators).

- The timing of return flows should be estimated based on the relative distance between the centroid of the irrigated acreage producing the return flows and the return flow location (e.g., above a stream gage or the centroid of another node’s acreage). The distances identified for all of the nodes and all of the return flow locations should be ordered to identify common ranges of distances that may exhibit similar return properties. For example, previous modeling efforts in river basins with similar soils throughout the basin have classified return flow patterns for distances a) less than 100 feet from the river, b) between 100 feet and 500 feet, c) between 500 feet and 2,000 feet, and d) greater than 2,000 feet, which will provide four patterns, of varying lengths, representing the combination of surface water returns and lagged ground water returns. Specific classifications will depend on the basin being studied. Variability in soil types and aquifer properties may benefit from classification by distance and by soil type.

Quantification of the return timing can be estimated from previous work in the basin, including USGS studies and geological investigations, SCS soil reports, basic Glover analysis runs, or other methods.

- StateMod has the option to estimate seepage losses from a reservoir based on input rates. The timing of seepage losses and their return to the river or to other model nodes can be represented based on inputs similar to that described above regarding return flow locations and return flow timing.

Crop irrigation requirements – The spreadsheet model used Wet, Dry, and Average monthly CIR based on a 1992 study by Pochop et al. (WWRC #92-06). To extend CIR through the study period, the Blaney-Criddle method was applied, using crop coefficients calibrated to the Pochop data in the Level II Studies. This was necessary because the CIR model developed by Pochop has not been maintained. We calibrated Blaney-Criddle monthly crop coefficients so the calculated Blaney-Criddle CIR matches the available CIR results from the Pochop study on an
average monthly basis. The calibrated crop coefficients can then be used to estimate CIR beyond when the Pochop data are available.

- The historical crop irrigation water requirement was estimated with the StateCU Model for all irrigation nodes based on node acreage, crop types (i.e., mountain meadow hay), and climate data from the Big Piney weather station over the May 1 to September 15 season, as defined in the Pochop study and used in the spreadsheet model.

Historical diversions – Historical diversion data are key inputs used to estimate baseflow and system efficiencies. Historical diversion data should be collected for the model study period, whenever available, from the Hydrographers Reports, municipal and industrial users, and other sources. Note the model requires complete data sets for historical diversions with no missing data.

- Explicit structures – Missing diversion data can be filled based on monthly averages, or average-, dry-, and wet-year historical monthly average diversions. These filling methods, and others, are available in the TSTool (Time Series Tool) DMI software.
  - Monthly system efficiencies are calculated in the StateCU model for the explicit structures based on monthly CIR divided by monthly river headgate diversions. Monthly efficiencies for the explicit structures in the Upper Green River StateMod data set were limited to 55 percent. The maximum efficiency values for other basin modeling efforts should be estimated based on irrigation practices in the basin. The calculated efficiencies are averaged on a monthly basis. The average system efficiencies are inputs to the StateMod data set for the explicit structures to represent the amount of water consumed by the node, and the amount of water that is not consumed and returned to the river.
  - Historical irrigation practices, especially during the spring runoff, may show very low efficiencies, since irrigators are often diverting as much water as possible – much more than the crops need. Using these very low efficiencies in the basin may not represent actual practices in the future, especially if irrigators are purposely more efficient to provide more water that could be stored in a reservoir. The StateCU model allows input of a minimum efficiency that caps the lower end of efficiency
calculations. That way, for instance, the structure efficiencies could be maintained above 30 percent, or some other appropriate value.

- Aggregate structures – Historical diversions are estimated based on CIR for irrigated crops served by the acreage assigned to the aggregates divided by the average monthly efficiencies calculated for similar explicit structures (e.g., aggregate and explicit structures both located on the main stem; aggregate and explicit structures both located on nearby tributaries; etc.).

- Municipal and industrial users – Estimate historical diversion based on spreadsheet inputs, available diversion records, or information gathered through user interviews.

- Reservoir structures - Reservoir inputs consist of monthly changes in storage based on end-of-month storage contents.

