TASK 'A'

LARAMIE RIVER DIVERSION DAM
EVALUATION AND REHABILITATION PLAN
FINAL REPORT
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LARAMIE RIVER DIVERSION DAM
EVALUATION AND REHABILITATION PLAN
FINAL REPORT

Prepared For: Wyoming Water Development Commission
Wheatland Irrigation District

Prepared By: Kennedy Engineering
608 9th Street
Wheatland, WY 82201
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APPENDIX I - INVESTIGATION INTO THE CAUSES OF FISH KILLS IN THE LARAMIE RIVER DOWNSTREAM OF THE WHEATLAND TUNNEL DIVERSION DAM - W.E.S.T.

APPENDIX II - EVALUATION OF DIVERSION DAM, TUNNEL AND TUNNEL HEADGATE WHEATLAND DIVERSION DAM REHABILITATION PROJECT - INBERG-MILLER ENGINEERS

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1.0 PURPOSE:

The purpose of Task A is to identify structural measures or changes in operation that would correct water quality standards violations associated with the operations of the Wheatland Irrigation Districts' Laramie River Diversion into Bluegrass Creek.

The operation of the Wheatland Tunnel Diversion from the Laramie River into Bluegrass Creek has resulted in fish kills in the Laramie River at least twice in the last 10 years. The fish kills occur when diversions from the Laramie River into Bluegrass Creek are stopped at the end of the irrigation season and the tunnel is shut down for the winter. Water and sediment impounded behind the diversion dam is sluiced into the Laramie River resulting in draining of the impoundment and water quality standards violations. The study will investigate structural and management alternatives to prevent these events from occurring in the future.

2.0 PHASE I Subtask 2.

Condition of the Diversion Dam and Tunnel Diversion:

Inberg-Miller Engineers, subconsultants for this task, have performed a Geotechnical and structural investigation and assessment of the tunnel and the diversion dam. Their report is appended hereto as APPENDIX-II.

2.1 Condition of the Tunnel:

The Hydrogeologist, Eric Graney, and Engineer, Steve Moldt, generally found the tunnel to be in good condition. There are a few short stretches where interior erosion from the loss of ceiling rock has resulted in enlarged sections from 12 to 15 feet high other than the enlarged sections originally constructed near the inlet and outlet of the tunnel. The tunnel walls are unlined cut through highly fractured though apparently stable rock and are comparatively rough. No immediate rehabilitation of the tunnel was recommended. However, due to the significant interior erosion evident, especially around water bearing quartz seams, periodic walkthrough inspections of the tunnel were recommended by Inberg-Miller.

2.1a Tunnel Hydraulics: (Existing Conditions)

1. Maximum flow diverted in the past - 550 c.f.s. (normally);
   ± 600 c.f.s. (once)
   Ref.- Manager W.I.D.
2. Wheatland Irr. Dist. has direct flow Water Right - 633 c.f.s.
   Ref.- Manager W.I.D.
EXHIBIT 'A'
LOCATION MAP FOR TASK 'A'
LARAMIE RIVER DIVERSION DAM
EVALUATION AND REHABILITATION PLAN
3. Cross-Section of Tunnel:
   Nominally 8'x8' square with rough rock walls - having approximately 6-8 inch deep roughness.

   There are three or four significant enlarged areas in the tunnel where the X-section approximately doubles in area. Ref.- Inberg-Miller "Evaluation of Diversion Dam, Tunnel and Tunnel Headgate . . . "

4. Slope:
   Varies due to inconsistent slope throughout the 2985 feet length, but averages: 32/2985 = 0.0107
   Ref.- "As Built" Tunnel No. 1 Profile and Plan Circa 1896

To mathematically model the Tunnel would make a good subject for someone’s Ph.D. thesis. From practical experience, we know that at 550 c.f.s. the two headgates are approximately 2/3 open with a head of approximately 16 feet.

Assuming that the headgates in this situation are operating submerged, the head loss across the headgates may be estimated using the suppressed orifice analysis:

\[ A_1 = 5' \times \left(\frac{2}{3}\right)(5') = 16.7 \text{ ft}^2 \]
\[ A_2 = 6' \times \left(\frac{2}{3}\right)(6') = 24.0 \text{ ft}^2 \]
\[ \text{Total Orifice Area} = 40.7 \text{ ft}^2 \]

The two square headgates are set side by side in a vertical plane across the Tunnel entrance. (See Exhibit ‘C’) The flow will contract as it accelerates through the top of the gate openings. The effective suppressed orifice opening may be estimated as: total orifice area:

\[ \text{Effective orifice area} = (0.61)(1+0.15x0.69)(0.7) = 27.4 \text{ ft}^2 \]
\[ V \text{ gate} = \frac{550}{27.4} = 20.1 \text{ f.p.s.} \rightarrow h_L = 6.3 \text{ ft.} \]

The Tunnel entrance is expanded immediately inside the headgates to approximately 12 feet wide by 15 feet high.

The ave. velocity inside the headgates is:
\[ 550 \div (12' \times 10') = 4.6 \text{ f.p.s.} \]

The Tunnel contracts in approximately 100 feet to its nominal dimension of 8’x 8’: \[ V = \frac{550}{(8 \times 8)} = 8.6 \text{ f.p.s.} \]

For each contraction and expansion combination the head loss may be estimated as \[ 1.2 \times (8.6-4.6)^2 \div 64.4 = 0.3 \text{ feet.} \]

Assuming four contraction and expansion combinations through the length of the tunnel yields a head loss of:
\[ H_{L-C&E} = 4 \times 0.3 = 1.2 \text{ feet.} \]
Therefore: working backwards the friction hydraulic slope of The Tunnel (flowing full) is:

\[ S = \frac{(32' + (9.7 - 8)) - 1.2 + 2985}{29} = 0.0109 \]

The hydraulic radius of the tunnel (flowing full) is:

\[ R = \frac{8' \times 8'}{32} = 2.0 \]

\[ R^{2/3} = 2.0^{2/3} = 1.59 \]

Mannings \( N = (1.486)S^{1/2}R^{2/3} + V = 0.03 \)

As a check on the validity of the assumptions made in arriving at a manning's \( N = 0.03 \), what friction head loss computes using Darcy-Weisbach with a roughness value observed in the rock wall of the Tunnel of \( E = 8'' \) inches?

Although the Tunnel is roughly square, the average diameter for the flow is approximately:

\[ \text{Equivalent} = (64 \times 4 + 4) \div 8 = 9.0 \text{ feet} \]

\[ E = 0.67 \text{ feet}; \ E/D = 0.074 \]

From the Moody diagram in completely turbulent flow:

\[ f = 0.085 \]

The length of the Tunnel is 2985 feet = \( L \).

The average velocity at \( Q = 550 \) c.f.s. = 8.6 f.p.s. = \( V \)

Darcy-Weisbach: \( h_f = f \frac{L V^2}{D 2g} = 0.085 \times 2985 \times (8.6)^2 \div 9.0 \div 64.4 \)

\[ h_f = 32.4 \text{ feet} \]

This compares favorably with the 32.5 feet friction head loss estimated above to determine the friction hydraulic slope \( S = 0.0109 \) which was used to determine the average Mannings \( N \) factor for the tunnel of 0.03.

2.1a

Furthermore: at \( Q = 600 \) c.f.s.

\( V_{ave} \) in 8'x8' nominal tunnel section = 9.4 f.p.s.

Assuming tunnel Headgates are wide open:

\[ A_1 = 5 \times 5 = 25 \text{ ft}^2 \]

\[ A_2 = 6 \times 6 = 36 \text{ ft}^2 \]

Effective suppressed Orifice Area =

\[ (0.61)(1+0.15\times0.73)(61) = 41.3 \text{ ft}^2 \]

\[ V_{gates} = 600/41.3 = 14.5 \text{ f.p.s.} \rightarrow h_L = 3.3 \text{ ft.} \]
The friction head loss using Darcy-Weisbach computes as:
\[ h_f = 0.0085 \times 2985 \times (9.4)^2 + 9 + 64.4 = 38.7 \text{ feet.} \]

The contraction/enlargement losses may be estimated as:
\[ (9.4 \div 8.6)^2 \times (0.3)(4) = 1.4 \text{ feet} \]

Therefore: at \( Q = 600 \text{ c.f.s.} \) and with the headgates wide open, the total losses are calculated as: \( 3.3 + 38.7 + 1.4 = 43.4 \text{ feet.} \)

This requires a head at the headgates of 19.4 feet, which relates to a water surface elevation in the diversion pond of: \( 6444 + 19.4 = 6463.4 \).

The Manager of the W.I.D. has indicated that to his recollection, at 600 c.f.s. the two headgates were 90-100\% open and the water surface in the diversion pond was close to the crest of the emergency spillway. This supports the average estimation for the roughness co-efficient to determine the total hydraulic head loss for the tunnel.

2.2 Existing Tunnel Headgates:

Inberg-Miller's report also indicated that the existing tunnel headgate structure "appears to be performing satisfactorily from a stability standpoint". However, if the existing tunnel headgates remain in use, regular inspections of the gate works and connection to the tunnel entrance, and the structural condition of the operating platform are recommended.

2.3 Condition of Diversion Dam:

Inberg-Miller's opinion after inspection of the diversion dam is that the "overall condition of the diversion dam is good". There is some surface deterioration of the concrete spillway and concrete wingwalls, and steel reinforcing bar is exposed. It is recommended that "those areas of surface spalling and especially reinforcing steel exposure should be repaired". These areas should be sandblasted clean of all loose material and rust and repaired with a cement based non-shrink epoxy grout.

2.4 Existing Measuring Devices:

The existing method of measuring the flow diverting through the Bluegrass Tunnel is a flow recording station below the tunnel outlet. This measuring system has numerous problems some of which are summarized below:

(a) The rock lined open channel at the tunnel outlet is rough, steep, irregular in cross-section, and has significant and frequent bottom slope changes and vertical drops.
(b) The attempt to estimate flow by measuring the water level in this turbulent, irregular channel results only in an order-of-magnitude flow measurement requiring good judgement of an experienced operator to even obtain reading estimates within ± 10% accuracy. (Note: The manager of the W.I.D. indicated that the flow measurement was typically no better than ± 50 c.f.s. when correlated with measurements into the W.I.D. canal system downstream.)

(c) Operation of the headgates and measurement-of diverted flow is extremely unwieldy and inefficient. First the headgates are opened, then the operator drives over the top of the mountain approx. 3/4 mile on a jeep trail to get to the flow recording station where he estimates the flow and then drives back to adjust the headgate. We are told that typically this takes three round trips.

(d) Any attempt to still the flow at the tunnel outlet should not create backwater effect in the tunnel which may reduce the hydraulic capacity of the tunnel below the 550 c.f.s. peak flow currently being diverted through the tunnel. Stilling the flow and constructing an accurate measuring device would require considerable rock excavation, stabilization, concrete work and expense. However, being able to accurately measure the flow does not change the inherent problem with operation and measurement as described in paragraph (c) above.

(e) The time lag between the operation of the headgate and the change of flow at the measuring device at the tunnel outlet complicates automatic control of the headgate as an option in the future. This time lag will vary with flowrate and it would be very difficult to dampen oscillations between headgate control and measurement.

(f) Considerable additional expense for extension of power and communication to the measuring site at the tunnel outlet will be required for automatic data acquisition and control of the diversion in the future. Also, security for sensitive equipment at the tunnel outlet is more difficult and adds another location to the capital and operation and maintenance expense.

(g) The Tunnel outlet channel to the Bluegrass Creek is used by Kayakers and for other "wilderness type" recreation activities. From an environmental standpoint disturbance of this area should be kept to a minimum.

It is the recommendation of Kennedy Engineering that the flow measuring station at the tunnel outlet be abandoned. The flow may be much more accurately and conveniently measured at or near the tunnel headgate as show on the conceptual plan for Alternate A.
View Downstream At Tunnel Outlet Past Flow Level Recording Station

View Downstream Past Washed-out 1983 SCS Headgate Structure to Headgates at Tunnel Entrance
The flow in the Laramie River allowed to pass through the diversion dam sluice gate is measured by an 8 foot Parshall Flume installed in the river approximately 1600 feet below the diversion dam. This flume is equipped with a continuous gage level recorder.

The flow out of Wheatland Irrigation District No. 2 Reservoir is accurately measured into the Laramie River approximately 19 river miles upstream from the Tunnel Diversion Dam.

3.0 PHASE I Subtask 3.
Hydrology and Water Quality Studies:

Western EcoSystems Technology, Inc. (WEST, Inc.), subconsultants for this task, have performed water quality studies and an "Investigation Into the Causes of Fish Kills in the Laramie River Downstream of the Wheatland Tunnel Diversion Dam". Their report is appended hereto as APPENDIX I.

3.1 Water Quality & Fish Mortality:

The report by WEST, Inc. authored by fish biologist, Rick Huber, explains that the 1995 irrigation season was not at all "typical" due to the very unusual extended period of precipitation through April, May and June, 1995. In fact the flow in the Laramie River between the W.I.D. Reservoir No. 2 and the Laramie River Diversion Dam was approximately three to six times the "typical" 4 to 10 c.f.s. passing through the dam. The diversion pond at normal operating water level has a capacity of approximately 160 Acre-Feet. The Laramie River below the diversion dam ran in the neighborhood of 25 to 30 c.f.s. during the study period. This results in only 3 days retention time in the pond. As stated in the WEST, Inc. report, the diversion pond in 1995 did not set up a thermocline with any significant low temperature zone at the bottom compared with the temperature in the Laramie River below the dam. No fish kill occurred when the diversion dam sluice gate was opened to pass 50-60 c.f.s. on September 21, 1995.

The WEST, Inc. report concludes that high silt/sediment concentrations during the sudden release of water from the diversion pond after the irrigation season probably does not directly kill fish in the Laramie River. Furthermore, the report indicates that low dissolved oxygen (DO) and/or hydrogen sulfide (H₂S) or other water quality contaminants such as phosphorus and organic carbon do not likely cause the fish kills observed in past years in the Laramie River. The general conclusion of the report is that the observed fish kills are most likely the result of temperature shock. This may be rectified very simply by changing the operating procedure to eliminate the sudden increase in release of water from the diversion pond at the end of the irrigation season.
3.2 Estimate of Sediment in Diversion Pond:

The diversion pond area was surveyed on November 15, 1995, by Kennedy Engineering. On the same date, four test probes were made by Inberg-Miller Engineers to determine the depth of silt/sediment in the diversion pond. Based on this survey, the amount of silt/sediment stored in the diversion pond is estimated at 35,000 c.y. as shown on the map included with the Alternate 'A' - Conceptual Plan in this report. Most of this silt is not flushed out into the Laramie River below the diversion dam at the end of the irrigation season. Silt being flushed out is basically along the thread of the Laramie River through the diversion pond. The volume of this silt load is estimated at 4,000 c.y. which is equivalent to 1900 ppm average silt load for 5 months winter flow at 7 c.f.s. in the Laramie River.

