WYOMING WATER DEVELOPMENT COMMISSION

MIDDLE FORK POWDER RIVER DAM AND RESERVOIR PROJECT

INTERIM REPORT
EXECUTIVE SUMMARY

Prepared by

HARZA ENGINEERING COMPANY
Englewood, Colorado
Chicago, Illinois

and

WRIGHT WATER ENGINEERS
Cheyenne, Wyoming

WESTERN RESEARCH CORPORATION
Laramie, Wyoming

JANUARY 1985
SUMMARY OF FINDINGS

• THE POWDER RIVER RESERVOIR CORPORATION HOLDS TWO WATER STORAGE PERMITS FOR THE MIDDLE FORK PROJECT ISSUED BY THE STATE ENGINEER.

• THE POWDER RIVER RESERVOIR CORPORATION HAS PUT FORTH CONSIDERABLE EFFORT TOWARD IMPLEMENTING THIS PROJECT. THESE EFFORTS INCLUDE FEASIBILITY STUDIES, GEOTECHNICAL FIELD INVESTIGATIONS, MAPPING, AND PURCHASE OF PRIVATE LAND.

• THE SIZE AND PRIORITY OF EXISTING WATER STORAGE PERMITS CAN PROVIDE A RELIABLE INDUSTRIAL AND IRRIGATION WATER SUPPLY OF ABOUT 32,000 ACRE-FEET PER YEAR.

• THE SITE CONDITIONS OF THE MIDDLE FORK DAM AND RESERVOIR ARE SUITABLE FOR THE DESIGN AND CONSTRUCTION OF A SAFE, ECONOMICAL PROJECT.

• THE 1984 CONSTRUCTION COST OF THE MIDDLE FORK PROJECT IS ESTIMATED TO BE $34 MILLION.

• THE UNIT COSTS OF WATER YIELD FROM THE PROJECT ARE ESTIMATED TO BE $65 TO $115/ACRE-FOOT (FOR INTEREST RATES OF 4% AND 8%, RESPECTIVELY), WHICH APPEAR TO BE VERY COMPETITIVE WITH OTHER WATER DEVELOPMENT PROJECTS IN WYOMING.

• THE PROJECT WOULD NOT HAVE A SIGNIFICANT IMPACT ON WATER QUALITY IN THE POWDER RIVER.

• THE IDENTIFIED AGRICULTURAL BENEFICIARIES HAVE A LIMITED ABILITY TO PAY FOR THE WATER FROM THE PROJECT.

• A SYSTEM OF PUMPING PLANTS AND PIPELINES WILL BE REQUIRED TO CONVEY THE WATER TO MUNICIPAL AND INDUSTRIAL USERS IN NORTHEAST WYOMING.

• FURTHER INVESTIGATION OF KEY ISSUES IS REQUIRED TO FACILITATE THE SUCCESSFUL IMPLEMENTATION OF THE MIDDLE FORK PROJECT.
EXECUTIVE SUMMARY

The Middle Fork Dam and Reservoir Project will regulate the natural streamflows of the Middle Fork Powder River to provide firm water supplies for industrial users and irrigators in Northeast Wyoming. The Project currently is under study for possible State-sponsored implementation. This summary of the Level II evaluations completed to date presents the following:

- Study Purpose and Scope
- History of the Middle Fork Project
- Review and Evaluation of the Middle Fork Project
- Water Supply
- Ability to Pay of Agricultural Water Users
- Conveyance of M&I Water

The study was authorized by the 1984 Wyoming Legislature (Enrolled Act No. 30) and administered by the Wyoming Water Development Commission (WWDC).

Study Purpose and Scope

The WWDC is considering developing the Middle Fork Project as a project owned and operated by the State of Wyoming. To this end, the scope of these studies included the following eight tasks:

Task 1: Review and Evaluate Existing Studies
Task 2: Generate a Level II Reservoir Operations Study
Task 3: Perform an Ability to Pay Analysis
Task 4: Estimate the Present Day Value of Prior Studies and Designs
Task 5: Estimate the Cost for Water Deliveries to the Gillette Coal Fields and North Platte River
Task 6: Participate in a Public Meeting
Task 7: Conduct a Detailed Water Quality Analysis
Task 8: Prepare an Interim Report
Task 8 includes this Executive Summary and a separate volume for the Main Report and Appendices presenting the results of the studies. A Public Meeting was held in Kaycee, Wyoming on December 19, 1984. The present day value estimates were documented in a separate report.

**History of the Middle Fork Project**

The constricted valley at the Middle Fork Powder River site, shown on Figure 1, was identified over 45 years ago as a potential dam site for water supply storage.

The first report on developing the site was made by the Wyoming State Engineer's Office in 1940. Based on that report, the Johnson County Public Irrigation District filed a water storage permit application for this site (Permit number 7548R, 41,110 acre-feet with a priority date of March 7, 1940).

The U.S. Bureau of Reclamation (USBR) investigated irrigation projects in the late 1940's and early 1950's in the Powder River Basin, including the potential Middle Fork site.

In 1967, the USBR prepared a feasibility report on the Middle Fork Project which recommended an active conservation storage of 40,000 acre-feet at the Middle Fork site to furnish a full water supply to 4,700 acres of irrigable land, a supplemental supply to the existing 4,000 acres of irrigated land, and 10,000 acre-feet per year for industrial uses.

In 1970, the Powder River Reservoir Corporation (PRRC), current project sponsors and holders of the 1940 water storage permit, authorized a feasibility study of the Middle Fork Project. The report is entitled "Engineering Feasibility Report on the Hole-in-the-Wall Dam and Reservoir". Based on the 1970 feasibility study, the PRRC filed a water storage permit application for enlargement of the storage (Permit No. 7549R, 8,473 acre-feet, priority date of December 29, 1970), and took steps to implement the Project.