- Instream Flow Structures - Historical diversions for instream flow structures are not input to the StateMod data set. These uses are non-consumptive and are therefore not considered in baseflow calculations.

Future Demands – Future demands for irrigators, municipalities, reservoirs, and instream flow structures represent the objective calculations for model simulations. During model simulations, the demands are met by available physical flows, in priority, limited by the minimum of: 1) the river demand, 2) the amount of physical flow at the diversion structure, 3) the amount of legally available flow, based on the node’s permit priority in relation to other priorities in the river basin. Note the model requires complete data sets for future demands with no missing data.

- Explicit and Aggregate Structures – River headgate demands are calculated based on CIR for irrigated crops divided by average monthly system efficiencies.

- Municipal and industrial users – Set future demands equal to historical diversion inputs unless changes in operations are projected (e.g., increasing municipal population, industrial uses coming online).

- Reservoir structures – Set future demands to full capacity each month to estimate how hydrology and reservoir priorities control reservoir operations.

- Instream Flow Structures - Future demands are set equal to permitted monthly or annual flow rates.
Water Rights – Water permits assigned to model nodes represent the legal rights to water during model simulations.

- Preliminary representation of water permits in the StateMod model will be based on products from the Round 1 basin plans, and available SEO water rights attribution data. Information included in WIRSOS basin models can also be included, if available.
  - Based on recommendations identified in the Greybull River StateMod modeling efforts, water permits in the direct diversion rights file will include the Wyoming permit number at the beginning of the diversion right name field (e.g., PA88002TD-0501903). Based on recommendations identified in the Greybull River StateMod modeling efforts, the priority dates are included as administration numbers in the format YYYYY.MMDD (e.g., 1879.0501)
  - Active water right permits can be updated based on water permit tabulations maintained by the State Engineer’s Office

- Aggregate structures represent multiple ditch headgates and irrigated lands within certain sections of the main stem and tributaries. Water permits for aggregate structures are assigned based on location of the permits for structures within tributary basins and location above and below explicitly modeled structures. This is expected to provide sufficient water rights for meeting the modeled demands but shortages are still expected to occur due to limited physical water supply.

- Surplus water rights are included in the model, for all pre-1985 permits, as follows:
  - Water permits senior to March 1, 1945 are assigned a surplus water right of 3/1/1945 (administration number 1945.0301) with an amount equal to the senior permit amount. In cases with more than one senior permit, the surplus rights will be assigned subsequent dates (3/1/1945, 3/2/1945, 3/3/1945, etc.) in order of the seniority of the original permits.
  - Water permits senior to March 1, 1985 and junior to March 1, 1945 will be assigned a surplus water right of 3/1/1985 (administration number 1985.0301) with an amount equal to the original permit amount. Surplus rights will be assigned subsequent dates,
as noted above, for cases with more than one permit between March 1, 1945 and March 1, 1985.

- Individual water rights can be turned ON or OFF for model simulation. Supplemental rights could be turned off if users were expected to forego the 2\textsuperscript{nd} cfs to improve diversions to storage.

- Historical diversions of water in excess of the appropriator’s entitlements (free river situation) should be identified and replicated in the model for incorporation during analyzing “what if” scenarios.

- Municipal structures will be modeled in accordance with the priority right of their permit.

- Reservoir structures can be represented in different ways:
  - Existing reservoirs are assigned administration numbers based on the specific storage water permits associated with the reservoir.
  - Potential future reservoirs are assigned a junior administration number (e.g., 2008.0101, representing January 1, 2008), with amounts equal to the active storage capacity, to limit the reservoir’s ability to store to free river periods.
  - Other operational scenarios with future reservoirs can be represented in various ways. For example, allowing surplus water rights to be stored can be operated by assigning irrigation water rights to bypass the ditch headgate to storage in the reservoir. These operations could be assigned a priority equal to the surplus water right administration number (e.g., 1945.xxx or 1985.xxxx)

- Instream flow structures are assigned priorities based on their permit date in amounts equal to the flow rate included in the instream flow permit.