4.0 PHASE I SUBTASK 4. Rehabilitation Plan Alternatives:

On Jan. 25, 1996, the draft rehabilitation plan with alternatives was presented to the Wyoming D.E.Q., W.W.D.C. and Wheatland Irrigation district Board. After this meeting, the W.W.D.C. and the Wheatland Irrigation District opted for alternate 'A' for further study.

The WY.D.E.Q. accepted the recommendations in the WEST report for mitigating the fish kills in the Laramie River below the Diversion Dam.

4.1 Recommended Procedure for Mitigating Fish Kills:

It is important to control the flushing of colder water into the Laramie River. This can quite simply be done by gradually opening the sluice gate in the Laramie River Diversion Dam and slowly draining the water impounded behind the Dam. The sluice gate should be opened to increase the flow by no more than 25% per day, with a maximum increase of 5 c.f.s. per day. In the worst case, during dry years when the 'average' flow is only 4 c.f.s., the following table shows the daily volume of water loss in the Laramie River Diversion Pond:
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The diversion pond has been calculated to hold between 160 to 235 acre-feet. As shown in the table, the Diversion Pond may be drained in 9 to 10 days.

NOTE: A SCADA system which would monitor flow and control the diversion dam sluice gate from the W.I.D. headquarters in Wheatland would greatly simplify this operation.

Exhibit 'B' herein is a copy of a letter dated March 22, 1996, from the Wheatland Irrigation District to John Wagner of the WY. D.E.Q. This letter does not really address a procedure for draining the impounded water behind the diversion dam at the end of the irrigation season. It is our recommendation that the Wheatland Irrigation District adopt the procedure outlined above to mitigate fish kills which occur when the diversion pond is drained at the end of the irrigation season.

This plan is not intended to be the final answer. The water quality and temperature fluctuations should be monitored and the plan for gradually draining the diversion pond adjusted accordingly.

4.2 Alternates for accurate Measurement at Tunnel Outlet:

Upon review and analysis of the existing flow recording station at the Tunnel Outlet as described in Section 2.4 above, it is our recommendation that no money be spent for improvements on the existing flow recorder.
March 22, 1996

Mr. John F. Wagner
Technical Supervisor
Department of Environmental Quality
Water Quality Division
Herschler Building
122 West 25th Street
Cheyenne, WY 82002

Dear Mr. Wagner,

Thank you for attending our most recent Scoping Meeting with Kennedy Engineering. As we discussed at the conclusion of that meeting, it seems the proper operation of the Tunnel Diversion Dam in the future will be for a 5 to 10 c.f.s flow to be maintained through the downstream headgate at times when we shut down the outflow of Reservoir No. 2.

I spoke to Bill Jones, Division No. One Superintendent, of the State Board of Control. He has assured me that he would allow the headgate to be operated in this manner to help alleviate silting problems downstream of the tunnel diversion.

Thank you for your cooperation in this matter. Please feel free to let us know if problems arise that we are not aware of.

Sincerely,

Bart Trautwein,
President
No specific plan and cost estimate was developed for construction of an accurate measuring device to replace the existing flow level recorder. The inaccessibility of the site for heavy construction equipment would require significant work on the jeep trail leading to the site. The stilling area upstream from any measuring device (weir or flume) would require rock excavation. The measuring device would have to be set at an elevation which would not force backwater into the tunnel. All this taken into consideration, it would probably cost between $40,000 to $80,000 to construct an accurate measuring device at the Tunnel Outlet.

The W.I.D. Manager has estimated that in order to adjust the Tunnel Headgates for the desired flow, at least two trips and more often three trips, are required over the mountain to read the flow recorder at the Tunnel Outlet. It is estimated that this consumes approximately 2 hrs. per flow adjustment which averages 4 days per week through 17 weeks of irrigation season. The labor cost provided by the W.I.D. is $14.20 per hour plus Social Security and benefits estimated at 30% results in a total labor cost of: $14.20 x 1.30 = $18.46/hr. Therefore, the yearly labor cost is: 2 x 4 x 17 x $18.46/hr. = $2,510/yr.

For equipment cost: the round trip over the mountain jeep trail is approximately 1½ miles and assuming three round trips at a per mile cost of $0.50/mile results in an equipment cost of: 1½ x 3 x 4 x 27 x $0.50/mi. = $153/yr.

Total estimated Labor & Equipment Cost incurred solely due to the location of the flow measuring device at the Tunnel Outlet on the other side of the mountain from the Tunnel Headgates is: $2,510 + $153 = $2663/irrigation year.

Using an average yearly cost inflation of 3%, in 30 years the total labor and equipment cost adds up to: $2663 x 47.5754 = $126,693.

At an interest of 7.25% for a 30 year loan, a total accumulative payment of $126,693 results in a principal amount on the loan of: $51,115.

The reason for this economic exercise is to demonstrate that the estimated real cost of constructing an accurate measuring device at the tunnel outlet ranges between $90,000 and $130,000. The W.I.D. would still have the same disadvantages and operation costs summarized in 2.4 above.

4.3 Description of Alternate 'A':

Alternate 'A' is divided into basic elements and optional
elements:

The basic portion of alternate 'A' essentially involves the repair of the spalling areas on the concrete portion of the diversion dam and the construction of new headgates with a Parshall flume measuring device attached. This new headgate structure would be constructed in the rock cut channel approximately 100 feet upstream for the tunnel entrance.

The optional elements of Alternate 'A' involve the installation of Supervisory Control and Automatic Data Acquisition (SCADA) to monitor and control the tunnel headgates and the diversion dam sluice gate. This includes:

(a) Remote Terminal Units (RTU’s) to monitor the critical conditions at the tunnel headgates and at the diversion dam sluice gate. At the tunnel headgates these conditions would include the gage reading on the Parshall flume; the open distance on each of the 6 foot square headgates; the water level in the diversion pond; and the water level at the tunnel entrance; and the power, voltage status.

At the diversion dam sluice gate some of the conditions to be monitored include the open distance on the sluice gate; water temperature in the Laramie River below the diversion dam; water level in the diversion pond; water temperature at the diversion pond surface; water temperature at approximately 2/3 of the pond depth; and the power voltage status.

(b) Electric gate operators for the two tunnel headgates and the diversion dam sluice gate

(c) UHF Radio Transceivers from RTU’s to the base station at the W.I.D. Headquarters in Wheatland.

(d) Power supply to run the R.T.U.’s, Electric gate operators and Radio transceivers. There are several options for power supply:

i Extend R.E.A. power from the nearest site 2½ miles away. Estimated cost = $90,000: disadvantage - during bad weather when control and monitoring is most critical is also the highest probability of power failure.

ii Storage batteries with solar panels for recharging. Estimated cost = $20,000 including batteries and solar panels for both locations at the tunnel headgates and the diversion dam sluice gate: disadvantages: operation and maintenance costs
include setup and monitoring of solar panels and batteries each irrigation season and replacement of batteries and solar panels. It is estimated that the maintenance costs for the batteries and solar panels would amount to replacement cost ($2,000) for batteries every 5 years and replacing the solar panels (12,000) every 15 years due to loss by vandalism and hail damage. Within the 30 year life of the loan, the Maintenance costs using an average of 3% per year inflation factor total:

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Solar Panels:

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<tr>
<td>30</td>
<td>12,000 (2.36)</td>
<td>$28,320</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>TOTAL</strong> $46,440</td>
</tr>
</tbody>
</table>

The total estimated maintenance cost through the 30 year loan term is: $66,500.

Storage batteries with small gasoline engine powered generator (5 H.P.) for recharging. Estimated cost = $16,000 including batteries and generators for both locations at the tunnel headgates and the diversion dam sluice gate: disadvantage: operation and maintenance costs include setup and monitoring of batteries and generators each irrigation season and replacement of batteries and repair/replacement of generators. It is estimated that the maintenance costs for the batteries and generators would amount to replacement cost ($2,000) for batteries every 5 years and replacing the generators ($3,000 ea.) every 10 years. Within the 30 year life of the loan, the maintenance costs using an average of 3% per year inflation factor total:
Batteries: Refer to the table in item 4.3(d)ii above:
Total maintenance cost = $20,160

Gasoline Engine Powered Generators:

<table>
<thead>
<tr>
<th>Year</th>
<th>3% Factor</th>
<th>Maintenance Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>6000 (1.30)</td>
<td>$7800</td>
</tr>
<tr>
<td>20</td>
<td>6000 (1.75)</td>
<td>10500</td>
</tr>
<tr>
<td>30</td>
<td>6000 (2.36)</td>
<td>14160</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$32,460</td>
</tr>
</tbody>
</table>

The total estimated maintenance cost through the 30 year loan term is: $52,620

Kennedy Engineering recommends the power supply option described in 4.3(d)iii above using storage batteries with gasoline engine powered generators.

COMPARISONS:

<table>
<thead>
<tr>
<th>Consideration Item</th>
<th>REA Power</th>
<th>Batteries w/Solar Panels</th>
<th>Batteries w/Gas Generators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Cost</td>
<td>$90,000 initial installation</td>
<td>$20,000 - For two installations @ headgates &amp; div. dam</td>
<td>$16,000 - For two installations @ headgates &amp; div. dam</td>
</tr>
<tr>
<td>Maintenance cost - 30 yr.</td>
<td>R.E.A. Maintains</td>
<td>$66,500.00</td>
<td>$52,620.00</td>
</tr>
<tr>
<td>Reliability</td>
<td>Subject to disruption by Storm damage when needed most. Should have back-up batteries also.</td>
<td>Requires a secure enclosures for batteries and electronic controls. Solar panels must be exposed &amp; are susceptible to hail &amp; vandalism damage.</td>
<td>Require a secure enclosures for batteries, electronic controls and generators. Most secure of options</td>
</tr>
</tbody>
</table>

(e) The removal of the reinforced concrete remains of the failed SCS headgate structure is an optional element for Alternate 'A'. The new headgate and parshall flume structure is planned downstream from the remains of the SCS headgate structure a clear distance of approximately 30 feet. It would not be necessary to remove this structure. It may have some potential, albeit questionable, benefit as a trash deflector. Primarily it is a monument to the opportunistic forces of nature revealing what on paper appears to be a comparatively minor design flaw. (i.e. an under-sized air vent set below maximum flood level.)
(f) The removal of silt from the diversion pond is not recommended. The WEST, Inc. water quality report indicates that it is very unlikely that silt causes any fish kills below the diversion dam. Besides the cost of removing the silt, such action may create a greater potential environmental hazard through the process of excavation, trucking and disposal at some remote site. The operation plan in item 4.1 above will also mitigate the short term flushing of higher silt concentrations into the Laramie River at the end of the irrigation season.

(g) the safety cable/float trash deflector is not recommended. The location of the tunnel headgates coupled with the submergence of the gates minimizes the problem of trash interfering with the flow through the gates, over the parshall flume and into the tunnel. The existing headgates do not have a problem with trash interfering in their operation. The chief advantage of the safety cable/float would be as a safety device to keep swimmers and boaters away from the headgates. The diversion pond is not a public facility and is not used for this type of recreation.

Therefore the cost of constructing and maintaining a safety cable/float trash deflector cannot be justified.
PROFILE
PROPOSED NEW HEADGATE AND MARSHALL FLUME
ALTERNATE 'A'

PLAN
PROPOSED NEW HEADGATE AND MARSHALL FLUME
ALTERNATE 'A'

LEGEND
- Normal operating water surface - Elev. 6440, Area = 2.06 Acres
- Areas having negligible silt contributing to Laramie River - Area = 19.8 Acres
- Areas with silt contributing to Laramie River Area = 0.60 Acres, Area = 1.5 Acres
- Margins of Laramie River as surveyed 11/18/95.

RESERVOIR CAPACITY TABLE

<table>
<thead>
<tr>
<th>Contour Level</th>
<th>Area</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>6440</td>
<td>2.06</td>
<td>96</td>
</tr>
<tr>
<td>6450</td>
<td>0.60</td>
<td>30</td>
</tr>
<tr>
<td>6460</td>
<td>0.10</td>
<td>17</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2.86</td>
<td>143</td>
</tr>
</tbody>
</table>

WHEATLAND DIVERSION DAM REHABILITATION PROJECT - LEVEL II
IMPOUNDMENT BEHIND LARAMIE RIVER DIVERSION DAM
AND
CONCEPTUAL PLAN FOR REHABILITATION OF TUNNEL
DIVERSION HEADGATES AND WATER MEASUREMENT

ALTERNATE 'A'.

SCALE
1000' 100 200
### 4.3 Alternate 'A' – Conceptual Plan w/Engineers' Opinion of Probable Cost:

#### Basic Elements of Conceptual Plan:

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Est. Quant.</th>
<th>Unit</th>
<th>Probable Cost Unit Cost</th>
<th>Probable Item Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Clean Blast &amp; Epoxy Patch Spalled Areas on Div. Dam Concrete Emergency Spillway.</td>
<td>500</td>
<td>S.F.</td>
<td>$10.00</td>
<td>$5,000.00</td>
</tr>
<tr>
<td>2.</td>
<td>Construct New Re-inf. Conc. Headwall Across Entrance Channel to Tunnel.</td>
<td>60</td>
<td>c.y.</td>
<td>$550.00</td>
<td>$33,000.00</td>
</tr>
<tr>
<td>3.</td>
<td>Salvage 72&quot;x72&quot; Sluice Gate for Use on New Headwall - Provide new operator comparative w/conversion to power operation.</td>
<td>1</td>
<td>Ea.</td>
<td>$15,000.00</td>
<td>$15,000.00</td>
</tr>
<tr>
<td>4.</td>
<td>Remove 60&quot;x60&quot; Sluice Gate to W.I.D. Maint. Yard.</td>
<td>1</td>
<td>Ea.</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>5.</td>
<td>Install New 72&quot;x72&quot; Sluice Gate on New Headwall.</td>
<td>1</td>
<td>Ea.</td>
<td>$30,000.00</td>
<td>$30,000.00</td>
</tr>
<tr>
<td>6.</td>
<td>Backfill Behind New Headwall under P.F. Structure.</td>
<td>270</td>
<td>c.y.</td>
<td>$10.00</td>
<td>$2,700.00</td>
</tr>
<tr>
<td>6.a</td>
<td>Rock Rip-Rap at flume outlet</td>
<td>25</td>
<td>c.y.</td>
<td>$50.00</td>
<td>$1,250.00</td>
</tr>
<tr>
<td>7.</td>
<td>Construct New 16' Throat P.F. w/Stilling Basin.</td>
<td>50</td>
<td>c.y.</td>
<td>$550.00</td>
<td>$27,500.00</td>
</tr>
</tbody>
</table>