In 1973, the PRRC filed an application for right-of-way to the Bureau of Land Management (BLM) because the reservoir would inundate 141 acres of land administered by the BLM.

From 1973 to 1975, studies, preliminary designs, and geological investigations were undertaken by J.T. Banner and Associates for the PRRC. In 1975, the BLM indicated they would
not grant a right-of-way to construct the Project and work on project development was stopped.

In 1982-83, Harza Engineering Company undertook a Level I Reconnaissance Study for the WWDC which identified the Middle Fork Project as the most attractive project in the basin from the standpoints of water supply, water rights, water quality, and cost-effectiveness.

The PRRC filed a second right-of-way application on July 20, 1983. An Environmental Assessment was prepared by the BLM in September 1983 and the right-of-way was granted on September 28, 1983.

In 1984, the Water Development Commission received legislative authorization to contract for studies aimed at determining the feasibility of developing the Middle Fork Dam and Reservoir Project as a state-owned project.

Water Supply

Initial evaluations of the Middle Fork Project under Level II studies began with the water supply and water rights aspects. Prior studies, including the J.T. Banner and Associates' operation studies and the Powder River Basin Level I operation studies, were reviewed in detail. This section summarizes the water supply aspects of the Project in five parts:

- Existing Water Supply and Water Rights Situation
- Development of a Level II Operations Model
- Results of Water Supply Analyses
- Yield Reliability
- Impacts on Water Quality

Existing Water Supply and Water Rights Situation

The Middle Fork Powder River derives the majority of its flow from springtime snowmelt runoff, and the flow diminishes to a small base flow throughout the summer, fall, and winter. The spring and summer flows are appropriated for irrigation use, and water is in short supply during the summer months. There are several small head gates that divert water from the Middle Fork. The Sahara Ditch, the largest, diverts water for irrigating 5,100 acres of land out of a total of 6,020 acres with original supply and supplemental supply water rights. A primary purpose
of the proposed Middle Fork reservoir is to augment the water supply to the Sahara Ditch.

The drainage area at the dam site is 450 square miles and the mean annual runoff is 76 cubic feet per second (cfs). Average monthly flows range from 270 cfs in May to about 20 cfs in the summer period (July-September).

Historical Streamflow Conditions. Streamflow data for a 40-year period were developed during the Level I Studies of the Powder River Basin and have been used in the project evaluations described in this report. Similar streamflow sequences were developed for the Red Fork and North Fork. The records were used to simulate existing and expanded with-project irrigation diversions and the requirements of existing water rights for Middle Fork water. They also were used to derive the quantity of storable water at the proposed Middle Fork dam site.

Water Rights and the Yellowstone River Compact. When completed, the project would operate under: the storage water rights that have been granted or that would be granted by the Wyoming State Engineer for the Project; the existing direct flow water rights which include senior irrigation water rights for which water must be bypassed before water can be stored in the reservoir; and the junior water rights which will continue to receive water in times of surplus. The terms of the Yellowstone River Compact are important to the Middle Fork Project in that the Compact affects future Wyoming water use, provides for development of additional supplies, and has implications that affect other water supply projects in the Powder River Basin in Wyoming.

There are 39 adjudicated water rights or unadjudicated rights or permits in good standing on the Middle Fork Powder River. There are also six adjudicated water rights on Beaver Creek, a tributary of the Middle Fork. A total of 12 of the rights, encompassing 7 ditches (5 on the Middle Fork and two on Beaver Creek), would be inundated by the Middle Fork Project. There are 33 water rights or permits on the Powder River from the Middle Fork/North Fork junction, which is the beginning of the Powder River, to the confluence with Crazy Woman Creek.
Water storage permits associated with the Middle Fork Powder River Reservoir are as follows:

<table>
<thead>
<tr>
<th>Priority</th>
<th>Permit</th>
<th>Permit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7548 R</td>
<td>7549 R (Enl)</td>
</tr>
<tr>
<td>Capacity Allocations (acre-feet)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td>10,164.7</td>
<td>1,445</td>
</tr>
<tr>
<td>Industrial</td>
<td>30,945.3</td>
<td>5,161</td>
</tr>
<tr>
<td>Dead Pool</td>
<td>-</td>
<td>1,867.5</td>
</tr>
<tr>
<td>Total</td>
<td>41,110.0</td>
<td>8,473.5</td>
</tr>
</tbody>
</table>

Water supply studies were performed to examine the effect of other senior storage water rights from the Powder River on the water storage and yield from the Middle Fork Project. The 1940 Middle Fork Reservoir water right would not be affected by any of the other potential projects because of its senior priority date and location in the river system.

**Level II Simulation Model**

A Level II Simulation Model was developed to simulate the operation of the Middle Fork Powder Reservoir and the downstream water users including the diversion to the Sahara Ditch. The three primary objectives of the model are:

- Determination of the storable flows in the Middle Fork after accounting for senior irrigation water rights, while at the same time, determining the demand for storage for the Sahara Ditch rights.

- Operation of the Middle Fork Reservoir under three storage accounts (1940, 1970, and 1984) and assuming various other projects are constructed to develop remaining Yellowstone River Compact supplies.

- Determination of streamflows downstream from the Middle Fork Project, depletions caused by the Project, and the streamflows in the Powder River at Sussex and at Moorhead, Montana.

A series of simulation studies were undertaken to prepare storage-yield curves which define yields that can be obtained from reservoirs that operate under a wide range of conditions.
Results of Level II Simulation

The Middle Fork Project is envisioned to develop about 25,000 acre-feet of firm supply for municipal and industrial use and an irrigation supply which can be met, without shortages, 8 years out of 10.