Operating rules – The operating rule file for the Upper Green StateMod data set includes rules to represent future reservoir operations. These uses represent supplementary reservoir releases to beneficiary irrigation nodes via the river, and are assigned priorities just junior to the most junior permit assigned to the node receiving the supplemental supply. Downstream nodes receiving storage water will divert the storage releases directly out of the river. Upstream nodes receiving storage water must do so by exchange, and are therefore limited by the amount of physical supply available at their diversion point.
As noted in Section 4, the StateMod model currently has 49 generic operating rules, which provides for many other opportunities to model reservoir operations, water right trades, exchanges, alternate diversion points, etc.

Future operations could include reservoir releases by pipeline, use of the second cfs to fill reservoir storage rather than for direct irrigation, etc.
APPENDIX B

CDSS Planning Model User Manual Table of Contents

Table of Contents

Table of Contents ............................................................................................................................. i
Table of Tables .............................................................................................................................. vi
Table of Figures ............................................................................................................................. vi

1. Introduction ............................................................................................................................. 1-1
   1.1 Background ................................................................................................................. 1-1
   1.2 Development of the Yampa River Basin Water Resources Planning Model ......... 1-2
   1.3 Acknowledgements ................................................................................................. 1-2

2. What’s in This Document ........................................................................................................ 2-1
   2.1 Scope of this Manual ............................................................................................... 2-1
   2.2 Manual Contents .................................................................................................... 2-4
   2.3 What’s in other CDSS documentation ................................................................... 2-6

3. The Yampa River Basin .......................................................................................................... 3-1
   3.1 Physical Geography ............................................................................................... 3-1
   3.2 Human and Economic Factors .............................................................................. 3-2
   3.3 Water Resources Development ............................................................................. 3-6
   3.4 Water Rights Administration ................................................................................. 3-8
   3.5 Section 3 References ............................................................................................. 3-11