**BASIC ELEMENTS SUBTOTAL** $114,450.00

#### Optional Elements of Conceptual Plan:

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Est. Quant.</th>
<th>Unit</th>
<th>Probable Cost Unit Cost</th>
<th>Probable Item Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.</td>
<td>Extend R.E.A. Power to Tunnel Headgate Site.</td>
<td>2½</td>
<td>miles</td>
<td>NOT RECOMMENDED</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Install Electric Operators on Tunnel Gates.</td>
<td>2</td>
<td>Ea.</td>
<td>$11,000.00</td>
<td>$22,000.00</td>
</tr>
<tr>
<td>10.</td>
<td>Install R.T.U. with Radio Link to W.I.D. Hq. In Wheatland with Automatic Control of Tunnel Div. Gates incl. battery power w/generator; Programming &amp; Training; And Engineering, Documentation &amp; Drawings.</td>
<td>1</td>
<td>L.S.</td>
<td>L.S.</td>
<td>$60,000.00</td>
</tr>
<tr>
<td>11.</td>
<td>Construct Safety Cable/float Trash Deflector.</td>
<td>730</td>
<td>L.F.</td>
<td>NOT RECOMMENDED</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Remove remains of SCS Re-inf. Conc. Headgate Structure.</td>
<td>1</td>
<td>L.S.</td>
<td>L.S.</td>
<td>$5,000.00</td>
</tr>
<tr>
<td></td>
<td>PROBABLE COST CONTINUED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-------------------------</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>Remove Silt from Reservoir.</td>
<td>35,000</td>
<td>c.y.</td>
<td>NOT RECOMMENDED</td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Extend R.E.A. Power to Diversion Dam Headgate.</td>
<td>3/4</td>
<td>mile</td>
<td>NOT RECOMMENDED</td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>Replace Existing Operator with Electric Operator on Diversion Dam Gate.</td>
<td>1</td>
<td>Ea.</td>
<td>$11,000.00</td>
<td>$11,000.00</td>
</tr>
<tr>
<td>16.</td>
<td>Install R.T.U. With Radio Link to W.I.D. Hq. In Wheatland with Automatic Control of Div. Dam Gate incl. battery power w/generator.</td>
<td>1</td>
<td>Ea.</td>
<td>L.S.*</td>
<td>$7,000.00</td>
</tr>
<tr>
<td></td>
<td><strong>OPTIONAL ELEMENTS SUBTOTAL</strong></td>
<td></td>
<td></td>
<td>$105,000.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL ESTIMATED CONSTRUCTION COST - 1996 DOLLARS</strong></td>
<td></td>
<td></td>
<td>$219,450.00</td>
<td></td>
</tr>
</tbody>
</table>
4.4 Description of Alternate 'B':

Alternate 'B' is also divided into basic elements and optional elements:

The basic portion of Alternate 'B' also involves the repair of the spalling areas on the concrete portion of the diversion dam. Alternate 'B' differs from alternate 'A' as described in item 4.3 above as follows:

i The existing tunnel headgates remain in place across the tunnel entrance.

ii The remains of the failed SCS reinforced concrete headgate structure must be removed to make way for the pipe to be used as a measuring device.

iii In lieu of the parshall flume, a straight length of 10 foot diameter pipe is installed in the entrance channel upstream from the tunnel headgates. The velocity of flow may be measured in this 10 foot diameter pipe as a means to measure the flow diverted through the tunnel. This pipe must be long enough to establish a uniform velocity profile in order to more accurately measure the flowrate.

The optional elements of alternate 'B' involve the installation of a "SCADA" system to monitor and control the existing tunnel headgates and the diversion dam sluice gate. The "SCADA" system is identical to the system described in 4.3(a), (b), (c) & (d) above with the only exception being that instead of measuring the gage reading on a Parshall flume, the "RTU" at the tunnel headgates would relay the reading from Ultrasonic Velocity Sensors on the 10 foot diameter pipe.
PROFILE

PROPOSED NEW MEASURING DEVICE

ALTERNATE 'B'
4.4 Alternate 'B' – Conceptual Plan w/Engineers' Opinion of Probable Cost:

**Basic Elements of Conceptual Plan:**

<table>
<thead>
<tr>
<th>No</th>
<th>Item</th>
<th>Est. Quant.</th>
<th>Unit</th>
<th>Probable Cost Unit Cost</th>
<th>Probable Item Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Clean Blast &amp; Epoxy Patch Spalled Areas on Div. Dam Concrete Emergency Spillway.</td>
<td>500</td>
<td>S.F.</td>
<td>$10.00</td>
<td>$5,000.00</td>
</tr>
<tr>
<td>2.</td>
<td>Construct 10 ft. diameter polymer coated 12 ga. C.S.P. pipe in entrance channel to Tunnel headgates</td>
<td>160</td>
<td>L.F.</td>
<td>$220.00</td>
<td>$35,200.00</td>
</tr>
<tr>
<td>3.</td>
<td>Existing Tunnel headgates to remain in place.</td>
<td>1</td>
<td>L.S.</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>4.</td>
<td>Construct un-reinforced concrete cut-off wall around 10 ft. dia. pipe and across entrance channel to Tunnel headgates</td>
<td>75</td>
<td>c.y.</td>
<td>$250.00</td>
<td>$18,750.00</td>
</tr>
<tr>
<td>5.</td>
<td>Earth fill over 10 ft. dia. pipe and around concrete cut-off wall in entrance channel to Tunnel headgates</td>
<td>2500</td>
<td>c.y.</td>
<td>$5.00</td>
<td>$12,500.00</td>
</tr>
<tr>
<td>5.a</td>
<td>Rock rip-rap on faces of fill</td>
<td>250</td>
<td>c.y.</td>
<td>$40.00</td>
<td>$10,000.00</td>
</tr>
<tr>
<td>6.</td>
<td>Install pitot meter to measure flow in 10 ft. dia. pipe</td>
<td>1</td>
<td>L.S.</td>
<td>$10,000.00</td>
<td>$10,000.00</td>
</tr>
<tr>
<td>7.</td>
<td>Remove remains of SCS reinforced concrete headgate structure</td>
<td>1</td>
<td>L.S.</td>
<td>$5,000.00</td>
<td>$5,000.00</td>
</tr>
</tbody>
</table>

**Basic Elements Subtotal** | **$96,450.00**

**Optional Elements of Conceptual Plan:**

<table>
<thead>
<tr>
<th>No</th>
<th>Item</th>
<th>Est. Quant.</th>
<th>Unit</th>
<th>Probable Cost Unit Cost</th>
<th>Probable Item Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.</td>
<td>Extend R.E.A. Power to Tunnel Headgate Site.</td>
<td>2½</td>
<td>miles</td>
<td>NOT RECOMMENDED</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Replace existing operators with electric operators on Tunnel gates</td>
<td>2</td>
<td>Ea.</td>
<td>$15,000.00</td>
<td>$30,000.00</td>
</tr>
<tr>
<td>10.</td>
<td>Install R.T.U. with Radio Link to W.I.D. Hq. In Wheatland with Automatic Control of Tunnel Div. Gates incl. battery power w/generator; Programming &amp; Training, And Engineering, Documentation &amp; Drawings.</td>
<td>1</td>
<td>L.S.</td>
<td>$60,000.00</td>
<td>$60,000.00</td>
</tr>
<tr>
<td>11.</td>
<td>Construct Safety Cable/float Trash Deflector.</td>
<td>730</td>
<td>L.F.</td>
<td>NOT RECOMMENDED</td>
<td></td>
</tr>
</tbody>
</table>
### PROBABLE COST CONTINUED

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Price 1</th>
<th>Price 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Install ultrasonic velocity sensors to measure flow in 10 ft. dia. pipe</td>
<td>1</td>
<td>L.S.</td>
<td>$9,000.00</td>
<td>$9,000.00</td>
</tr>
<tr>
<td>13</td>
<td>Remove Silt from Reservoir.</td>
<td>35,000</td>
<td>c.y.</td>
<td>NOT RECOMMENDED</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Extend R.E.A. Power to Diversion Dam Headgate.</td>
<td>3/4 mile</td>
<td>NOT RECOMMENDED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Replace Existing Operator with Electric Operator on Diversion Dam Gate.</td>
<td>1</td>
<td>Ea.</td>
<td>$11,000.00</td>
<td>$11,000.00</td>
</tr>
<tr>
<td>16</td>
<td>Install R.T.U. With Radio Link to W.I.D. Hq. In Wheatland with Automatic Control of Div. Dam Gate incl. battery power w/generator.</td>
<td>1</td>
<td>Ea.</td>
<td>$7,000.00</td>
<td>$7,000.00</td>
</tr>
</tbody>
</table>

**OPTIONAL ELEMENTS SUBTOTAL** $117,000.00

**TOTAL ESTIMATED CONSTRUCTION COST - 1996 DOLLARS** $213,450.00

### 4.5 Comparison of Alternatives:

<table>
<thead>
<tr>
<th>Consideration Item</th>
<th>Alternate 'A'</th>
<th>Alternate 'B'</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operation</strong></td>
<td>This design is self regulating. With the div. dam sluice gate adjusted, the Tunnel headgates may be left wide open. The crest of the parshall flume will maintain a nearly constant level in the diversion pond. When releases out of Res. No. 2 change, the flow diverted into the Tunnel will automatically adjust accordingly with very minor fluctuation in the div. pond level.</td>
<td>This design requires adjustment of the headgates at the Tunnel entrance in coordination with the adjustment of the div. dam sluice gate in order to balance incoming and outgoing flows in the diversion pond to maintain a constant level in the diversion pond.</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>Minimal maintenance is required. The removal of the existing headgates at the Tunnel entrance will mitigate the erosion of the floor at the Tunnel entrance which is caused by the high velocity of flow under the existing headgates.</td>
<td>The pitot gage or ultrasonic velocity sensors will require maintenance and calibration checks for accuracy. The existing Tunnel headgates appear to be structurally sound, however the erosion of the floor at the Tunnel entrance and the erosion under the foundation for the catwalk access to the headgate operators should be closely monitored.</td>
</tr>
<tr>
<td><strong>Capital Cost</strong></td>
<td>Basis Elements: $114,450 Optional Elements: $105,000 Total: $219,450</td>
<td>Basic Elements: $96,450 Optional Elements: $117,000 Total: $213,450</td>
</tr>
</tbody>
</table>
Mr. Russell Schamel, P.E.
Kennedy Engineering
608 9th St.
Wheatland, Wyoming 82201

Subject: Phase II of the Wheatland Diversion Dam Rehabilitation Project

Dear Russell:

Thank you for your very thorough discussion of the options for rehabilitating the Laramie River Diversion Dam and outlet. I believe your explanation of the Phase I findings to the Wheatland Irrigation District Board greatly aided their understanding of the alternatives. The Phase I report that you prepared for the diversion dam rehabilitation task was adequate. As you know, the information presented in this report must be incorporated into the final report.

The Wheatland Irrigation District board has informed me that their preferred alternative for addressing the deficiencies you noted in the Phase I report, is the basic elements of Alternative A. Please prepare preliminary designs and cost estimates for that alternative.

I will talk to John Wagner about his recommendations/requirements for operation of the diversion dam to prevent fish kills in the future.

Thank you for the work completed by your firm to date. I look forward to the completion of this project. If you have any questions, do not hesitate to call me.

Sincerely,

Mike Carnevale
Project Manager
1.0 PHASE II

Subtask 1. Conceptual Design Preferred Alternate 'A':

The preferred Alternate 'A' Conceptual plan for improvements to the Diversion Dam and the Tunnel Diversion Headgate is graphically shown on the plan sheet herein. The Conceptual Plan is divided into Basic Elements and Optional Elements.

The Basic Elements of the plan assume that manual control of the headgates will continue. These basic elements simply involve some minor maintenance on the concrete emergency spillway portion of the diversion dam and a Parshall Flume with new Tunnel Diversion headgates to provide convenient and accurate measurement of the flow directed into the Tunnel.

The Optional Elements of the plan involve this construction of Supervisory Control and Automatic Date Acquisition (SCADA) systems for automated control of the Tunnel Diversion headgate and the Laramie River Diversion Dam sluice gate from the W.I.D. Headwaters in Wheatland, Wyoming. In the following table the item numbers and descriptions correlate with the numbers on the Conceptual Plan sheet attached.

1.1 Hydraulic Design for Parshall Flume:

The throat of the 16 foot parshall flume should be set to attain the maximum diversion of flow through the tunnel without flowing over the crest of the emergency dam spillway.

Elev. Crest of spillway = 6463.6
Max. Design Elev. in diversion dam pool = 6462.6

Tunnel Diversion headgates consist of 2 each - 6'x6' square sluice gates:

These gates will perform like suppressed orifices. With both gates wide open and assuming 600 c.f.s. flow, the headloss through the sluice gates may be estimated as:

\[ H = \frac{(600+(0.61)(1+0.15\times0.5)+72)}{72} = 2.51 \text{ feet} \]

For the 16 foot parshall flume, the required velocity head is:

\[ h_v = \frac{(600+3.93+20.22)^2}{72} = 0.89 \text{ feet} \]

The crest elevation for the flow of the 16 foot throat parshall flume is:

\[ 6462.6 - 2.51 - 0.89 - 3.93 = 6455.27 \]
For free-flow conditions, the tailwater elevation should not exceed 70% of the gage reading. Therefore, the maximum tailwater elevation at $Q = 600$ c.f.s. is:

$$6455.27 + 0.70(3.93) = 6458.02 \text{ feet}$$
PROFILE
PROPOSED NEW HEADGATE AND PARshall FLUME
ALTERNATE 'A'

PLAN
PROPOSED NEW HEADGATE AND PARshall FLUME
ALTERNATE 'A'

STA 14950
X-SECTION OF HEADGATES
ALTERNATE 'A'

LOCATION MAP

RESERVOIR CAPACITY TABLE

<table>
<thead>
<tr>
<th>CONTENT ELEV</th>
<th>AREA ACRE</th>
<th>VOLUME FT.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>6424</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>6400</td>
<td>3</td>
<td>70</td>
</tr>
<tr>
<td>6390</td>
<td>3</td>
<td>74</td>
</tr>
<tr>
<td>6340</td>
<td>0.1</td>
<td>17</td>
</tr>
<tr>
<td>TOTALS</td>
<td></td>
<td>199</td>
</tr>
</tbody>
</table>

LEGEND
- Normal operating water surface - Cont. 6424, Area = 1.22 Acres.
- Areas having negligible water contributing to Laramie River, Area = 0.4 Acres.
- Areas with soils contributing to Laramie River Area = 0.40 Acres.
- Areas with soils contributing to Laramie River Area = 0.35 Acres.
- Margin of Laramie River as surveyed 01/15/93.