Chart 1 of Figure 2 presents the storage-yield curves for storage reservoirs which would include, besides the active content, a minimum pool of 4,000 acre-feet to provide for sediment deposition and proper submergence of the intake structure. Table 1 and the upper graph on Chart 1 show that, with no minimum releases for instream flow maintenance, the firm yield of the reservoir varies with active reservoir size up to 34,400 acre-feet. Above this capacity, the firm yield of the reservoir is limited to that which can be derived from inflows during the low-water years. Non-firm supply is the water supply provided to supplement the Sahara Ditch irrigation water rights at least 80% of the time. Increasing the reservoir size does not substantially increase the non-firm supply; however, it does reduce the number of years in which irrigation supply shortages occur.

Table 1

<table>
<thead>
<tr>
<th>Storage (ac-ft)</th>
<th>Industrial Yield (ac-ft)</th>
<th>Irrigation Yield (ac-ft)</th>
<th>Total Yield (ac-ft)</th>
<th>Years With Irrigation Shortages (ac-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,500</td>
<td>10,000</td>
<td>-</td>
<td>10,000</td>
<td>-</td>
</tr>
<tr>
<td>34,400</td>
<td>27,600</td>
<td>4,400</td>
<td>32,000</td>
<td>9 of 40</td>
</tr>
<tr>
<td>41,100</td>
<td>27,600</td>
<td>4,800</td>
<td>32,400</td>
<td>5 of 40</td>
</tr>
<tr>
<td>47,700</td>
<td>27,600</td>
<td>5,100</td>
<td>32,700</td>
<td>4 of 40</td>
</tr>
</tbody>
</table>

The lower graph, shown on Chart 1 of Figure 2, indicates a significantly lower yield for the project if the 1940 and 1970 permits are not used, and a new 1984 priority storage permit is obtained instead. The reason for the reduction in reservoir yield is that there are 21 storage projects with outstanding permits (or application for permits) totaling 1,476,000 acre-feet that would be ahead of the Middle Fork project for developing Wyoming's allocation of the Powder River under the Yellowstone River Compact.
Table 2 and Chart 2 of Figure 2 present the storage-yield data for operations of the Middle Fork Powder River Reservoir that would include a 20% minimum pool and releases for instream flow maintenance. The Wyoming Game and Fish Department prefers a minimum flow criteria of releasing from a dam an amount equal to 33% of the average daily flow at the dam site or the inflow, whichever is less, with releases from the dam to the stream for other purposes counting against the minimum flow requirement. For the Middle Fork site, 33% of the average daily flow is equal to 25 cfs. During the irrigation season, senior water rights require the release of more than 25 cfs from the reservoir; so, normally, specific releases to meet instream flow needs are required only in the non-irrigation season. The Middle Fork flows exceeded 25 cfs during the entire 40-year study period during the non-irrigation season. If instream flows of 25 cfs are provided, however, the maximum firm supply is reduced to about 12,700 acre-feet per year. If the minimum flow is 5 cfs (the flow level studied by the PRRC), then 25,000 acre-feet per year industrial supply can be provided along with the irrigation supply for the Sahara Ditch.

Table 2

STORAGE-YIELD RELATIONSHIPS

(20% Minimum Pool and Minimum Release for Instream Flow Maintenance)

<table>
<thead>
<tr>
<th>Active Storage (ac-ft)</th>
<th>Industrial Yield (ac-ft)</th>
<th>Irrigation Yield (ac-ft)</th>
<th>Total Yield (ac-ft)</th>
<th>Years With Irrigation Shortages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimum Release = 25 cfs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25,000</td>
<td>6,000</td>
<td>-</td>
<td>6,000</td>
<td>-</td>
</tr>
<tr>
<td>41,100</td>
<td>12,700</td>
<td>4,000</td>
<td>16,700</td>
<td>9 of 40</td>
</tr>
<tr>
<td>47,700</td>
<td>12,600</td>
<td>4,600</td>
<td>17,200</td>
<td>8 of 40</td>
</tr>
<tr>
<td>60,000</td>
<td>12,300</td>
<td>4,800</td>
<td>17,100</td>
<td>7 of 40</td>
</tr>
<tr>
<td><strong>Minimum Release = 5 cfs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25,000</td>
<td>18,500</td>
<td>-</td>
<td>18,500</td>
<td>-</td>
</tr>
<tr>
<td>41,100</td>
<td>24,800</td>
<td>4,300</td>
<td>29,100</td>
<td>9 of 40</td>
</tr>
<tr>
<td>47,700</td>
<td>24,700</td>
<td>4,700</td>
<td>29,400</td>
<td>7 of 40</td>
</tr>
<tr>
<td>60,000</td>
<td>24,400</td>
<td>4,900</td>
<td>29,300</td>
<td>4 of 40</td>
</tr>
</tbody>
</table>

The objective of the simulated reservoir operation is to maximize the firm yield (without infringement upon the minimum
pool) and then to supply non-firm irrigation water with the goal being to provide the full supply 80% of the time. Under this guideline and with no instream flow provision, the 1940 water right capacity (41,100 acre-feet) could develop a firm supply for industrial water and provide water for irrigation. Increasing reservoir size primarily would reduce the shortages to the Sahara Ditch and the number of years in which shortages occurred. The analysis also showed that increasing the irrigated acreage could increase reservoir yield during high flow years, but that the irrigation supply would not be met 80% of the time. In summary, it was found that increasing reservoir size above an active capacity of 40,000 acre-feet to irrigate additional lands only results in an extremely non-firm irrigation supply situation.

Based on existing cropping patterns, the demands for irrigation water are about 3.8 acre-feet per acre. As shown in Table 3, the 5,100 acres of land currently irrigated from the Sahara Ditch receive an average supply of 2.7 acre-feet per acre and shortages occur nearly every year. With the Project, an average supply of 3.7 acre-feet per acre could be provided for the 5,100 acres and shortages would occur only 1 year in 10. If the irrigated area is expanded to 6,020 acres, average supply rates per acre would be reduced and shortages would be more frequent as shown in Table 3. However, a full supply of 3.8 acre-feet per acre could be provided to 6,020 acres in 31 out of 40 years, nearly 80 percent of the time.