4. Modeling Approach .................................................................................................................. 4-1
   4.1 Modeling Objectives ............................................................................................ 4-1
   4.2 Model coverage and extent .................................................................................... 4-1
       4.2.1 Network Diagram ...................................................................................... 4-2
       4.2.2 Diversion Structures ................................................................................. 4-3
           4.2.2.1 Key Diversion Structures ...................................................... 4-4
           4.2.2.2 Aggregation Of Irrigation Structures .................................. 4-5
           4.2.2.3 Aggregation of Municipal and Industrial Uses ..................... 4-6
4.2.3. Reservoirs ...................................................................................................... 4-6
   4.2.3.1 Key Reservoirs .............................................................................. 4-7
   4.2.3.2 Aggregation of Reservoirs............................................................. 4-7
4.2.4. Instream Flow Structures ............................................................................. 4-8
4.3 Modelig Period .................................................................................................. 4-9
4.4 Data Filling ...................................................................................................... 4-9
   4.4.1. Historical Data Extension For Major Structures................................. 4-11
      4.4.1.1 Historical Diversions ................................................................... 4-11
      4.4.1.2 Historical Reservoir Contents ..................................................... 4-12
   4.4.2. Automated Time Series Filling............................................................. 4-13
   4.4.3. Baseflow Filling ................................................................................... 4-15
4.5 Consumptive Use And Return Flow Amounts .................................................. 4-17
   4.5.1. Variable Efficiency Of Irrigation Use .................................................. 4-17
   4.5.2. Constant Efficiency For Other Uses And Special Cases ...................... 4-18
4.6 Disposition of Return Flows ........................................................................... 4-20
   4.6.1. Return Flow Timing ............................................................................ 4-20
   4.6.2. Return Flow Locations ....................................................................... 4-20
4.7 Baseflow Estimation ....................................................................................... 4-21
   4.7.1. Baseflow Computations At Gages ....................................................... 4-21
   4.7.2. Baseflow Filling .................................................................................. 4-22
   4.7.3. Distribution Of Baseflow To Ungaged Points ..................................... 4-22
4.8 Calibration Approach ..................................................................................... 4-24
   4.8.1. First Step Calibration .......................................................................... 4-25
   4.8.2. Second Step Calibration .................................................................... 4-26
4.9 Baseline Data Set ........................................................................................... 4-27
   4.9.1. Calculated Irrigation Demand ............................................................. 4-27
   4.9.2. Municipal And Industrial Demand ...................................................... 4-28
   4.9.3. Transbasin Demand .......................................................................... 4-28
   4.9.4. Reservoirs .......................................................................................... 4-28
5. Baseline Data Set ............................................................................................... 5-1
5.1 Response File (*.rsp) ................................................................................................... 5-1
  5.1.1 For Baseline Simulation .................................................................................... 5-2
  5.1.2 For Generating Baseflow ................................................................................. 5-2
5.2 Control File (*.ctl) ..................................................................................................... 5-3
5.3 River System Files ..................................................................................................... 5-4
  5.3.1 River Network File (*.rin) ................................................................................ 5-4
  5.3.2 River Station File (*.ris) ................................................................................ 5-5
  5.3.3 Baseflow Parameter File (*.rib) ..................................................................... 5-6
  5.3.4 Historical Streamflow File (*.rih) ................................................................. 5-7
  5.3.5 Baseflow Files (*.xbm) ................................................................................. 5-7
5.4 Diversion Files .......................................................................................................... 5-9
  5.4.1 Direct Diversion Station File (*.dds) ............................................................. 5-9
    5.4.1.1 Key Structures ...................................................................................... 5-11
    5.4.1.2 Aggregate Structures .......................................................................... 5-12
    5.4.1.3 Special Structures .............................................................................. 5-12
      5.4.1.3.1 Stillwater Ditch ............................................................................ 5-13
      5.4.1.3.2 Wyoming Historical Diversion Structures ................................ 5-14
      5.4.1.3.3 Future Use Diversion Structures .................................................. 5-14
  5.4.2 Return Flow Delay Tables (*.dly) .................................................................... 5-15
  5.4.3 Historical Diversion File (*.ddh) ................................................................. 5-16
    5.4.3.1 Key Structures ...................................................................................... 5-17
    5.4.3.2 Aggregate Structures .......................................................................... 5-18
    5.4.3.3 Special Structures .............................................................................. 5-18
      5.4.3.3.1 Stillwater Ditch ............................................................................ 5-19
      5.4.3.3.2 Wyoming Historical Diversion Structures ................................ 5-19
      5.4.3.3.3 Future Use Diversion Structures .................................................. 5-19
  5.4.4 Direct Diversion Demand File (*.ddm) ............................................................. 5-20
    5.4.4.1 Key Structures ...................................................................................... 5-21
    5.4.4.2 Aggregate Structures .......................................................................... 5-21
    5.4.4.3 Future Use Diversion Structures ......................................................... 5-21
5.4.5. Direct Diversion Right File (*.ddr) .............................................................. 5-22
  5.4.5.1 Key Structures .................................................................................. 5-24
  5.4.5.2 Aggregate Structures ................................................................... 5-24
  5.4.5.3 Special Diversion Rights ............................................................. 5-24
    5.4.5.3.1 Stillwater Ditch.................................................................. 5-24
    5.4.5.3.2 Wyoming Historical Diversion Structures ................ 5-24
    5.4.5.3.3 Future use diversion structures ........................................... 5-24

5.5 Irrigation Files ........................................................................................................... 5-25
  5.5.1. Structure Parameter File (*.par) ................................................................. 5-27
  5.5.2. CU Time Series File (*.tsp) .......................................................................... 5-27
  5.5.3. Irrigation Water Requirement File (*.iwr) ............................................. 5-28