WHEATLAND DIVERSION DAM REHABILITATION PROJECT - LEVEL II
IMPOUNDMENT BEHIND LARAMIE RIVER DIVERSION DAM
AND
CONCEPTUAL PLAN FOR REHABILITATION OF TUNNEL
DIVERSION HEADGATES AND WATER MEASUREMENT

ALTERNATE 'A'
PROFILE
PROPOSED NEW HEADGATE AND PARSHALL FLUME
ALTERNATE 'A'
3.0 PHASE II - Subtask 3. Cost Estimates:

Basic Elements of Conceptual Plan:

<table>
<thead>
<tr>
<th>No</th>
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<tr>
<td>1.</td>
<td>Clean Blast &amp; Epoxy Patch Spalled Areas on Div. Dam Concrete Emergency Spillway.</td>
<td>500</td>
<td>S.F.</td>
<td>$10.00</td>
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<td>2.</td>
<td>Construct New Re-inf. Conc. Headwall Across Entrance Channel to Tunnel.</td>
<td>60</td>
<td>c.y.</td>
<td>$550.00</td>
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<td>3.</td>
<td>Salvage 72&quot;x72&quot; Sluice Gate for Use on New Headwall - Provide new operator comparative w/conversion to power operation.</td>
<td>1</td>
<td>Ea.</td>
<td>$15,000.00</td>
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<td>4.*</td>
<td>Remove 60&quot;x60&quot; Sluice Gate to W.I.D. Maint. Yard.</td>
<td>1</td>
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<td>5.</td>
<td>Install New 72&quot;x72&quot; Sluice Gate on New Headwall.</td>
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<td>6.</td>
<td>Backfill Behind New Headwall under F.F. Structure.</td>
<td>270</td>
<td>c.y.</td>
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<td>6.a</td>
<td>Rock Rip-Rap at flume outlet</td>
<td>25</td>
<td>c.y.</td>
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<td>7.</td>
<td>Construct New 16' Throat P.F. w/Stilling Basin.</td>
<td>50</td>
<td>c.y.</td>
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SUBTOTAL $114,450.00

* W.I.D. Forces:

Optional Elements of Conceptual Plan:

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<tr>
<td>8.</td>
<td>Extend R.E.A. Power to Tunnel Headgate Site.</td>
<td>2 1/2</td>
<td>miles</td>
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<td>9.</td>
<td>Install Electric Operators on Tunnel Gates.</td>
<td>2</td>
<td>Ea.</td>
<td>$11,000.00</td>
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<td>10.</td>
<td>Install R.T.U. with Radio Link to W.I.D. Hq. In Wheatland with Automatic Control of Tunnel Div. Gates incl. battery power w/generator; Programming &amp; Training. And Engineering, Documentation &amp; Drawings.</td>
<td>1</td>
<td>L.S.</td>
<td>L.S.</td>
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<td>11.</td>
<td>Construct Safety Cable/float Trash Deflector.</td>
<td>730</td>
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<td>12.</td>
<td>Remove remains of SCS Re-inf. Conc. Headgate Structure.</td>
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<td>13. Remove Silt from Reservoir.</td>
<td>35,000 c.y.</td>
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<td>14. Extend R.E.A. Power to Diversion Dam Headgate.</td>
<td>3/4 mile</td>
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<td>15. Replace Existing Operator with Electric Operator on Diversion Dam Gate.</td>
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<td>16. Install R.T.U. With Radio Link to W.I.D. Hq. In Wheatland with Automatic Control of Div. Dam Gate incl. battery power w/generator.</td>
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<td>ACQUISITION OF ACCESS AND RIGHTS-OF-WAY</td>
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<td>PROJECT COST TOTAL</td>
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<td>* Per Acre per year cost - 30 year loan at 7.25% for 40% of $312,932.38</td>
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<td><strong>$0.19</strong></td>
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* The total assessed acreage in the Wheatland Irrigation District is 54120 acres.
4.0 PHASE II - Subtask 4. Economic Analysis/Ability to Pay

4.1 This project will not increase any acreage under irrigation. The existing crops within the Wheatland Irrigation District generally consist of:

1. Alfalfa/Native Grass Hay
2. Beans (Pinto) (White)
3. Corn
4. Sugar Beets
5. Small Grains
6. Sorghum
7. Irrigated Pasture

4.2 This project will not increase crop yields within the Wheatland Irrigation District due to any predictable increase in water delivery to the fields.

4.3 This project will greatly enhance the measurement accuracy of water being diverted into the tunnel from the Laramie River. The State Board of Control has indicated that accurate measurement of the flow into and out of the Laramie River is important to the State of Wyoming for the water accounting of flows in the North Platte River into Nebraska. The Laramie River is tributary to the North Platte River at old Fort Laramie in Wyoming.

To estimate a monetary benefit for the Wheatland Irrigation District due for this increased accuracy of flow measurement is not feasible. It is uncertain whether accurate measurement would increase or decrease the calculation of losses or gains in the Laramie River between the No. 2 Reservoir and the Diversion Dam. Therefore, accurate measurement may increase or decrease the flow of water diverted into the tunnel.

4.4 The basic elements of this project have a measurable benefit for the Wheatland Irrigation District in operation cost savings. The need to drive back & forth over the mountain to estimate the flow after adjusting the headgate will be eliminated.

From time estimated provided by the W.I.D. manager, eliminating the need to drive over the mountain and back will save approximately 2 hrs. per gate adjustment event on an average of 4 days per week through 17 weeks of irrigation season at a cost of $18.46 per hour (14.20x1.3 for S.S. & Benefits).

Labor Cost Savings per Irr. Season = 2 x 4 x 17 x $18.46 = $2,510/yr.
Vehicle Cost Savings = 1½mi. = 3 x 4 x 17 x $0.50/mi. = $153/yr.
Total Labor & Equipment=$2663/year

NOTE: The labor cost "savings" does not mean that the W.I.D. pays their employee(s) any less money. However, this time can be spent on other work within the district that has been left undone or wanting attention. It may be more appropriate to consider this labor cost "savings" more as a labor trade-off benefit.

Using a modest inflation rate estimate of 3% per year for the 30 year loan term to pay off the capital debt; the total "future savings" in 30 years from the current saving of $2663/yr. operation cost savings is: $126,693

4.5 An intangible but significant benefit from this project is the safety of the headgate operator. The jeep trail over the mountains between the Tunnel headgates and the gaging station at the Tunnel outlet has its obvious hazards.

4.6 The optional elements of this project will have a measurable benefit for the Wheatland Irrigation District in additional operation cost savings. Currently, the manager of the District estimates an average of 4 days per week with a minimum of 4 hours per day through 17 weeks of irrigation season for operation of the Tunnel Diversion headgates. This requires that he drive approximately 33 miles in a 4WD vehicle to the Tunnel Diversion Dam and back. We have already estimated that the basic element part of this project would cut the 4 hours per day by 2 hours per day. It is estimated that the automation of the headgates would eliminate at least 90% of the remainder of the current operation costs:

Labor Cost Savings per Season = 0.90 x 2 x 4 x 17 x $18.46 = $2259/yr.
Vehicle Cost Savings per Season = 0.90 x 33 x 2 x 4 x 17 x 0.26 = $1050/yr.
Total Labor & Equipment = $3309/year

Using the modest inflation rate estimate of 3% per year for the 30 year loan term to pay off the capital debt; the total "future savings" in 30 years from the current saving of the $3309/yr. Operation cost savings is: $157,427

4.7 The intangible benefits of the optional SCADA element of this project are numerous:
   a) Significant enhancement for the personal safety of employees in minimizing required travel during all types of weather and all times of day.
   b) Reports can automatically be produced for any time frame wanted for flow records, etc.
c) The District may be able to divert more of the direct flow right in the Laramie River due to accurate measurements coupled with the capability to respond quickly to changing conditions.

d) The manipulation of the diversion dam headgate to comply with the recommended operation plan for the mitigation of fish kills will be much easier and take a fraction of the time and effort for manual operation.

Conclusion:

Along with significant intangible benefits, there are tangible direct benefits resulting from this project. These direct benefits equate to $284,120 in potential savings during the 30 year loan term.

The total cost of this project including the basic and optional elements is $312,932. Assuming a 60% grant for new construction and a 7.25% loan for 30 years on the remaining 40%; the yearly payment on the loan would be $10,341.73. The total cost to the W.I.D. for the 30 year loan is: $310,251.87.

NOTE that this number compares favorably with the potential savings in operating costs.

The W.I.D. office manager computes the total assessed average under the W.I.D. at 54,120 acres. Therefore the cost to pay off the loan would be $10,341.73/54,120 = $0.19 per acre per year.

This assumes no credit for the potential operation cost savings since this time will probably be spent doing work that needs attention elsewhere for the benefit of the Irrigation District.

The current assessment to farmers within the W.I.D. includes $9.50/acres/year to the W.I.D. Some of the farmers then pay an additional assessment to the individual smaller ditch companies. This assessment generally ranges around $1.00/acre/year and varies from ditch to ditch.

It appears that this project’s potential benefits match the cost if the W.W.D.C. authorizes the 60% grant with a 7.25% loan for 30 years on the remaining 40%. 
5.0 PHASE II - Subtask 5.
Permitting:

5.1 C.O.E. Clean Water Act - Section 404 - Permit Not Required:
Ordinarily, work within the limits of any stream in the United States requires a permit from the Corps of Engineers. This work probably falls under the nationwide irrigation exemption. A description of the project with photos should be sent to:

Mr. Matthew Bildeau  
Corps of Engineers  
Wyoming Regulatory Office  
2232 Dell Range Blvd.  
Suite 210  
Cheyenne, WY 82009  
Ph: (307) 772-2300  
Fax: (307) 772-2920

5.2 Albany County Planning Dept. - No Permit required:
The Albany County Planning Division has indicated that no development permits would be required for this project. They have asked for a complimentary summary of the project so the department is aware of the proposed project.

5.3 FCC Permit for radio transceivers for Optional SCADA System:
Permits will be required for radio frequencies and communications from the FCC for the transceivers to communicate between the RTU's and the base station in the W.I.D. Headquarters in Wheatland, Wyoming.

5.4 Easements for radio repeater antenna sites for Optional SCADA:
A location may not be available on the W.I.D. property for direct UHF signal to the W.I.D. Headquarters in Wheatland. An easement with access may be required for a radio repeater antenna should a location with direct UHF line of site not be available on W.I.D. property.
APPENDIX I

INVESTIGATION INTO THE CAUSES OF FISH KILLS IN THE LARAMIE RIVER DOWNSTREAM OF THE WHEATLAND TUNNEL DIVERSION DAM - W.E.S.T.
INVESTIGATION INTO THE
CAUSES OF FISH KILLS IN THE LARAMIE RIVER
DOWNSTREAM OF THE WHEATLAND TUNNEL DIVERSION DAM

Submitted to:

KENNEDY ENGINEERING
608 9TH STREET SUITE 4
WHEATLAND, WY 82201

Submitted By:

WESTERN ECOSYSTEMS TECHNOLOGY, INC.
2003 CENTRAL AVE.
CHEYENNE, WY 82001
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1.0 INTRODUCTION

1.1 PURPOSE

The Wheatland Irrigation District serves approximately 55,284 acres and 911 water users. Fish kills have occurred in the Laramie River downstream of the Wheatland Tunnel Diversion Dam at least twice in the last ten years. The fish kills occur when diversions from the Laramie River into Bluegrass Creek are stopped at the end of the irrigation season and the tunnel is shut down for the winter. Water and sediment impounded behind the diversion dam is released into the Laramie River resulting in draining of the impoundment.

Western Ecosystems Technology, Inc. (WEST) was retained by Kennedy Engineering to evaluate water quality as a possible factor contributing to fish kills.

The purpose of this study was to determine whether the release of sediment, or poor water quality, or the combination of the two, results in the killing of fish in the Laramie River downstream of the Wheatland Diversion Tunnel Dam. The investigation into the fish kills concentrated on two likely causes:

1) the sudden release of sediment that has become trapped behind the dam; and,

2) the release of colder, oxygen-deficient water into the Laramie River.

To address these two factors WEST measured dissolved oxygen (DO), temperature, and collected water and sediment samples from both the Wheatland Tunnel Diversion Reservoir and the Laramie River.

Suspended solid, particularly inorganic particles can have detrimental effects on aquatic organisms (Cairns, 1967, Lloyd, 1987, Hall, 1984). The mechanical action of such particles can lead to clogging of the gills or the irritation of gill filaments and other membranes. Wallen (1951) determined the direct effects of montmorillonite clay turbidity on 16 species of fish. Behavioral reactions occurred when turbidities exceeded 20,000 mg/liter, but most individuals of all species survived exposure to 100,000 mg/liter of clay turbidity for a week or longer. Appreciable mortality occurred at clay turbidities above 175,000
mg/liter. Also, McLeay et al. (1983) reported the survival of arctic grayling (*Thymallus arcticus*) which were acclimated to warm waters in stream cages and subjected to short term exposures of concentrations up to 250,000 ppm. Lloyd (1987) in an extensive review, quoted a number of unpublished reports that included results as either fatal or lowered survival; most of these included suspended sediment concentrations from 500 to 6,000. Lloyd (1987), Sigler et al. (1984), and Reynolds et al. (1989) reported that direct mortality from suspended sediment usually took 12 to 96 hours depending on the size and species of fish. Turbidities in natural waters seldom exceed 20,000 mg/liter and even "muddy waters" usually have less than 2,000 mg/liter (Irwin, 1945). Even though turbidity caused by suspended soil particles will seldom have direct effects on fish, it may adversely affect fish populations (Buck, 1956; Duchrow and Everhart, 1971). Turbidity restricts light penetration and limits photosynthesis and thus DO. Sedimentation of soil particles may also smother fish eggs and destroy communities of bottom organisms.

The release of colder and/or oxygen deficient water from the bottom of an impoundment can also present a problem to fish. Many standing bodies of water become thermally stratified during the summer months. During this period the water temperature in the lower stratum (hypolimnium) is approximately 4°C, much colder than the water in small rivers such as the Laramie River. Fish cannot tolerate rapid changes in temperature and a rapid increase or decrease of more the 2°C may lead to stress and even mortality (Stickney, 1979).

In thermally stratified lakes, photosynthesis normally maintains a fairly high concentration of dissolved oxygen (DO) in the upper stratum (epilimnion). Concentrations of DO are also high in the hypolimnion at the onset of thermal stratification. However, due to the lack of photosynthesis in deeper, darker waters, DO in this layer declines until the water destratifies. Oxygen levels also decline with time because the decay of aquatic vegetation and other benthic organisms consumes available DO.

1.2 DESCRIPTION OF STUDY AREA

1.2.1 Location of Study Area

The Wheatland Diversion Dam is located approximately 28 miles west-southwest of Wheatland, Wyoming in Albany County. The Wheatland Tunnel Diversion Reservoir is approximately 300 feet wide and 3,000 feet long and holds approximately 150 acre-feet of water. The Laramie River flowing into the Wheatland Tunnel Diversion Reservoir is a slow moving river (appr. 3-5 cfs), 10-15 feet wide and with an average depth of 8-10 feet. The Laramie River downstream of the diversion dam is approximately 6 feet wide and 1.5 to 2 feet deep.
2.0 STUDY METHODS

2.1 Sampling Protocol

Nine sampling stations were established to determine DO and temperature (Figure 1). At each sampling station with a depth greater than three feet samples were collected at the surface, at 3-feet, at 5-feet, and at subsequent 5-foot intervals until the bottom was reached. Once the bottom was reached DO and temperature samples were taken 1-foot above the bottom.

The first sampling station was located approximately 1/4-mile upstream of the diversion tunnel in the center of the river channel. Although station 1 is in the upper reach of the reservoir, it is assumed that the water and sediment at station 1 is characteristic of the water and sediment entering the reservoir from the Laramie River. The average depth of the river during the study at Station 1 was 8 feet.