Table 3

<table>
<thead>
<tr>
<th>Condition</th>
<th>Area</th>
<th>Average</th>
<th>Average</th>
<th>Years With</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Irrigated</td>
<td>Supply</td>
<td>Shortage</td>
<td>Irrigation</td>
</tr>
<tr>
<td></td>
<td>(acres)</td>
<td>(ac-ft/acre)</td>
<td>(ac-ft/acre)</td>
<td>Shortages</td>
</tr>
<tr>
<td>Current</td>
<td>5,100</td>
<td>2.7</td>
<td>1.1</td>
<td>39 of 40</td>
</tr>
<tr>
<td></td>
<td>6,020</td>
<td>2.6</td>
<td>1.2</td>
<td>39 of 40</td>
</tr>
<tr>
<td>With Project</td>
<td>5,100</td>
<td>3.7</td>
<td>0.1</td>
<td>1 of 10</td>
</tr>
<tr>
<td></td>
<td>6,020</td>
<td>3.5</td>
<td>0.3</td>
<td>9 of 40</td>
</tr>
</tbody>
</table>

Note: Required full supply is 3.8 acre-feet per acre per year.

Figure 3 shows the average yield to the 6,020 acres of direct flow water rights, the average storage water supply to
the Sahara water rights, and the average remaining shortage if the project is designed to provide a firm water supply 80% of the time to the Sahara Ditch.

Yield Reliability

Statistical studies were carried out to evaluate the reliability of the yield estimates prepared using the Level II Operations Model. These studies confirmed that yield estimates based on the 40-year historic (and estimated) flow record are very reliable. Based on thirty 40-year streamflow records generated by stochastic procedures, it was found that the yield estimate from the historical sequence has a 98.4 exceedance probability, the highest probability of exceedance of all flow sequences.

Impacts on Water Quality

The effect of the Project on total dissolved solids (TDS) in the Powder River near the Wyoming-Montana border (at Moorhead, Montana) was determined using a computer simulation model. Present TDS conditions in the Powder River were estimated for the 40-year period of streamflow using a harmonic, multi-variable regression technique applied to published TDS data. Average annual TDS concentrations at Moorhead were estimated to be 1,013 mg/l under present conditions.

As summarized in Table 4, the simulation analysis showed that average annual flow-weighted TDS at Moorhead under with-project conditions are expected to increase by about 25 to 32 mg/l on an average annual basis. On the average, TDS in June are expected to be reduced by 4 to 15 mg/l; and in July, TDS are expected to be reduced by 48 to 91 mg/l. Overall, the changes are not anticipated to be significant considering the historical quality of Powder River water at Moorhead, Montana.
Table 4

CHANGE IN TDS CONCENTRATION OF POWDER RIVER WATER AT MOORHEAD, MONTANA

(Based on Simulation Modeling)

<table>
<thead>
<tr>
<th>Month</th>
<th>TDS Concentration in mg/l Without Project</th>
<th>With Project</th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1540</td>
<td>1855</td>
<td>1602</td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>1500</td>
<td>1664</td>
<td>1542</td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>1231</td>
<td>1275</td>
<td>1248</td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>1127</td>
<td>1252</td>
<td>1226</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>818</td>
<td>920</td>
<td>924</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>678</td>
<td>663</td>
<td>674</td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>1015</td>
<td>924</td>
<td>967</td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>1311</td>
<td>1080</td>
<td>1121</td>
<td></td>
</tr>
<tr>
<td>September</td>
<td>1233</td>
<td>1060</td>
<td>1127</td>
<td></td>
</tr>
<tr>
<td>October</td>
<td>1379</td>
<td>1610</td>
<td>1452</td>
<td></td>
</tr>
<tr>
<td>November</td>
<td>1422</td>
<td>1652</td>
<td>1489</td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>1461</td>
<td>1741</td>
<td>1524</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>1013</td>
<td>1045</td>
<td>1038</td>
<td></td>
</tr>
</tbody>
</table>

Case 1 - No minimum release, total storage = 45,100 acre-feet, active storage = 41,100 acre-feet.

Case 2 - 25 cfs minimum release, total storage = 59,600 acre-feet, active storage = 47,700 acre-feet (reservoir has 20% minimum pool).

Review and Evaluation of the Middle Fork Project

A review and analysis of the Middle Fork Project was undertaken to develop a cost vs. storage curve and perform the evaluations needed to assist the WWDC in deciding whether to obtain the rights and interests from the current sponsors (PRRC) and implement this Project. These aspects are addressed as follows:

- Review of Existing Studies and Designs
- Evaluation of Existing Studies and Designs
- Description of Proposed Middle Fork Project
- Cost vs. Storage Volume Curve
- Unit Cost of Water and Range of Reservoir Sizes
Review of Existing Studies and Designs

The most recent studies and designs for the Middle Fork Project were performed during the period between 1969 and 1975. These studies included geotechnical investigations, planning studies, mapping, and preliminary design. By 1975, no definite project arrangement had been established, nor has one been established in the ensuing years between 1975 and 1984.

The general status of each of the project features and the flood studies at the beginning of the Level II evaluations was as follows:

- **Dam Embankment** - a preliminary layout was presented in the 1970 feasibility report. That dam section is shown on Figure 4.

- **Principal Spillway** - preliminary design studies were performed between 1973-1975. Estimates of costs were developed from these studies and used in the optimization of the emergency spillway.

- **Emergency Spillway** - preliminary design studies were performed in 1975 and used to estimate costs for optimizing the spillway width. It is surmised that design of these features at the selected size would have been carried out had the studies not been halted.

- **Low-level Outlet Works** - Designs suitable for contract document preparation were completed by 1975.

- **Flood Studies** - The spillway design flood has been the subject of at least six studies by four consultants and the Bureau of Reclamation between 1965 and 1975. There is a wide variation among the estimates both in peak flow and flood volume.