5.6 Reservoir files ............................................................................................................ 5-29
  5.6.1. Reservoir Station File (*.res) ................................................................. 5-30
    5.6.1.1 Key Reservoirs ........................................................................... 5-31
    5.6.1.2 Aggregate Reservoirs ................................................................. 5-32
    5.6.1.3 Reservoir Accounts ...................................................................... 5-32
      5.6.1.3.1 Stillwater Reservoir ............................................................ 5-33
      5.6.1.3.2 Yamcolo Reservoir .......................................................... 5-33
      5.6.1.3.3 Allen Basin Reservoir .................................................. 5-33
      5.6.1.3.4 Stagecoach Reservoir .............................................. 5-34
      5.6.1.3.5 Lake Catamount ........................................................... 5-34
      5.6.1.3.6 Fish Creek Reservoir .................................................. 5-34
      5.6.1.3.7 Steamboat Lake .............................................................. 5-34
      5.6.1.3.8 Lester Creek Reservoir (Pearl Lake) ......................... 5-35
      5.6.1.3.9 Elkhead Reservoir ..................................................... 5-35
      5.6.1.3.10 Wyoming Reservoirs ............................................... 5-35
  5.6.2. Net Evaporation File (*.eva) .......................................................................... 5-36
  5.6.3. EOM Content File (*.eom) .......................................................................... 5-36
    5.6.3.1 Key Reservoirs ........................................................................... 5-37
    5.6.3.2 Aggregate Reservoirs ................................................................... 5-37
5.6.4. Reservoir Target File (*.tar) ................................................................. 5-38
5.6.5. Reservoir Right File (*.rer) ................................................................. 5-38
  5.6.5.1 Key Reservoirs ........................................................................ 5-39
  5.6.5.2 Aggregate Reservoirs ................................................................. 5-39
  5.6.5.3 Special Reservoir Rights ............................................................. 5-40
    5.6.5.3.1 Yamcolo Reservoir ..................................................... 5-40
    5.6.5.3.2 Stagecoach Reservoir ................................................ 5-40
5.7 Instream Flow Files .................................................................................. 5-41
  5.7.1. Instream Station File (*.ifs) .......................................................... 5-41
  5.7.2. Instream Demand File (*.ifa) ....................................................... 5-41
  5.7.3. Instream Right File (*.ifr) .......................................................... 5-41
5.8 Operating Rights File (*.opr) .................................................................. 5-42
  5.8.1. Stillwater Reservoir ...................................................................... 5-42
  5.8.2. Yamcolo Reservoir ...................................................................... 5-42
  5.8.3. Allen Basin Reservoir ................................................................. 5-43
  5.8.4. Stagecoach Reservoir ................................................................... 5-43
  5.8.5. Lake Catamount .......................................................................... 5-44
  5.8.6. Fish Creek Reservoir ................................................................... 5-44
  5.8.7. Steamboat Lake Reservoir .......................................................... 5-44
  5.8.8. Lester Creek Reservoir ............................................................... 5-45
  5.8.9. Elkhead Creek Reservoir ............................................................ 5-45
6. Baseline Results .......................................................................................... 6-1
  6.1 Baseline Streamflows .......................................................................... 6-1
7. Calibration .................................................................................................. 7-1
  7.1 Calibration Process ................................................................................ 7-1
  7.2 Historical Data Set ................................................................................ 7-2
    7.2.1. Demand file ............................................................................... 7-2
    7.2.2. Reservoir Station File and Reservoir Target File ............................ 7-3
    7.2.3. Operational Rights File ............................................................. 7-4
  7.3 Calibration issues .................................................................................... 7-5
7.3.1. Stagecoach Reservoir................................................................. 7-5
7.3.2. Fortification Creek Basin......................................................... 7-5
7.3.3. Williams Fork Basin................................................................. 7-6
7.3.4. Milk Creek Basin................................................................. 7-6
7.3.5. Reservoir Administration....................................................... 7-6

7.4 Calibration Results .................................................................... 7-7
7.4.1. Water Balance ....................................................................... 7-7
7.4.2. Streamflow Calibration Results ........................................... 7-8
7.4.3. Diversion Calibration Results .............................................. 7-8
7.4.4. Reservoir Calibration Results .............................................. 7-8

Appendix A: Aggregation of Irrigation Diversion Structures ............ A-1
Appendix B: Aggregation of Non-Irrigation Structures ...................... B-1
Appendix C: Yampa River Modeling Assumptions used for Wyoming's Historic, Current, and future Uses on the Little Snake River ................................................................. C-1
Appendix D: Calibration Results with Calculated Irrigation Demand .... D-1