The second sampling station was established approximately 50 feet downstream from the diversion tunnel. A transect was established with three sampling sites at a distance of 20%, 50%, and 80% of the total distance between the eastern and western shores, respectively. Site 2A was located approximately 50 feet (20%) from the eastern shore. The average depth of the reservoir at Site 2A was 8 feet. Site 2B was located approximately 125 feet (50%) from the eastern shore. The average depth of the reservoir at Site 2B was 13 feet. Site 2C was located approximately 200 feet (80%) from the eastern shore. The average depth of the reservoir at Site 2C was 9 feet.

The third sampling station was established immediately upstream of the dam face in maximum water depth. The same sampling protocol was used at this sampling station as described for Sampling Station 2. Site 3A was located approximately 5 feet (20%) from the eastern shore. The average reservoir depth at Site 3A was 16 feet. Site 3B was located approximately 13 feet (50%) from the eastern shore. The average reservoir depth at Site 3B was 18 feet. Site 3C was located approximately 20 feet (80%) from the eastern shore. The average reservoir depth at Site 3C was 19 feet.

Stations four thru nine were located in the center of the Laramie River downstream of the diversion dam. Station 4 was located at the spillway; station 5 was 100 feet downstream from the spillway; station 6 was 200 feet downstream from the spillway; station 7 was 300 feet downstream from the spillway; station 8 was 400 feet downstream from the spillway; and station 9 was 500 feet downstream from the spillway.
downstream from the spillway. Since the Laramie River downstream from the diversion dam was approximately 6-feet wide and 1.5 to 2 feet deep, only one DO and temperature sample was taken at each station, 1-foot below the surface.

2.2 Diurnal DO/Temperature sampling and the collection of water and sediment samples.

Diurnal DO and temperature data should indicate if there was an increase or decrease in the oxygen level due to normal photosynthetic/respiration processes in both the Wheatland Tunnel Diversion Reservoir and the Laramie River. Diurnal sampling of DO and temperature occurred every four hours for a 24-hour period with YSI Model 57 oxygen meter. Sampling occurred three times; (1) July 20-21 at 1000, 1400, 2200, 0200, 0600, and 1000 (a sample was not taken at 1800 because of severe weather); (2) August 17-18 at 0600, 1000, 1400, 1800, 2200, 0200, and 0600 and; (3) September 20-21 at 1000, 1400, 1800, 2200, 0600, and 1000 (a sample was not taken at 0200 because of weather conditions).

Water and sediment samples were collected at selected stations in conjunction with the diurnal DO samples. Water samples were collected at stations 1, 2B, 3B, 4, 7, and 9, just below the surface. In addition, water samples were collected 12-inches above the bottom of the reservoir at stations 2B and 3B. Water samples were analyzed for the following parameters: acidity, alkalinity, pH, nitrite, ammonia-nitrogen, nitrate nitrogen, nitrite nitrogen, total nitrogen, total phosphorous, total organic carbon, sulfate, carbon dioxide, chloride, hardness, biological oxygen demand (BOD), chemical oxygen demand (COD), sulfide, and conductivity. Water samples were collected using a Wildco Alpha Vertical water bottle. Acidity, alkalinity, nitrite, pH, carbon dioxide, chloride, hardness, and ammonia-nitrogen were analyzed using a HACH test kit Model FF-2. Conductivity, nitrate nitrogen, nitrite nitrogen, total nitrogen, BOD, COD, total phosphorous, sulfate, sulfide, and total organic carbon were analyzed at Inter-Mountain Laboratories, Inc., in accordance with 40 CFR 141, "National Primary Drinking Water Regulations". Water samples were collected on July 20, August 17, and September 20.

Sediment samples were collected at stations 1, 3B, 4, and 9 using a Wildco Ponar deep lake dredge. Sediment samples were analyzed for the following: total organic carbon, total sulfur, total sulfur acid base, neutralization potential, total sulfur acid base potential, total phosphorous, ammonium nitrogen, nitrate nitrogen, alkalinity, and sulfate. Sediment samples were analyzed at Inter-Mountain Laboratories, Inc., according to Wyoming Department of Environmental Quality (WYDEQ) "Guidelines for Topsoil and Overburden," November 1984. Sediment samples were collected on July 20 and September 20.
Since the WYDEQ has no standards regulating contaminants in sediment, a statistical analysis was used to determine if contaminants in the sediment from samples collected from the Wheatland Diversion Tunnel Reservoir were significantly different from levels in sediment samples collected from the Laramie River downstream of the diversion dam.

2.3 Bi-weekly DO/Temperature Samples

Originally, bi-weekly DO and temperature samples were planned to determine if and when a thermocline developed. Since the sampling period was shortened because of high flows through the Wheatland Diversion Tunnel Reservoir, there were only two sampling periods. DO and temperature samples were collected every two hours for a 6-hour period on August 4 and September 1. The August 4 sampling period began at 0600 and ended at 1200, while the September 1 sampling period began at 0800 and ended at 1400. The same sampling sites were used as in Task 2.2. DO and temperature readings were taken with YSI Model 57 oxygen meter.
Figure 1. Location of Sampling Sites

2.25" = 1,000'
3.0 RESULTS

3.1 Sediment

The results of the analysis of sediment for contaminants is contained in Tables 1 and 2. Since the WYDEQ has no standards regulating contaminants in sediment, a comparison between the stations was used to determine if contaminants in the sediment of the Wheatland Tunnel Diversion Reservoir is affecting both the sediment and the water quality in the Laramie River downstream of the diversion dam.

Two-sample t-tests were used to compare the mean of each of the parameters listed in Table 1 for stations 1 and 3 (upstream) to the mean of stations 4 and 9 (downstream), across one sampling date (July 20). This test compares the sediment upstream of the dam to the sediment downstream of the dam. Two-tailed p-values below 0.10 were considered statistically significant (Table 1).

On the first sampling period (July 20), there appeared to be no difference between the sediment upstream of the diversion dam (stations 1 & 3) compared to sediment downstream of the diversion dam (stations 4 & 9) for seven of the eleven sediment parameters (Table 1). The four sediment parameters that appeared to be different were total sulfur, total sulfur acid base, total phosphorus, and sulfate.

A comparison could not be made between the sediment upstream of the diversion dam to the sediment downstream of the diversion dam for the second sampling date (September 20) because the sample bottle containing the sediment sample from station 1 was broken in transit to Inter-Mountain Laboratories, Inc. Additional sediment samples from station 1 could not be collected because the reservoir had already been drained when the loss was discovered.

Paired t-tests were used to compare the mean of each of the parameters listed in Tables 2 and 3 for station 3 to the mean for station 4; and the mean of station 4 to the mean of station 9, across the two sampling dates (July 20 & Sept. 20). Two-tailed p-values below 0.10 were considered statistically significant (Table 2).

Results from the t-tests comparing stations 3 and 4, indicate that there were only two sediment parameters that were statistically significantly different (p=0.10); total organic carbon and total phosphorous (Table 2). Results from the t-test comparing stations 4 and 9, indicate that there was no significant
difference in the sediment parameters between the two stations and across the two sampling dates (Table 2). However, our ability to detect significant differences is limited (i.e. we have low power) due to small sample sizes.

3.2 Water Quality

At the designated sampling points, tests indicated that the water quality parameters in both the Wheatland Tunnel Diversion Reservoir and the Laramie River were within the limits established by the WYDEQ and USEPA (Tables 3, 4, & 5). For all parameters except one (sulfide), there was no difference in the water quality between the incoming water (station 1) and water within the reservoir (stations 2 and 3). Additionally, there was no difference in the water quality within the reservoir from the water quality in the Laramie River downstream of the diversion dam (stations 4, 7, & 9).

The one parameter that increased over the course of the summer was the sulfide concentration at station 1, station 2B bottom and station 3B bottom (Tables 3, 4, & 5). Over the summer, the sulfide concentration at station 1 increased from <0.4 ppm to 1.2 ppm. The sulfide concentration at station 2B decreased from 0.8 ppm to <0.4 ppm between the sampling periods of July 20 to August 17. The sulfide concentration then increased from <0.4 ppm to 4.7 ppm between the sampling periods of August 17 to September 20. The sulfide concentration at station 3B increased from <0.4 ppm on July 20, to 4.1 ppm on September 20.

3.3 DO and Temperature

Except for the water at the bottom of the reservoir at stations 1, 2, and 3, DO concentrations within the Wheatland Tunnel Diversion Reservoir were above 5 ppm, the standard established by WYDEQ (Figure 2). Although the water at the bottom of the reservoir was below 5 ppm, the DO returned to 5 ppm or higher at the sampling points in the Laramie River (Figure 3).

There was no difference between the water temperature at station 1 compared to the water temperature at the stations established in the Wheatland Diversion Tunnel Reservoir (stations 2 & 3). Additionally there was no difference in the water temperature between the reservoir compared to the water temperature at the stations in the Laramie River downstream from the diversion dam.
Table 1. Values of various parameters for sediment samples collected on July 20-21, 1995.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sediment Standards</th>
<th>Station 1</th>
<th>Station 3B</th>
<th>Station 4</th>
<th>Station 9</th>
<th>P-values* (df = 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Organic Carbon (%)</td>
<td>NA</td>
<td>8.7</td>
<td>5.9</td>
<td>4.2</td>
<td>5.1</td>
<td>0.213</td>
</tr>
<tr>
<td>Total Sulfur (%)</td>
<td>NA</td>
<td>0.14</td>
<td>0.07</td>
<td>0.28</td>
<td>0.30</td>
<td>0.0366</td>
</tr>
<tr>
<td>Total Sulfur Acid Base Potential (t/1000t)</td>
<td>NA</td>
<td>4.37</td>
<td>2.19</td>
<td>8.75</td>
<td>9.37</td>
<td>0.0364</td>
</tr>
<tr>
<td>Neutralization Potential (t/1000t)</td>
<td>NA</td>
<td>160.0</td>
<td>86.2</td>
<td>90.4</td>
<td>115.0</td>
<td>0.652</td>
</tr>
<tr>
<td>Total Sulfur Acid Base Potential (t/1000t)</td>
<td>NA</td>
<td>156.0</td>
<td>84.0</td>
<td>81.6</td>
<td>106.0</td>
<td>0.562</td>
</tr>
<tr>
<td>Total Phosphorous (ppm)</td>
<td>NA</td>
<td>665.0</td>
<td>535.0</td>
<td>275.0</td>
<td>219.0</td>
<td>0.0379</td>
</tr>
<tr>
<td>Ammonium Nitrogen (ppm)</td>
<td>NA</td>
<td>24.0</td>
<td>8.5</td>
<td>14.6</td>
<td>24.3</td>
<td>0.760</td>
</tr>
<tr>
<td>Nitrate Nitrogen (ppm)</td>
<td>NA</td>
<td>3.44</td>
<td>0.70</td>
<td>0.46</td>
<td>0.48</td>
<td>0.363</td>
</tr>
<tr>
<td>Alkalinity (meg/L)</td>
<td>NA</td>
<td>3.62</td>
<td>3.41</td>
<td>3.02</td>
<td>2.43</td>
<td>0.128</td>
</tr>
<tr>
<td>Total Chromium (ppm)</td>
<td>NA</td>
<td>42.5</td>
<td>51.0</td>
<td>51.0</td>
<td>82.5</td>
<td>0.345</td>
</tr>
<tr>
<td>Sulfate (meg/L)</td>
<td>NA</td>
<td>12.5</td>
<td>15.9</td>
<td>8.45</td>
<td>7.81</td>
<td>0.072</td>
</tr>
</tbody>
</table>

*P-values from a two-sample t-test comparing sediment upstream (Stations 1 & 3B) of the diversion dam and the sediment downstream of the diversion dam (Stations 4 & 9). P-value less than 0.10 are considered significant.
Table 2. Values of various parameters for sediment samples collected on September 20-21, 1995.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sediment Standards</th>
<th>Station 1</th>
<th>Station 3B</th>
<th>Station 4</th>
<th>Station 9</th>
<th>P-Values* (df = 1)</th>
<th>P-Values# (df = 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Organic Carbon (%)</td>
<td>NA</td>
<td>NA*</td>
<td>6.4</td>
<td>4.5</td>
<td>6.0</td>
<td>0.035</td>
<td>0.156</td>
</tr>
<tr>
<td>Total Sulfur (%)</td>
<td>NA</td>
<td>NA*</td>
<td>0.25</td>
<td>0.27</td>
<td>0.17</td>
<td>0.45</td>
<td>0.627</td>
</tr>
<tr>
<td>Total Sulfur Acid Base (t/1000t)</td>
<td>NA</td>
<td>NA*</td>
<td>7.81</td>
<td>8.43</td>
<td>5.31</td>
<td>0.44</td>
<td>0.625</td>
</tr>
<tr>
<td>Neutralization Potential (t/1000t)</td>
<td>NA</td>
<td>NA*</td>
<td>135.0</td>
<td>92.4</td>
<td>101.0</td>
<td>0.56</td>
<td>0.286</td>
</tr>
<tr>
<td>Total Sulfur Acid Base Potential (t/1000t)</td>
<td>NA</td>
<td>NA*</td>
<td>127.0</td>
<td>84.0</td>
<td>95.9</td>
<td>0.46</td>
<td>0.211</td>
</tr>
<tr>
<td>Total Phosphorous (ppm)</td>
<td>NA</td>
<td>NA*</td>
<td>497.0</td>
<td>308.0</td>
<td>287.0</td>
<td>0.0998</td>
<td>0.271</td>
</tr>
<tr>
<td>Ammonium Nitrogen (ppm)</td>
<td>NA</td>
<td>NA*</td>
<td>79.5</td>
<td>47.8</td>
<td>49.1</td>
<td>0.62</td>
<td>0.415</td>
</tr>
<tr>
<td>Nitrate Nitrogen (ppm)</td>
<td>NA</td>
<td>NA*</td>
<td>6.08</td>
<td>2.10</td>
<td>2.28</td>
<td>0.46</td>
<td>0.430</td>
</tr>
<tr>
<td>Alkalinity (meg/L)</td>
<td>NA</td>
<td>NA*</td>
<td>4.30</td>
<td>5.28</td>
<td>11.2</td>
<td>0.74</td>
<td>0.563</td>
</tr>
<tr>
<td>Total Chromium (ppm)</td>
<td>NA</td>
<td>NA*</td>
<td>44.5</td>
<td>53.5</td>
<td>54.5</td>
<td>0.5</td>
<td>0.480</td>
</tr>
<tr>
<td>Sulfate (meg/L)</td>
<td>NA</td>
<td>NA*</td>
<td>16.2</td>
<td>14.0</td>
<td>13.6</td>
<td>0.32</td>
<td>0.144</td>
</tr>
</tbody>
</table>

NA* Sample was broken in transit to laboratory.

\*P-values from a paired t-test comparing the mean of station 3B between the mean of station 4 across two sampling dates (July 20 & Sept. 20, 1995). \#P-values from a paired t-test comparing the mean of station 4 between the mean of station 9, across two sampling dates (July 20 & Sept. 20, 1995). P-value less than 0.10 are considered significant.
Table 3. Comparison of water samples collected on July 20-21, 1995 with the state of Wyoming water quality standards and USEPA standards.