Evaluation of Existing Studies and Design

The evaluation consisted of an analysis of the flood and sediment studies, the embankment section, the spillway arrangement, the outlet works, and reservoir area-capacity vs. elevation. In general, the dam site, orientation of the dam axis, and the general project layout concept, with some exceptions, were found to be acceptable.

**Probable Maximum Flood.** From 1965 to 1975, six estimates of the Probable Maximum Flood (PMF) for the Middle Fork site
have been prepared. The resultant peaks and volumes are listed below:

<table>
<thead>
<tr>
<th>Source (date)</th>
<th>Peak Flow (cfs)</th>
<th>Period (days)</th>
<th>Volume (ac-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USBBR (1965)</td>
<td>118,400</td>
<td>5</td>
<td>207,900</td>
</tr>
<tr>
<td>Banner (1970)</td>
<td>110,000</td>
<td>3</td>
<td>172,000</td>
</tr>
<tr>
<td>Fisk (1973)</td>
<td>118,000</td>
<td>5</td>
<td>200,000</td>
</tr>
<tr>
<td>ECI (1974)</td>
<td>156,600</td>
<td>4.5</td>
<td>205,900</td>
</tr>
<tr>
<td>Banner (1974), Revised</td>
<td>119,400</td>
<td>3</td>
<td>172,000</td>
</tr>
<tr>
<td>EECO (1975)</td>
<td>135,000</td>
<td>5</td>
<td>302,200</td>
</tr>
</tbody>
</table>

Several of these estimates were prepared using the USBR's publication "Design of Small Dams". The remainder were developed from site specific studies of Probable Maximum Precipitation (PMP) which included transposing a June 1964 storm originally located in Montana. Since these estimates were prepared, new estimates of Probable Maximum Precipitation (PMP) have become available. The National Weather Service, Corps of Engineers, and the USBR have jointly prepared a publication (HMR-55, March 1984) which indicates a greater PMP for the Middle Fork area than given in prior publications and reports. A comparison of several PMP estimates is provided below:

<table>
<thead>
<tr>
<th>Basis</th>
<th>Depth (inches)</th>
<th>Duration (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design of Small Dams</td>
<td>16.85</td>
<td>48</td>
</tr>
<tr>
<td>Montana Storm</td>
<td>17.0</td>
<td>36</td>
</tr>
<tr>
<td>HMR-55</td>
<td>22.5</td>
<td>48</td>
</tr>
</tbody>
</table>

Based on a review of the descriptions of the PMF studies, it was concluded that the IECO PMF inflow should be used for this evaluation phase. A new PMF study, based on HMR-55, will be undertaken during later studies.

**Flood Frequency.** Flood peak and flood volume frequency analyses were undertaken and they incorporate two additional years of available data (1969 and 1970) not available when prior studies were completed. Log Pearson Type III flood frequency analyses were performed on the 1949-1970 annual peak discharges, peak 3-day volumes, and peak 7-day volumes. (The gaging station
was discontinued in 1970). The peak discharges and volumes are as follows:

<table>
<thead>
<tr>
<th>Return Period (years)</th>
<th>Peak Discharge (cfs)</th>
<th>3-day Flood Volume (ac-ft)</th>
<th>7-day Flood Volume (ac-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1,390</td>
<td>5,000</td>
<td>10,000</td>
</tr>
<tr>
<td>10</td>
<td>1,810</td>
<td>6,300</td>
<td>13,100</td>
</tr>
<tr>
<td>25</td>
<td>2,410</td>
<td>8,300</td>
<td>17,700</td>
</tr>
<tr>
<td>50</td>
<td>2,910</td>
<td>9,800</td>
<td>21,500</td>
</tr>
<tr>
<td>100</td>
<td>3,450</td>
<td>11,400</td>
<td>25,600</td>
</tr>
</tbody>
</table>

Reservoir Sedimentation. An estimate of deposition of sediment in the reservoir was made using an annual flow-duration curve based on daily flow data and a sediment rating curve. The sediment rating curve was developed for this evaluation using data collected during 1950 through 1953 and 1966 through 1968. Results are tabulated below:

<table>
<thead>
<tr>
<th>Deposition in Reservoir (ac-ft)</th>
<th>After 50 years</th>
<th>After 100 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation of Deposition at the Dam (ft)</td>
<td>4906.4</td>
<td>4937.0</td>
</tr>
</tbody>
</table>

Embankment Section. The layout of the embankment section apparently has not changed since first conceived in 1970. As part of the evaluation, a new dam section (Figure 4) was developed which is considered to be better adapted to the conditions at the site.

Spillway Arrangement. The spillway arrangement proposed in 1975 consisted of a principal gated chute spillway and an emergency spillway. The emergency spillway was sized to pass the PMF with the principal spillway operating and the outlet works not operating.

As a result of the current evaluations, it is proposed to use the low-level outlet conduits to pass up to the 100-year flood event with minimal surcharge storage and the emergency spillway to pass the PMF with the outlet works not operating.

This proposal is based on three concepts: a) the gated chute (principal) spillway is an expensive structure, b) the erosion occurring during operation of the emergency spillway chute is not expected to be significant nor is it expected to endanger the embankment, and c) the emergency spillway will be used very infrequently. The resulting arrangement, therefore, will provide a safe but less expensive project. Optimization of
the dam/spillway arrangement will be accomplished during later studies.

**Outlet Works.** A cut-and-cover type outlet/diversion conduit was selected as the most cost-effective for the outlet/diversion works during the 1975 studies. The primary factor in this selection over a tunnel arrangement was that the rock is subject to swelling when wet and very costly tunnel supports would be needed.

The cut-and-cover-type outlet works, as proposed in the earlier studies, is accepted as the most appropriate plan. The outlet conduit also is accepted as the best means to provide diversion during construction. However, the outlet works, as conceived in 1975, comprises a single outlet conduit and only releases flows into the downstream channel. Consequently, a revised outlet works is proposed that (a) incorporates features to convey water to a M&I pipeline and (b) improves water supply reliability.

The proposed low-level outlet works are planned to serve several purposes:

- Diversion during construction.
- Passage of the more-frequent floods, thereby requiring less frequent use of the spillway.
- Release of water to downstream users (primarily agricultural).
- Release of water to meet minimum instream flow requirements (if any).
- Release of water to meet senior water rights or Yellowstone River Compact requirements.
- Emergency evacuation of the reservoir (if required by the State Engineer).
- Release of water to a pipeline for conveyance to municipal/industrial users.

**Reservoir Area-Capacity vs Elevation.** The most recent area-capacity curve was developed in 1975 from reservoir mapping at a scale of 1:2400 made in 1970-75. To more nearly represent the area-capacity versus elevation relationship over the life of the project (assumed to be 100 years), a modification was made to the existing curve to reflect sediment accumulation over a 50-year period. A curve developed in 1970, the 1975 curve, and
the modified curve are shown on Figure 4. The modified area-capacity curve was used in all reservoir operation studies.

**Description of Proposed Middle Fork Project**

A plan view of the selected project configuration is shown on Figure 5. The principal project features include an embankment dam, low-level outlet works, and a spillway. The proposed Middle Fork Project is described below under six headings:

- Dam
- Diversion During Construction
- Low-level Outlet Works
- Spillway
- Relocations
- Land Acquisition

**Dam**

**Embankment Section.** A zoned embankment section has been selected for the site. This section, shown on Figure 4, is consistent with the foundation conditions and available construction materials. The zoning configuration was selected based on the known properties of the materials available from required excavation and a consideration of cost and ease of construction. The dam section developed in 1970 also is shown on Figure 4 for comparison.

The dam section currently proposed will have a central impervious core extending to rock with a rockfill shell on the upstream side and a random fill shell on the downstream side. The upstream and downstream shells generally will be founded on overburden deposits. The upstream slope will be 2.5H:1V and the downstream slope will be 2H:1V. Transition, drain, and filter zones will be provided as shown on Figure 4.

**Construction Materials for the Dam.** There are sufficient clay materials for core material in the indentified borrow areas and in the emergency spillway excavation area. Selective excavation and water sprinkling to increase the moisture content to near optimum probably will be necessary during construction of the core.

The filter and drain materials will be processed from the terrace materials in the borrow areas and the emergency spillway excavation. The oversize cobbles and boulders and excavated
siltstone, clay shale, and sandstone will be used in the pervious rockfill zone of the upstream shell. Semi-pervious silty and clayey sands or sandy clays will be used in the transition zone of the upstream shell. All the other excavated materials will be used in the random zone in the downstream shell.

**Foundation Treatment.** The dam site will be stripped of topsoil, soft clay and silt, and any other unsuitable materials. A core trench will be excavated through the alluvium in the valley and the terrace gravel on the right abutment to rock. Thin overburden on the left abutment will be stripped to bedrock. A single line grout curtain will be provided.

**Diversion During Construction**

The river flows will be diverted through the low-level outlet works during project construction. An upstream cofferdam, about 30 feet high, will be incorporated into the embankment dam, as shown on Figure 4. A 10-foot high downstream cofferdam also will be provided. The outlet works and cofferdams will be capable of diverting the 25-year flood during construction.

**Low-Level Outlet Works**

The low-level outlets will be a cut-and-cover type founded on rock in the right abutments as shown on Figure 5. The low-level outlet works will be sized to pass the diversion flood (25-year) while requiring a 30-foot high cofferdam.

Additionally, the low-level outlet works will be capable of passing the 100-year flood, with a reservoir surcharge of less than one foot over the normal maximum reservoir level. The flood-passing capability of the low-level outlet works probably will preclude the need for the principal spillway proposed in the 1970 Feasibility Report.

The low-level outlet works will include five main features: a horizontal-axis reinforced concrete intake structure; two 400-foot long, 6-foot by 9-foot upstream concrete conduits; a gate shaft with control gates; two 400-foot long, 6-foot by 9-foot downstream concrete conduits; and an energy dissipation structure. Each conduit will be capable of discharging the maximum downstream release requirements under minimum pool conditions. Therefore, water demands can be met if one conduit is closed for maintenance.

In addition, a pipeline for the conveyance of the municipal and industrial supply will extend downstream, adjacent to the downstream concrete outlet conduits, the pipeline will begin at the gate chamber and will be capable of being supplied from
either outlet conduit thereby providing a high degree of reliability. Conveyance of water from this point to either Gillette or the North Platte River is described later in this summary.

**Spillway**

The spillway will be located on the right abutment as shown on Figure 5. The spillway will be an excavated channel and will not be gated.

The spillway is sized to pass the PMF adopted for this evaluation (peak flow = 135,000 cfs).

A large portion of the rock and overburden material excavated from the spillway will be used in constructing the dam.

At this time, it is anticipated that only a portion of the spillway will need to be lined. The side slopes will be lined with a gabion blanket. The upper reaches of the bottom of the spillway chute channel will be unlined. Some erosion of the rock surfaces due to intermittent flowing water in the spillway should be expected. The erosion, however, is not expected to be significant.

**Relocations**

Facilities in the reservoir area that will require relocation include:

- County Road (Barnum Road)
- 14.4-kV Transmission Line (Sheridan-Johnson REA)
- Telephone Cable (Mountain Bell)

About 4.3 miles of county road will be relocated and 1.4 miles of unimproved road will be upgraded. Approximately 4.5 miles of telephone cable and one mile of 14.4-kV REA transmission line will need to be relocated because of the Project.