<table>
<thead>
<tr>
<th></th>
<th>Water Quality Standards</th>
<th>Station 1</th>
<th>Station 2B Surface</th>
<th>Station 2B Bottom</th>
<th>Station 3B Surface</th>
<th>Station 3B Bottom</th>
<th>Station 4</th>
<th>Station 7</th>
<th>Station 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidity (ppm CaCO₃)</td>
<td>111</td>
<td>90</td>
<td>56</td>
<td>65</td>
<td>79</td>
<td>82</td>
<td>67</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Alkalinity (ppm CaCO₃)</td>
<td>144</td>
<td>151</td>
<td>150</td>
<td>140</td>
<td>175</td>
<td>145</td>
<td>150</td>
<td>144</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>6.5-9.0</td>
<td>7.2</td>
<td>7.2</td>
<td>7.2</td>
<td>7.2</td>
<td>7.2</td>
<td>7.2</td>
<td>7.2</td>
<td>7.2</td>
</tr>
<tr>
<td>Ammonia-N (ppm NH₃)</td>
<td>0.0105-0.0951</td>
<td>0.022</td>
<td>0.06</td>
<td>0.0</td>
<td>0.026</td>
<td>0.03</td>
<td>0.0386</td>
<td>0.006</td>
<td>0.012</td>
</tr>
<tr>
<td>Nitrite (ppm NO₂⁻)</td>
<td>&lt;4.0</td>
<td>1.32</td>
<td>0.0</td>
<td>0.0</td>
<td>1.32</td>
<td>0.33</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Nitrate Nitrogen (ppm)</td>
<td>10</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.20</td>
<td>0.51</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Nitrite Nitrogen (ppm)</td>
<td>10</td>
<td>0.001</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Total Nitrogen (ppm)</td>
<td>10</td>
<td>2.0</td>
<td>1.9</td>
<td>1.4</td>
<td>1.2</td>
<td>1.8</td>
<td>1.3</td>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Total Phosphorus (ppm)</td>
<td>1</td>
<td>0.11</td>
<td>0.05</td>
<td>0.07</td>
<td>0.06</td>
<td>0.09</td>
<td>0.09</td>
<td>0.07</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Total Organic Carbon (ppm)</td>
<td>NA</td>
<td>10.2</td>
<td>11.1</td>
<td>NA</td>
<td>12.4</td>
<td>9.6</td>
<td>NA</td>
<td>10.1</td>
<td></td>
</tr>
<tr>
<td>Sulfate (ppm)</td>
<td>250</td>
<td>173</td>
<td>173</td>
<td>171</td>
<td>171</td>
<td>188</td>
<td>172</td>
<td>172</td>
<td>172</td>
</tr>
<tr>
<td>Carbon Dioxide (ppm CO₂)</td>
<td>47</td>
<td>33</td>
<td>46</td>
<td>26</td>
<td>52</td>
<td>37</td>
<td>42</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>Chloride (ppm Cl⁻)</td>
<td>230-860</td>
<td>16.4</td>
<td>13.8</td>
<td>1.9</td>
<td>5.0</td>
<td>16.6</td>
<td>13.9</td>
<td>13.0</td>
<td>11.2</td>
</tr>
<tr>
<td>Hardness (ppm CaCO₃)</td>
<td>306</td>
<td>260</td>
<td>272</td>
<td>265</td>
<td>260</td>
<td>166</td>
<td>156</td>
<td>328</td>
<td></td>
</tr>
<tr>
<td>BOD (ppm)</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>1</td>
<td>&lt;1</td>
<td>2</td>
<td>1</td>
<td>&lt;1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>COD (ppm)</td>
<td>25</td>
<td>25</td>
<td>27</td>
<td>27</td>
<td>31</td>
<td>26</td>
<td>29</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Sulfide (S²⁻) (ppm)</td>
<td>36</td>
<td>&lt;0.4</td>
<td>0.8</td>
<td>0.7</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
</tr>
<tr>
<td>Conductivity (umhos/cm)</td>
<td>641</td>
<td>639</td>
<td>639</td>
<td>638</td>
<td>671</td>
<td>643</td>
<td>641</td>
<td>641</td>
<td></td>
</tr>
</tbody>
</table>

1. WYDEQ. Water Quality Rules and Regulations, Chapter 1.
3. EPA Quality Criteria for Water, 1976
Table 4. Comparison of water samples collected on August 17-18, 1995 with the state of Wyoming water quality standards and USEPA standards.

<table>
<thead>
<tr>
<th></th>
<th>Water Quality Standards</th>
<th>Station 1</th>
<th>Station 2B Surface</th>
<th>Station 2B Bottom</th>
<th>Station 3B Surface</th>
<th>Station 3B Bottom</th>
<th>Station 4</th>
<th>Station 7</th>
<th>Station 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidity (ppm CaCO₃)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkalinity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ppm CaCO₃)</td>
<td>&gt;20&lt;sup&gt;4&lt;/sup&gt;</td>
<td>143</td>
<td>163</td>
<td>174</td>
<td>144</td>
<td>193</td>
<td>152</td>
<td>163</td>
<td>159</td>
</tr>
<tr>
<td>pH</td>
<td>6.5-9.0&lt;sup&gt;1&lt;/sup&gt;</td>
<td>7.0</td>
<td>7.0</td>
<td>7.3</td>
<td>7.7</td>
<td>7.3</td>
<td>7.3</td>
<td>7.3</td>
<td>7.0</td>
</tr>
<tr>
<td>Ammonia-N</td>
<td>0.0105-0.095&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.001</td>
<td>0.0004</td>
<td>0.0004</td>
<td>0.004</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0004</td>
</tr>
<tr>
<td>Nitrite (ppm NO₂⁻)</td>
<td>&lt;4.0&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.0</td>
<td>0.33</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.33</td>
</tr>
<tr>
<td>Nitrate Nitrogen (ppm)</td>
<td>&lt;0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>0.03</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Nitrite Nitrogen (ppm)</td>
<td>&lt;0.1</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Total Nitrogen (ppm)</td>
<td>10&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1.8</td>
<td>2.3</td>
<td>1.4</td>
<td>2.1</td>
<td>1.6</td>
<td>1.3</td>
<td>1.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Total Phosphorous (ppm)</td>
<td>1&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.08</td>
<td>0.06</td>
<td>0.09</td>
<td>0.07</td>
<td>0.06</td>
<td>0.08</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>Total Organic Carbon (ppm)</td>
<td>9.8</td>
<td>9.8</td>
<td>11.3</td>
<td>9.7</td>
<td>10.8</td>
<td>9.7</td>
<td>9.7</td>
<td>9.7</td>
<td>9.8</td>
</tr>
<tr>
<td>Sulfate (ppm)</td>
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<td>193</td>
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<td>193</td>
<td>193</td>
<td>193</td>
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<tr>
<td>Carbon Dioxide (ppm CO₂)</td>
<td>19.0</td>
<td>54.2</td>
<td>12.8</td>
<td>40.4</td>
<td>51.8</td>
<td>28.4</td>
<td>38.8</td>
<td>53.6</td>
<td></td>
</tr>
<tr>
<td>Chloride (ppm Cl⁻)</td>
<td>230-860&lt;sup&gt;1&lt;/sup&gt;</td>
<td>12.5</td>
<td>12.6</td>
<td>17.2</td>
<td>16.1</td>
<td>17.4</td>
<td>14.0</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ppm CaCO₃)</td>
<td>0-75 Soft&lt;sup&gt;4&lt;/sup&gt;</td>
<td>323</td>
<td>301</td>
<td>287</td>
<td>267</td>
<td>293</td>
<td>276</td>
<td>279</td>
<td>335</td>
</tr>
<tr>
<td></td>
<td>75-150 mod. Hard</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>150-300 Hard</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;300 Very Hard</td>
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<td>COD (ppm)</td>
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<td>26</td>
<td>22</td>
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<td>23</td>
</tr>
<tr>
<td>Sulfide (S²⁻) (ppm)</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
</tr>
<tr>
<td>Conductivity (umhos/cm)</td>
<td>681</td>
<td>684</td>
<td>685</td>
<td>684</td>
<td>685</td>
<td>688</td>
<td>687</td>
<td>686</td>
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</tr>
</tbody>
</table>

1. WYDEQ. Water Quality Rules and Regulations, Chapter 1.
Table 5. Comparison of water samples collected on September 20-21, 1995 with the state of Wyoming water quality standards and USEPA standards.

<table>
<thead>
<tr>
<th>Water Quality Standards</th>
<th>Station 1</th>
<th>Station 2B Surface</th>
<th>Station 2B Bottom</th>
<th>Station 3B Surface</th>
<th>Station 3B Bottom</th>
<th>Station 4</th>
<th>Station 7</th>
<th>Station 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidity (ppm CaCO₃)</td>
<td>96</td>
<td>85</td>
<td>88</td>
<td>82</td>
<td>91</td>
<td>73</td>
<td>67</td>
<td>67</td>
</tr>
<tr>
<td>Alkalinity (ppm CaCO₃)</td>
<td>&gt;20³</td>
<td>133</td>
<td>125</td>
<td>121</td>
<td>135</td>
<td>120</td>
<td>139</td>
<td>190</td>
</tr>
<tr>
<td>pH</td>
<td>6.5-9.0¹</td>
<td>7.7</td>
<td>7.7</td>
<td>7.5</td>
<td>7.7</td>
<td>7.7</td>
<td>7.7</td>
<td>7.3</td>
</tr>
<tr>
<td>Ammonia-N (ppm NH₃)</td>
<td>0.0105-0.095³</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Nitrite (ppm NO₂⁻)</td>
<td>&lt;4.0²</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Nitrate Nitrogen (ppm)</td>
<td>10³</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.12</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Nitrite Nitrogen (ppm)</td>
<td>10¹</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
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<tr>
<td>Total Nitrogen (ppm)</td>
<td>10¹</td>
<td>2.2</td>
<td>1.1</td>
<td>1.6</td>
<td>1.0</td>
<td>1.4</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Total Phosphorus (ppm)</td>
<td>1³</td>
<td>0.20</td>
<td>0.09</td>
<td>0.20</td>
<td>0.06</td>
<td>0.10</td>
<td>0.06</td>
<td>0.08</td>
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<tr>
<td>Total Organic Carbon (ppm)</td>
<td>9.7</td>
<td>9.1</td>
<td>9.6</td>
<td>9.0</td>
<td>9.2</td>
<td>NA</td>
<td>8.7</td>
<td>8.8</td>
</tr>
<tr>
<td>Sulfate (ppm)</td>
<td>250²</td>
<td>209</td>
<td>206</td>
<td>209</td>
<td>207</td>
<td>208</td>
<td>201</td>
<td>209</td>
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<tr>
<td>Carbon Dioxide (ppm CO₂)</td>
<td>31.8</td>
<td>50.4</td>
<td>36.9</td>
<td>39.8</td>
<td>47.4</td>
<td>44.2</td>
<td>58.2</td>
<td>40.4</td>
</tr>
<tr>
<td>Chloride (ppm Cl⁻)</td>
<td>230-860¹</td>
<td>15.0</td>
<td>12.0</td>
<td>12.7</td>
<td>12.4</td>
<td>13.5</td>
<td>15.9</td>
<td>14.0</td>
</tr>
<tr>
<td>Hardness (ppm CaCO₃)</td>
<td>0-75 Soft³</td>
<td>310</td>
<td>291</td>
<td>234</td>
<td>194</td>
<td>208</td>
<td>272</td>
<td>296</td>
</tr>
<tr>
<td>BOD (ppm)</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>COD (ppm)</td>
<td>34</td>
<td>21</td>
<td>27</td>
<td>22</td>
<td>19</td>
<td>18</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Sulfides (S²⁻) (ppm)</td>
<td>1.2</td>
<td>&lt;0.4</td>
<td>4.7</td>
<td>&lt;0.4</td>
<td>4.14</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
</tr>
<tr>
<td>Conductivity (umhos/cm)</td>
<td>715</td>
<td>716</td>
<td>720</td>
<td>714</td>
<td>718</td>
<td>717</td>
<td>717</td>
<td>716</td>
</tr>
</tbody>
</table>

1. WYDEQ. Water Quality Rules and Regulations, Chapter 1.
Figure 2. DO profile vs. time at mid-depth, for Stations 1, 2, 3, and 4 thru 9. *DO values for Station 2 are the mean values of Sites 2A, 2B, and 2C. DO values for Station 3 are the mean values of Sites 3A, 3B, and 3C. DO values for Station 4 thru 9 are the mean values of Stations 4, 5, 6, 7, 8, and 9.
Figure 3. DO profile vs. time at the bottom, for Stations 1, 2, 3, and 4 thru 9. *DO values for Station 2 are the mean values of Sites 2A, 2B, and 2C. DO values for Station 3 are the mean values of Sites 3A, 3B, and 3C. DO values for Station 4 thru 9 are the mean values of Stations 4, 5, 6, 7, 8, and 9.
Figure 4. Temperature profile vs. time at mid-depth, for Stations 1, 2, 3, and 4 thru 9. *Temperature values for Station 2 are the mean values of Sites 2A, 2B, and 2C. Temperature values for Station 3 are the mean values of Sites 3A, 3B, and 3C. Temperature values for Station 4 thru 9 are the mean values of Stations 4, 5, 6, 7, 8, and 9.
Figure 5. Temperature profile vs. time at the bottom, for Stations 1, 2, 3, and 4 thru 9. *Temperature values for Station 2 are the mean values of Sites 2A, 2B, and 2C. Temperature values for Station 3 are the mean values of Sites 3A, 3B, and 3C. Temperature values for Station 4 thru 9 are the mean values of Stations 4, 5, 6, 7, 8, and 9.
4.0 DISCUSSION/RECOMMENDATIONS

It has been suggested that two likely causes of fish kills in the Laramie River downstream of the Wheatland Diversion Dam are: 1) the sudden release of sediment that was trapped behind the dam, or 2) the release of colder, oxygen-deficient water into the Laramie River. However, no fish kill occurred in the Laramie River in 1995. The following section will discuss the results of our water quality and sediment sampling in 1995 and offer a possible explanation for the absence of a fish kill.

4.1 Sediment

When water was first released on September 21, 1995, some sediment was flushed into the Laramie River. The amount of sediment that was released in 1995 was not as high as in previous years (Don Briton, pers. comm.). The apparent reason for this difference is that there were higher than usual flow rates through the spillway throughout the summer of 1995. At the beginning of the sampling period (July 20-21) the flow rate through the spillway was approximately 25-30 cubic feet per second (cfs). On August 17-18 the flow rate was approximately 10-15 cfs, and the flow rate on September 20-21 was approximately 8-10 cfs. The flow rates through the spillway during a normal year are between 4 and 10 cfs, with 4-6 cfs being the norm (Don Briton, pers. comm.). With the higher flow rates sediment was apparently flushed through the spillway instead of being trapped behind the dam.