**Land Acquisition**

Land acquisition maps and property descriptions were prepared as part of the prior studies. This information and the reservoir area vs. elevation curve were used to estimate land requirements for the alternative reservoir storage volumes considered.
Cost vs. Storage Volume Curve

A curve relating project cost to reservoir storage volume was developed for the Middle Fork Project based on estimates for three levels of development.

Water supply studies indicated an average annual firm industrial water supply of 27,600 acre-feet would be attained with an active storage of 34,400 acre-feet. Also by providing more active storage (6,000 to 25,000 acre-feet) an additional 4,000 to 5,000 acre-feet of irrigation water supply could be attained.

To prepare the cost vs. storage volume curve, three representative levels of development were considered as shown in Table 5. These three levels of development are considered to be representative of development potential at the site, considering the possible ranges of active and inactive storages.

Flood routing studies were performed to establish the spillway widths for each of the layout studies and/or the maximum reservoir elevations shown in Table 5. For Case A, the spillway width was set at the same width (500 feet) as the 1975 studies. For Case B, the width was set to maintain the maximum water surface elevation (El. 5030 feet) planned in the earlier studies. This elevation corresponds to the present land acquisition boundary. For Case C, the widest practical spillway was used to limit the height of dam.

Construction cost estimates at the 1984 price level were prepared from construction quantity estimates derived from preliminary project feature layouts. Cost estimates were based on unit prices derived using the contractor's cost method. Appropriate allowances for contingencies and for engineering and owner's overhead were included in the estimates. Construction costs were converted to total costs by adding an allowance for price escalation of 5% per year and interest during construction computed with an interest rate of 8 percent.

The construction cost and total cost vs. total storage curves are presented on Figure 5 and cost estimates for the three development levels are given in Table 5.
## Table 5

**PERTINENT DATA FOR THREE DEVELOPMENT LEVELS**

<table>
<thead>
<tr>
<th>Case</th>
<th>Storage Volume</th>
<th>Normal Pool</th>
<th>Maximum Pool</th>
<th>Dam Crest</th>
<th>1984 Construction Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active (ac-ft)</td>
<td>Total (ac-ft)</td>
<td>Elev. (feet)</td>
<td>Elev. 3/4</td>
<td>Elev. (feet)</td>
<td>($) million</td>
</tr>
<tr>
<td>A</td>
<td>30,000</td>
<td>34,000 1/</td>
<td>5003</td>
<td>5023</td>
<td>5028</td>
<td>32.8</td>
</tr>
<tr>
<td>B</td>
<td>41,100</td>
<td>45,100 1/</td>
<td>5013</td>
<td>5030</td>
<td>5035</td>
<td>33.3</td>
</tr>
<tr>
<td>C</td>
<td>47,700</td>
<td>59,600 2/</td>
<td>5025</td>
<td>5040</td>
<td>5045</td>
<td>34.0</td>
</tr>
</tbody>
</table>

1/ Active storage plus 4,000 acre-feet for sediment and intake submergence below El. 4952.

2/ Active storage plus 11,900 acre-feet below El. 4973 (20% minimum pool).

3/ Occurs during passage of PMF.

4/ Includes direct construction costs, contingency (20%), engineering and administration (15%), at 1984 price level.

5/ Includes escalation at 5% per year and interest during construction at 8% per year.

**Unit Costs of Water and Range of Reservoir Sizes**

Total costs were converted to equivalent annual costs based on interest rates of 4 and 8 percent and a 50-year economic evaluation period; an allowance of $100,000 per year for O&M was added. Annual costs were converted to unit costs of water yield...
($ per acre-foot) based on the storage-yield and storage-cost curves. The estimated unit costs of yield are as follows:

<table>
<thead>
<tr>
<th>Case</th>
<th>$i = 4%</th>
<th>$i = 8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>64</td>
<td>110</td>
</tr>
<tr>
<td>With Minimum Pool</td>
<td>68</td>
<td>117</td>
</tr>
<tr>
<td>With Minimum Pool and 5 cfs Minimum Flow</td>
<td>75</td>
<td>128</td>
</tr>
<tr>
<td>With Minimum Pool and 25 cfs Minimum Flow</td>
<td>127</td>
<td>219</td>
</tr>
</tbody>
</table>

Results for an interest rate of 8% are given in a series of curves of active storage vs. unit cost of yield, shown on Figure 5.

An inspection of the storage-yield curves (Figure 2) indicates that there is essentially no increase in yield for active storage capacities greater than 47,700 acre-feet, the permitted active storage amount. Therefore, this represents the maximum active storage to be considered. Also, the shapes of the unit cost of yield curves shown on Figure 5 indicate that the optimum range (least cost) of active storages would be between 41,100 (the 1940 permitted storage) and 47,700 acre-feet. Table 6 indicates that including a minimum pool for fisheries equal to 20% of the active storage does not significantly increase the project cost for the range of active storages considered.

The potential fish and wildlife benefits and potential recreation benefits associated with a 20% minimum pool may justify the relatively small expenditures for the additional storage.

For the range of development considered (41,100 to 47,700 acre-feet of active storage), the yields and costs with a fisheries pool provided are shown in Table 7.