A comparison of sediment samples from stations 1 and 3 (upstream) and from stations 4 and 9 (downstream), across one sampling date (July 20), indicated that four sediment parameters were statistically different. These four parameters were total sulfur, total sulfur acid base, sulfate, and total phosphorus. Total sulfur, total sulfur acid base and sulfate are closely related and indirectly might cause a fish kill in the Laramie River. Elevated sulfur concentrations in the sediment could lead to the formation of hydrogen sulfide (H$_2$S) within the water column (Boyd, 1979). Available data indicate that water containing concentrations of 2.0 ug/L undissociated H$_2$S would not be hazardous to most fish and other aquatic wildlife, but concentrations in excess of 2.0 ug/L would constitute a long term hazard (USEPA, 1976).

Hydrogen sulfide has a characteristic odor of rotten eggs. It is detectable in air by humans at a dilution of 2 ug/L (Boyd, 1979). When collecting sediment samples, no odor of rotten eggs was detected.
When sediment samples were analyzed and compared across the two sampling dates, there was no significant increase or decrease in the contaminants between the sediment in the reservoir and the river sediment except for total organic carbon and total phosphorous. Phosphorous and carbon are required nutrients for plant growth and are abundant in the bones and teeth of animals. Phosphorus is usually present only in minute concentrations in natural waters because of its high mobility, although the total phosphate concentrations in natural aquatic systems may range from 0.01 to more than 200 ppm (Wetzel, 1975). Unless present in extreme abundance, phosphorus is rapidly removed by primary producers (phytoplankton) (Stickney, 1979). A possible reason for higher organic carbon and phosphorous levels at station 3 than at station 4 was the accumulation of free floating wind blown aquatic macrophytes against the dam face. As the aquatic macrophytes sink to the bottom and decompose, organic carbon and phosphorous would likely be released into the water or become attached to sediment particles (Hutchinson, 1957 and Lee, 1970). Once the organic carbon and phosphorus are flushed into the Laramie River, they would likely be rapidly incorporated into the aquatic macrophytes growing in the Laramie River (Boyd, 1979).

4.2 Water Quality

WYDEQ and the USEPA has established standards for eleven of the eighteen parameters we measured. Tests results for these eleven parameters suggest that the water quality in both the reservoir and the Laramie River in 1995 were within the WYDEQ and USEPA established standards.

When testing the difference between the remaining seven parameters for water in the reservoir and water in the Laramie River, we found that for six of the seven parameters we found no change in water quality in 1995. There was an increase in the sulfide ($S^{2-}$) concentration near the bottom of the reservoir at stations 1, 2B, and 3B. However, the elevated sulfide concentration was not observed downstream in the Laramie River. As the water traveled through the spillway, it was aerated and the sulfide was probably released into the air. As flow rates increase, the amount of sulfide that is released into the air increases (Cole, 1979). This represents a possible explanation for the decrease in sulfide concentration between the reservoir and the Laramie River.

Therefore, in 1995, the impoundment of the Laramie River by the Wheatland Tunnel Diversion Dam did not appear to affect the water quality within the Laramie River downstream of the diversion dam.
4.3 DO and Temperature

Except for water at the bottom of the reservoir, DO concentrations within the Wheatland Tunnel Diversion Reservoir were above 5 ppm. The DO concentrations at the bottom of the reservoir were below 5 ppm, but returned to 5 ppm or higher in the Laramie River downstream of the diversion dam. This increase in DO was likely due to reaeration of the water as it passes through the spillway.

A possible reason for the increase in DO concentration over the summer is an increasing rate of photosynthesis due to an increase in the phytoplankton population. Another possible reason for increased oxygen levels, especially during the last sampling period, is that the water temperature decreased by more than 10°C. Colder water temperatures allow more oxygen to be dissolved within the water column (Cole 1979).

In 1995, no thermocline developed in the Wheatland Tunnel Diversion Reservoir. There were several factors that occurred in 1995 that probably prohibited the formation of a thermocline. Water was flowing over the top of the dam early in the summer and the water level in the reservoir did not become stable until mid-July. In normal years the water level would have become stable by the end of May or early June (Don Briton, pers. comm.). This additional time would likely allow a thermocline to become established (Cole, 1979).

Another possible reason that a thermocline did not develop is that once the water level became stable, the flow rates thru the spillway remained above normal. The flow rate in normal years is 4-6 cfs (Don Briton, pers. comm.). On July 20-21, the flow rate was approximately 25-30 cfs. At this flow rate, the time for the water to travel through the reservoir would be 2.5 to 3 days (flushing rate). The flushing rate for a flow rate of 10-15 cfs (August 17-18) would be 5 to 7.5 days, and the flushing rate on September 20-21 (8-10 cfs) would be 7.5 to 9.4 days. In a normal year with a flow rate of 4-6 cfs, the flushing rate would be 12.5 to 18.8 days. High flushing rates usually prevent a thermocline from becoming established (Everhart, 1981).

For fish kills to occur from thermal shock, a rapid temperature change of more than 2°C must occur (Stickney, 1979). Since a thermocline did not become established, water temperatures were the same in the upper level of the reservoir as the water temperatures in the lower level (Figures 4 and 5). Also, since a thermocline did not become established, there was no difference between the water temperature flowing through the spillway into the Laramie River and the water temperature in the Laramie River.

On September 21, 1995, the Wheatland Irrigation District released water from the diversion reservoir into the Laramie River.
DO concentrations and temperature levels were observed at station 4 and these observations were compared to the DO concentration and temperature observed at station 3, at the last sampling time (1000). As the flow rate increase through the spillway the was no temperature difference observed, and the DO concentration rose slightly from 9.5 ppm to 9.7 ppm (Appendix A & B).

4.4 Possible Explanations for Past Fish Kills

Although the amount of sediment release in 1995 was not as high as in previous years, a sudden release of sediment that has become trapped behind the dam would probably not directly kill fish in the Laramie River based on reported observations. Past fish kills in the Laramie River downstream of the diversion dam occurred immediately after the spillway gate was opened. According to Lloyd (1987), Sigler et al. (1984), and Reynolds (1989) direct mortality of fish from suspended sediment usually takes 12 to 96 hours. The most likely effect of a sudden release of sediment into the Laramie River is the inhalation of silt particles which inflame gill membranes and increase mucous secretions, reducing oxygen uptake (Cairns, 1967, Lloyd, 1987, Hall, 1984a). This problem can be short-term if the sediment is flushed downstream within a few days (Cairns, 1967, Lloyd, 1987, Hall, 1984a). Therefore, it is unlikely that a fish kill would have been caused by a sudden release of sediment into the Laramie River downstream of the diversion dam.

Increased concentrations of phosphorus and organic carbon were found in the sediment upstream of the diversion dam compared to the sediment downstream of the diversion dam. It is unlikely that an increase in the phosphorus and organic concentration in the Laramie River would have caused a fish kill in the past. Elevated phosphorus and organic carbon would most likely be rapidly incorporated into the aquatic macrophytes growing in the Laramie River. Even if high phosphorus concentration caused an algal bloom in the reservoir and a subsequent die-off of the algal bloom occurred, an immediate fish kill would not occur because of the 3-7 day time-lag for the bacteria to consume the available DO (Boyd, 1979). Therefore, elevated phosphorus and organic carbon levels probably did not cause past fish kills in the Laramie River downstream of the diversion dam as fish kills occurred immediately after the spillway was open (Don Briton, pers. comm.).

It is doubtful that low DO in the water flowing into the Laramie River caused a fish kill. In 1995, low DO was observed at the bottom of the reservoir but once the water past through the spillway the DO concentration increased above 5 ppm. If a thermocline did become established, and DO concentrations decreased, the water would probably be reaerated as it passed through the spillway, especially when the spillway is open at the end of the irrigation season and flow rates are 35-45 cfs.
Thermal shock is a possible cause of fish kills in the Laramie River. Fish cannot tolerate rapid changes in temperature and a rapid increase or decrease of more than $2^\circ C$ may lead to stress and even mortality (Stickney, 1979). Many standing bodies of water become thermally stratified during the summer months. During this period the water temperature in the lower stratum (hypolimnion) is approximately $4^\circ C$. Water temperatures in the Laramie River downstream of the diversion dam are likely higher than $4^\circ C$ under normal conditions. If sufficient water was released to cause a rapid temperature decrease of more than $2^\circ C$, a fish kill might have occurred.

Since the Wheatland Tunnel Diversion Reservoir is small compared to other reservoirs such as Wheatland Reservoir #2, fish kills from thermal shock may occur even if a thermocline does not become established. If colder than normal air temperatures occur in late August or early September, the water temperature in both the Wheatland Diversion Tunnel Reservoir and the Laramie River would decrease. Water temperatures in the Laramie River downstream of the diversion dam would likely rise with air temperature because the depth of the river is only 1.5 to 2 feet deep. In contrast, the water temperature in the diversion reservoir would probably not increase as rapidly because of its size and depth. If the diversion dam spillway happen to be opened at this time, and if the difference in the water temperature of the diversion reservoir compared to the water temperature of the Laramie River is greater than $2^\circ C$, then a fish kill might occur.

4.5 Recommendations

In the past, water was released from the diversion reservoir by opening the spillway gate on the diversion dam so that the flow rate was increased to 35-45 cfs. Fish kills in the Laramie River downstream of the diversion dam occurred at this time. To possibly prevent a fish kill and drain the Wheatland Tunnel Diversion Reservoir we recommend one of the following procedures. The first procedure entails temporarily closing the spillway gates on Wheatland Reservoir #2. Once the spillway gates are closed, the water flowing through the Wheatland Diversion Dam spillway would be maintained at the normal flow rate of 4-6 cfs. After the Wheatland Tunnel Diversion Reservoir is drained the spillway gates on Wheatland Reservoir #2 would be reopened. This procedure would allow the water within the diversion reservoir to mix thus reducing the potential for water quality problems and eliminate the thermocline. This procedure would also allow water flowing through the diversion dam spillway to mix with the water in the Laramie River without rapid changes in water quality and temperature. A possible disadvantage of this procedure is that it would take approximately 12 to 19 days to drain the Wheatland Tunnel Diversion Reservoir.

If the Wheatland Irrigation District wants to drain the
Wheatland Diversion Tunnel Reservoir faster than 12 to 19 days, we recommend the following procedure. After the spillway gates on Wheatland Reservoir #2 are closed, the spillway gate on the diversion dam could be slowly opened over several days until the desired flow rate is obtained. This procedure would allow fish in the river to become acclimated to gradually changing water conditions. After the diversion reservoir is drained the spillway gate on Wheatland Reservoir #2 would be reopened. A fish kill could possible occur if the flow rate becomes too high for the fish to acclimate. To prevent a fish kill due to thermal shock, water temperatures in the river should be monitored to determine the ideal flow rates which prevent temperature from fluctuating more than 5°C in any 24 hour period (Stickney, 1979). This procedure would require more time of the Wheatland Irrigation District personnel. This problem could be solved by automating the diversion dam spillway gate.

If there is a need to verify the cause of fish kills, we recommend additional sampling under normal water conditions. DO and temperature samples should be collected just before the water is released and during the release. Also additional sediment and water samples should be collected. If a fish kill is observed and is not likely caused by low DO or a temperature change, the sediment and water samples could be analyzed to determine if poor water quality could possibly be responsible.
5.0 REFERENCES CITED


APPENDIX II

EVALUATION OF DIVERSION DAM, TUNNEL AND TUNNEL HEADGATE WHEATLAND DIVERSION DAM REHABILITATION PROJECT INBERG-MILLER ENGINEERS
EVALUATION OF DIVERSION DAM, TUNNEL AND TUNNEL HEADGATE WHEATLAND DIVERSION DAM REHABILITATION PROJECT PLATTE COUNTY, WYOMING

Date
December 28, 1995

For
KENNEDY ENGINEERING
P. O. Box 1089
Wheatland, Wyoming 82201

Job No.
6924-CX

INBERG-MILLER ENGINEERS
1120 East "C" Street
Casper, WY 82601
December 28, 1995

Kennedy Engineering
P. O. Box 1089
Wheatland, Wyoming 82201

ATTENTION: KEN KENNEDY

RE: EVALUATION OF DIVERSION DAM,
   TUNNEL AND TUNNEL HEADGATE
   WHEATLAND DIVERSION DAM REHABILITATION PROJECT
   PLATTE COUNTY, WYOMING

Gentlemen:

Enclosed are five unbound copies and one bound copy of our Report of the Evaluation of Diversion Dam, Tunnel and Tunnel Headgate for the above-referenced project.

The work described in this report has been completed per our November 15, 1995 Agreement Between Engineer and Geotechnical Engineer for Professional Services.

It has been a pleasure participating in this project. We are available to provide additional services, at your request, to perform Phase II tasks. If you have any questions or comments, please contact us.

Sincerely,

INBERG-MILLER ENGINEERS

Steven F. Moldt, P.E.
Vice President

Enclosures: As stated
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   Site Location Map

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APPENDIX C - DIVERSION TUNNEL PHOTOGRAPHS

APPENDIX D - TUNNEL HEADGATE PHOTOGRAPHS

APPENDIX E - REFERENCES
SUMMARY

In general, the overall condition of the diversion dam, tunnel and tunnel headgate appear good. The diversion dam is showing signs of deterioration, which should be repaired. The tunnel is also showing signs of deterioration, however, any repair is probably not necessary at this time. If a new tunnel headgate structure is to be constructed, careful consideration of seepage conditions through the native weathered soil and rock at the proposed location will be necessary.

SCOPE OF SERVICES

The purpose of this study was to perform a visual evaluation of the condition of the existing Wheatland Diversion Dam, Tunnel and Tunnel Headgate and to provide conclusions and, if necessary, recommendations for rehabilitation of the structures. We understand that this report will be incorporated into a Phase I report being prepared by Kennedy Engineering for the Wyoming Water Development Commission by Kennedy Engineering.

PROJECT INFORMATION

Project information was furnished by Ken Kennedy and Russ Schamel of Kennedy Engineering. It is our understanding that the project will consist of the evaluation of the current condition and operation of the diversion dam, tunnel and tunnel headgate, to mitigate fish kills on the Laramie River as a result of the operation of the diversion dam, to improve the measurement accuracy of the irrigation water from the Laramie River into Bluegrass Creek, and to improve the operation of the headgates at the diversion tunnel.

Diversion Dam

The diversion dam is a reinforced concrete structure built circa 1920. It is located on the Laramie River, approximately 16 miles east of Wheatland No. 2 Reservoir. The dam consists of a reinforced concrete spillway and earthen embankment. The dam is used to back up flow on the Laramie River during irrigation season to allow diversion of water into the tunnel and Bluegrass Creek.
**PROJECT INFORMATION, Continued**

**Diversion Tunnel**
The diversion tunnel is an unlined tunnel, measuring approximately 8 feet by 8 feet by 2900 feet long. The tunnel was built by the Wyoming Development Company, reportedly completed in 1886. The original headgate reportedly consisted of 72-inch and 60-inch square slide gates at the tunnel entrance.