Refinement of the optimum reservoir size will be undertaken in later studies.
Table 6
INCREASE IN COST FOR PROVIDING A MINIMUM POOL FOR FISHERIES

<table>
<thead>
<tr>
<th>Condition</th>
<th>Active Storage = 41,100 ac-ft</th>
<th>Active Storage = 47,700 ac-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Storage (ac-ft)</td>
<td>Constructions Cost ($ million)</td>
</tr>
<tr>
<td>Minimum Operating Pool</td>
<td>45,100</td>
<td>33.3</td>
</tr>
<tr>
<td>Minimum Pool for Fisheries (20%)</td>
<td>51,400</td>
<td>33.6</td>
</tr>
<tr>
<td>Increase in Cost</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 7
YIELD AND COSTS FOR RANGE OF RESERVOIR SIZES

<table>
<thead>
<tr>
<th></th>
<th>Active Storage of 41,000 ac-ft (20% Fisheries Pool)</th>
<th>Active Storage of 47,700 ac-ft (20% Fisheries Pool)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial Yield</td>
<td>27,600</td>
<td>27,100</td>
</tr>
<tr>
<td>Irrigation Yield</td>
<td>4,300</td>
<td>4,700</td>
</tr>
<tr>
<td>Total Yield</td>
<td>31,900</td>
<td>31,800</td>
</tr>
</tbody>
</table>

1984 Construction Cost ($10^6) 33.6 33.9

Total Cost Including Escalation and Interest
Annual Cost (i = 4%) ($10^6) 2.17 2.19
Annual Cost (i = 8%) ($10^6) 3.73 3.77

Unit Cost of Yield ($/ac-ft)
i = 4% 68 69
i = 8% 117 119
Ability to Pay for Agricultural Users

A major objective of this Level II study was to determine an equitable price for the sale of agricultural water from the proposed Middle Fork Project. At the present time, potential irrigation water users are 21 landholders who irrigate approximately 5,100 acres of land served by the Sahara Ditch, east of Kaycee. These landholders have water rights for 6,020 acres in the area. Water from the proposed reservoir could be used as supplemental irrigation water on existing (presently irrigated) lands, as well as for bringing some new (presently unirrigated) lands into production.

Some of the landholders lease their acreage and are not actively engaged in farming. The 5,100 acres currently under irrigation are managed by 15 operators who irrigate an average of 340 acres each. To determine an equitable sale price for agricultural water from the proposed reservoir, estimates were made of these operators' ability-to-pay for additional water.

In-depth interviews were held with 13 of the 15 irrigators along the Sahara Ditch. Based upon these interviews, detailed crop budgets were developed reflecting current agricultural practices in the region. Cropping patterns and yields were projected with the availability of supplemental irrigation water through a State-operated storage project. Differences between net farm income with and without the project were used to estimate ability-to-pay. Ability-to-pay estimates were developed for two different scenarios concerning how future irrigation water might be used. These scenarios are described below:

- Scenario 1 - additional irrigation water would be used only on the existing 5,100 acres of irrigated land to supplement current water supplies and no new lands would be brought into production;

- Scenario 2 - additional irrigation water would be used as supplemental water on existing lands, and that approximately 900 acres of new land would be brought into production (total irrigated area of about 6,000 acres).
The results indicate that farmers and ranchers in the region could afford to pay up to about $26 per acre-foot for additional water to provide existing irrigated lands with a full water supply in 9 out of 10 years (Scenario 1). The analysis also indicated that if 900 acres of new land were brought into production, additional water would be available to provide supplemental water for existing land and a full water supply for new lands in 8 out of 10 years (Scenario 2). Under this scenario, farmers and ranchers could afford to pay up to $24 per acre-foot for irrigation water.

The ability-to-pay estimates are lower under Scenario 2 because of the costs for land improvements and irrigation systems that would be required to bring new lands into production. Because much of the newly irrigated acreage could not be served by gravity systems, the installation of pumps and other land improvement costs decreases a typical operator's ability-to-pay for water on a per acre-foot basis.

Conveyance of M & I Water

Two areas of potential use of municipal and industrial (M&I) water have been identified:

- Gillette Coal Fields
- North Platte River

Conveyance facilities from the low-level outlet works of the dam, consisting of pumping plants and pipelines, were planned to carry 25,000 acre-feet/year (continuous delivery of 34.5 cfs) to each of the use areas.

The conveyance length and estimated construction cost are given below:

<table>
<thead>
<tr>
<th>Conveyance</th>
<th>Length (miles)</th>
<th>Construction Cost&lt;sup&gt;a/&lt;/sup&gt; ($ million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>to Gillette</td>
<td>100</td>
<td>107.5</td>
</tr>
<tr>
<td>to North Platte</td>
<td>72.5</td>
<td>79.2</td>
</tr>
</tbody>
</table>

<sup>a/</sup> Includes contingency and engineering and administration costs and an allowance for right-of-way, at 1984 price level.
Further Study Requirements

The information presented in this report is intended to form the basis for deciding whether to implement the Middle Fork Project as one owned and operated by the State of Wyoming.

However, at this time, there are several outstanding issues that could impact significantly the successful implementation of the Middle Fork Project:

- Inclusion of a Minimum Pool for Fisheries
- Land Ownership
- Project Optimization
- Minimum Flow for Fisheries
- Permitting Requirements

These issues can be addressed over a reasonable period of time prior to making a commitment to Level III studies.
PROPOSED MIDDLE FORK DAM AND RESERVOIR

SCALE: 1"=20 MILES

WYOMING WATER DEVELOPMENT COMMISSION
MIDDLE FORK POWDER RIVER DAM AND RESERVOIR PROJECT
VICINITY MAP
Chart 1 STORAGE-YIELD CURVES FOR ACTIVE CAPACITY, MINIMUM POOL FOR OPERATING CONDITIONS ONLY AND NO MINIMUM DOWNSTREAM FLOW

Chart 2 STORAGE-YIELD CURVES FOR ACTIVE CAPACITY, MINIMUM POOL OF 20% OF TOTAL CAPACITY, AND MINIMUM DOWNSTREAM FLOWS

Legend:
- Synthetic hydrology data
- Historical record

Wyoming Water Development Commission
Middle Fork Powder River Dam and Reservoir Project

Middle Fork Reservoir
Storage-Yield Curves and Yield-Probability Curve

Harza Engineering Company October 1984
NOTES:
2. 1975 Area-Capacity Curves provided by Banner and Associates.
NOTES:
1. Topography taken from 1"=100' scale dam site mapping by J.T. Banner and Associates.
2. Layout shown is for Case B, Dam crest Elevation 5035 feet.
3. Unit costs of yield were computed using an 8% interest rate.