**Tunnel Headgate**
The existing tunnel headgate consists of one 72 by 72 inch and one 60 by 60 inch slide gates situated at the tunnel entrance. A previous headgate structure was built by the Soil Conservation Service in 1981, and consisted of a concrete inlet box with 72 inch and 60 inch square slide gates and an aluminum structural plate pipe measuring 10 feet 9 inches by 6 feet 10 inches by approximately 138 feet long. The headgate structure failed on June 9 and 10, 1983, apparently from collapse of the pipe and possible erosion of the pipe bedding. Following failure of the headgate in 1983, the original headgate configuration was re-employed and has been used since.

**FIELD OBSERVATIONS**
The diversion dam, tunnel and tunnel headgate were observed by Eric Graney and Steven Moldt of Inberg-Miller Engineers on November 15, 1995. The following paragraphs summarize our observations at each structure.

**Diversion Dam**
According to the design drawings provided to us by Kennedy Engineering, the dam is a reinforced concrete spillway structure that measures approximately 30 feet high, 41 feet wide at the base and 80 feet long. The right abutment terminates into a rock wall and the left abutment of the spillway consists of a 36 foot high earthen embankment. The design drawings show a 3 foot thick concrete core wall extending from the spillway structure into the embankment and supposedly into bedrock. The outlet is located adjacent to the left abutment, and consists of a 3 foot by 3 foot square slide gate.
FIELD OBSERVATIONS, Continued

Diversion Dam, Continued

At the time of our site visit, the outlet gate was open and no water was being retained by the dam (refer to photographs in Appendix B). The flow of the river is such that it passes along the front of the dam before exiting through the outlet gate. The flow was estimated at 20 to 40 cfs. The high water mark on the dam appears to be around 25 feet, however, we understand that the spillway has been overtopped at times. Based on the number of apparent joints observed on the upstream face, it appears that the concrete for the spillway was poured in several sections. The area near the low water mark and the outlet gate is experiencing considerable erosion of the concrete surface, as reinforcing steel has been exposed. In addition, the concrete in the lower 10 feet of the upstream face has a different texture than the remainder of the dam indicating that repairs have possibly occurred on this portion in the past. The concrete surface at the top of the spillway has experienced some deterioration, with aggregate and reinforcing steel exposed.

The right abutment of the dam appears to be founded into relatively competent rock and no evidence of erosion around the contact between the concrete and rock was observed. The left abutment of the concrete structure consists of a concrete wingwall where the earthen embankment begins. The top approximately 20 feet of the retaining wall on the upstream side is somewhat deteriorated. The entire upper surface appears to have been previously repaired by what appears to be gunite or shotcrete. Where this surface repair has peeled away, the underlying concrete appears to be pitted and aggregate is exposed.

The reservoir area above the dam appears to contain a considerable amount of silt. Four probes were made with a 3/4-inch steel pipe with a pointed end and driven with a fence post driver. The probes were driven to refusal, at depths of 4 feet, 5 feet, 5 feet and 3 feet for probe locations 1 through 4, respectively. The probe locations were surveyed by Kennedy Engineering.
FIELD OBSERVATIONS, Continued

Diversion Tunnel

The entire tunnel was walked from the outlet to the inlet (refer to photographs in Appendix C). At the time of our visit, the headgates were open and there was no flow through the tunnel. The depth of standing water in the tunnel ranged from 0 to approximately 3 feet. The general condition of the tunnel was noted, as well as any significant features. The tunnel is nominally 8 foot by 8 foot in size, roughly square. There are several areas that are larger, on the order of 15 foot wide by 12 foot high, where it appears that the tunnel was either constructed larger or has since eroded because of the condition of the rock. According to the Profile and Plan sheet of the tunnel provided to us by Kennedy Engineering after our site visit, it appears that there were two locations that the tunnel was originally enlarged, one near the inlet end and one near the outlet end. However, during our walk-through, we also noted a larger area approximately 1000 feet into the tunnel from the outlet end, which appears to be approximately 10 feet wide by 15 feet high. Because the Profile and Plan sheets do not show this area, it is possible that this larger area is a result of erosion of the tunnel.

The geology in which the tunnel was constructed consists of metasedimentary rocks considered to be Middle to Late Archean (2.8 billion years old). More specifically, the formation strikes northwest and dips from 30 to 65 degrees east. It consists of schists, phylites, metaconglomerate and quartz seams. The formation is jointed along bedding planes and ranges from moderately to highly fractured. Some minor displacement has occurred in places within the formation.

Although the rock can be highly fractured, it appears to be stable with no obvious signs of recent failure. Several areas within the tunnel appear to have eroded, generally in areas where abundant biotite-rich, coarse grained schist exists. These areas also generally correspond to areas where increased mining had occurred during excavation of the tunnel.
FIELD OBSERVATIONS, Continued

Diversion Tunnel, Continued

Quartz seams are abundant throughout the entire length of the tunnel. These seams range in thickness from less than 1 inch to more than 4 feet thick. These quartz seams are important in that water is seeping into the tunnel from within fractures in several of these seams. It is our opinion that if a significant failure was to occur within the tunnel, it would most likely occur near one of these water bearing quartz seams. Photographs of some of the rock observed within the tunnel are included in Appendix C.

Tunnel Headgate

The existing tunnel headgate was apparently installed in 1983, after the concrete inlet structure and pipe had failed. The existing headgate consists of 72 by 72 inch and 60 by 60 inch sliding gates mounted on vertical I-beams. The gates are actuated by a hand crank located on a steel platform above the headgate. The general appearance of the headgate, both inside and outside of the tunnel entrance, appears relatively good. Photographs of the existing headgate and remains of the previous headgate are included in Appendix D.

The remains of the previous headgate still remain upstream of the tunnel entrance. The remains consist of the concrete inlet structure. According to Russ Schamel of Kennedy Engineering, the headgate structure failed when the pipe reportedly collapsed, likely from negative pressures within the pipe. In addition, it is possible that there could have been significant seepage around the pipe through the backfill zone. The existing soils exposed in the channel leading up to the tunnel entrance consist of a highly weathered schist, which would be expected to be relatively pervious through fractures.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations have been developed based on our understanding of the goals of the project, our observations of the structures on November 15, 1995 and a review of maps and drawings provided to us by Kennedy Engineering.
CONCLUSIONS AND RECOMMENDATIONS, Continued

**Diversion Dam**

In our opinion, the overall condition of the diversion dam is good. Both the concrete spillway structure and the earthen embankment appear to be structurally sound, with no visible signs of distress noted. However, the surface of the concrete spillway and wingwalls are showing signs of deterioration. While the deterioration noted is likely not structurally threatening at this time, the fact that steel reinforcing is exposed is not good. An evaluation of the overall stability or hydraulic capacity of the dam were not performed, as they are not within the scope of this study.

Because of the surface deterioration observed on portions of the concrete dam, we recommend that those areas of surface spalling and especially reinforcing steel exposure should be repaired. The repair should consist of providing a cement based covering over all exposed surfaces. Prior to placing any new covering, all exposed surfaces of concrete and reinforcing steel should be cleaned of all loose material and rust.

**Diversion Tunnel**

In our opinion, the overall condition of the diversion tunnel is good. The interior of the tunnel is relatively rough, but it appears that the structure was generally constructed in that maner. Interior erosion in the tunnel appears to be limited to a few short stretches where it appears that additional loss of ceiling rock has occurred.

Provided that the hydraulic characteristics of the tunnel are not to be improved, eg. improving the roughness of the tunnel, it is our opinion that the tunnel does not require any rehabilitation or additional study at this time. However, based on our observations, it appears that sections of the tunnel are showing more deterioration than the remainder of the tunnel. This deterioration appears to be in the form of an increase in the loss of rock from the ceiling of the tunnel. The loss of material is likely a result of zones of softer rock and the presence of water seepage from the parent rock. We do recommend, however, that the tunnel be periodically monitored by walking through the tunnel, to
CONCLUSIONS AND RECOMMENDATIONS, Continued

**Diversion Tunnel, Continued**

document changes in the condition of the tunnel. This monitoring should be performed by qualified personnel, with a minimum of two people in the tunnel at any time, and adequate safety precautions, including the use of air quality monitoring equipment. If the deterioration continues to worsen, it may be necessary to perform stabilization to portions of the tunnel, such as lining portions and/or using rock anchors.

**Tunnel Headgate**

In our opinion, the existing tunnel headgate appears to be performing satisfactorily from a stability standpoint. However, we understand that a new headgate is preferred, similar to the headgate structure built in 1981. It is our understanding that a new headgate structure would allow better monitoring and control of flow through the tunnel. If the new headgate structure is to be located in the channel above the tunnel entrance, near where the previous structure was located, careful consideration of seepage potential through the native soils and rock will need to be addressed. It is possible that the highly fractured rock exposed in the channel could have had at least a partial impact on the failure of the previous structure.

If the existing tunnel headgate is replaced, we recommend that the existing gates and operating platform be removed. The location of a new headgate structure should be explored with a backhoe, to determine the condition of the soils and rock in the vicinity of the headgate structure. Because of the relatively fractured nature of the existing soil and rock in the vicinity of the previous headgate structure, we recommend that additional exploration of the subsurface conditions be performed, including coring of the rock to determine its quality and the extent of fractures. In our opinion, a structure similar to the structure built in 1981 could be utilized, however, we recommend that suitable precautions be taken to prevent the seepage of water along the backfill zone.
CONCLUSIONS AND RECOMMENDATIONS, Continued

**Tunnel Headgate, Continued**

If the existing tunnel headgate is continued to be used to regulate flows through the tunnel, we recommend that the gate works and control platform be regularly inspected for deterioration. This inspection should include observing the gate works and connection to the tunnel entrance, and the structural condition of the operating platform. A flow monitoring device could be installed in the channel above the existing headgate structure to allow convenient flow monitoring.

**CLOSURE**

This report has been prepared for the exclusive use of our client, Kennedy Engineering, for evaluation of the structures. It may contain insufficient information for applications other than is herein described.

We appreciate participating in your project, and look forward to assisting in Phase II activities, as may be required. Please call if you have any questions regarding this report.

Sincerely,

INBERG-MILLER ENGINEERS

Steven F. Moldt, P.E.
Vice President

SFM:cag:rpt

REVIEWED BY:

Eric T. Graney, P.G.
Hydrogeologist
APPENDIX A - SITE LOCATION MAPS
SITE VICINITY MAP

Project: Wheatland Diversion Dam
Job No.: 6924-CX
Location: West of Wheatland, Wyoming
Client: Kennedy Engineering

Source: Wyoming Highway Map
Source: U.S.G.S. 7.5 Minute Series "Bull Camp Creek, Wyo."
APPENDIX B - DIVERSION DAM PHOTOGRAPHS
SITE PHOTOGRAPHS

Project: Wheatland Diversion Dam
Location: West of Wheatland, Wyoming
Client: Kennedy Engineering

DIVERSION DAM PHOTOGRAPHS

Top Photo: Top of spillway, showing deterioration of concrete and exposure of reinforcing steel.

Bottom Photo: Wingwall on left abutment, showing deteriorated concrete.
SITE PHOTOGRAPHS

Project: Wheatland Diversion Dam
Location: West of Wheatland, Wyoming
Client: Kennedy Engineering

DIVERSION DAM PHOTOGRAPHS

Top Photo: Outlet gate-upstream side.
Note deterioration of concrete and exposure of reinforcing steel.

Bottom Photo: Outlet gate-upstream side and concrete windwall at left abutment.
SITE PHOTOGRAPHS

Project: Wheatland Diversion Dam
Location: West of Wheatland, Wyoming
Client: Kennedy Engineering

Job No.: 6924-CX

DIVERSION DAM PHOTOGRAPHS

Top Photo: Looking down spillway toward right abutment-downstream side.

Bottom Photo: Looking toward right abutment-upstream side.
SITE PHOTOGRAPHS

Project: Wheatland Diversion Dam                      Job No.: 6924-CX
Location: West of Wheatland, Wyoming                Client: Kennedy Engineering

DIVERSION DAM PHOTOGRAPHS

View of dam face on upstream side, adjacent to outlet gate. Note the deterioration of the concrete and exposure of reinforcing steel.
APPENDIX C - DIVERSION TUNNEL PHOTOGRAPHS
SITE PHOTOGRAPHS

Project: Wheatland Diversion Dam

Location: West of Wheatland, Wyoming

Job No.: 6924-CX

Client: Kennedy Engineering

DIVERSION TUNNEL PHOTOGRAPHS

Top Photo: Tunnel inlet and headgate.

Bottom Photo: Typical tunnel section.
SITE PHOTOGRAPHS

Project: Wheatland Diversion Dam
Job No.: 6924-CX
Location: West of Wheatland, Wyoming
Client: Kennedy Engineering

DIVERSION TUNNEL PHOTOGRAPHS

Top Photo: Metal debris within tunnel—probably from headgate failure in 1983.

Bottom Photo: Larger section of tunnel at approximately 150 feet from outlet.
SITE PHOTOGRAPHS

Project: Wheatland Diversion Dam
Location: West of Wheatland, Wyoming

DIVERSION TUNNEL PHOTOGRAPHS

Top Photo: Quartz seam-note the highly fractured surface.

Bottom Photo: Quartz seam-note water seepage.
SITE PHOTOGRAPHS

Project: Wheatland Diversion Dam
Location: West of Wheatland, Wyoming
Client: Kennedy Engineering

DIVERSION TUNNEL PHOTOGRAPHS

Top Photo: Schist-note water seepage along joint.

Bottom Photo: Metaconglomerate.
SITE PHOTOGRAPHS

Project: Wheatland Diversion Dam
Job No.: 6924-CX
Location: West of Wheatland, Wyoming
Client: Kennedy Engineering

DIVERSION TUNNEL PHOTOGRAPHS

Top Photo: Tunnel outlet.

Bottom Photo: Tunnel outlet with flow recording station.
APPENDIX D - TUNNEL HEADGATE PHOTOGRAPHS
SITE PHOTOGRAPHS

Project: Wheatland Diversion Dam
Job No.: 6924-CX
Location: West of Wheatland, Wyoming
Client: Kennedy Engineering

TUNNEL HEADGATE PHOTOGRAPHS

Top Photo: Existing headgate structure.

Bottom Photo: Previous headgate inlet-looking downstream.
SITE PHOTOGRAPHS

Project: Wheatland Diversion Dam    Job No.: 6924-CX
Location: West of Wheatland, Wyoming    Client: Kennedy Engineering

TUNNEL HEADGATE PHOTOGRAPHS

Top Photo: Previous headgate inlet-looking downstream.

Bottom Photo: Previous headgate inlet-looking upstream into reservoir basin.
APPENDIX E - REFERENCES
REFERENCES

"Laramie River Dam- Plan and Sections", Assorted Design Drawings, No Date, circa 1920.

"Profile and Plan of Tunnel No.1 of the Wyoming Development Company", No date, circa 1886.

"Verticle(sp) and Horizontal Section of Tunnel" by Frank Bartlett, March 19, 1886.

"Sheet No. 1-Right-of -Way Map" by J.A. Elliott, October 21, 1914.