RECLAMATION

Managing Water in the West

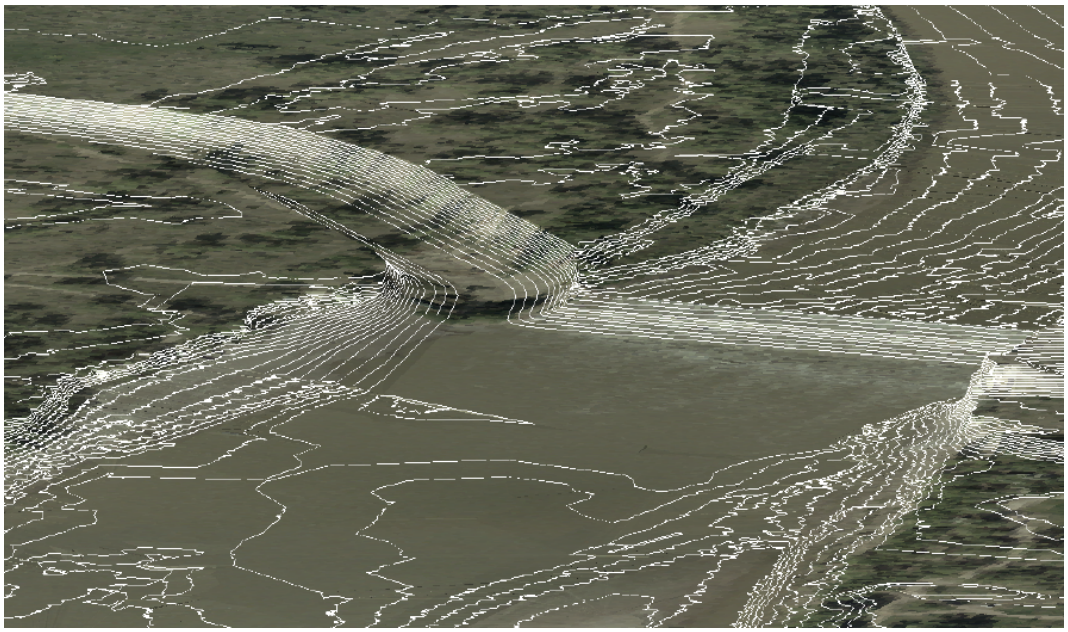
PAP-1053

Lower Yellowstone Intake Diversion Dam

Fish Bypass Channel Entrance and Exit Pre-appraisal Study

Progress Report March 2012

By Bryan Heiner, Dale Lentz, and Josh Mortensen



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services Group
Denver, Colorado

Lower Yellowstone Intake Diversion

Fish Bypass Channel Entrance and Exit Pre-appraisal Study

Progress Report

Prepared By:

Bryan Heiner
Hydraulic Engineer, Hydraulic Investigations and Laboratory Services Group, 86-68460

Dale Lentz
Hydraulic Engineer, Hydraulic Investigations and Laboratory Services Group, 86-68460

Josh Mortensen
Hydraulic Engineer, Hydraulic Investigations and Laboratory Services Group, 86-68460

Technical Approval: Robert F. Einhellig, P.E.
Manager, Hydraulic Investigations and Laboratory Services Group, 86-68460

Peer Review: Brent Mefford, P.E. 7/27/2012 Date
Technical Specialist, Hydraulic Investigations and Laboratory Services Group, 86-68460

This study was funded by the U.S. Corps of Engineers, Omaha District. The Corps is the lead agency for the design and construction of fish passage at Intake Diversion Dam on the Yellowstone River near Glendive Montana.

Project Background

Intake dam is a Bureau of Reclamation irrigation diversion dam on the Yellowstone River approximately 70 miles upstream from its confluence with the Missouri River. It presents a barrier to fish migration on the Yellowstone. The project consists of two phases, first the construction of a fish screen structure to prevent fish entrainment (including the federally protected pallid sturgeon). Construction of a fish screen structure was initiated in 2010. The second phase includes design and construction of fish passage over or around the diversion dam. Two alternatives for fish passage were identified from project scoping studies for further design development. These are a rock ramp downstream of the diversion dam that would provide passage over the structure and a split-channel bypass that would provide passage around the diversion dam. Feasibility level design of the rock ramp alternative based on numerical and physical modeling has been completed. This report covers pre-appraisal level development of the split-channel bypass alternative focusing on design of the channel entrance and exit which are key to achieving fish passage and long term channel stability.

The Biological Review Team (BRT) provided guidance for the split-channel bypass fishway design in March, 2011. Their recommendations addressing bypass entrance and exit issues were as follows:

> (1) The BRT has concern that existing tracking data for pallid sturgeon indicates limited use of side channels during upstream migratory movement. The BRT recommends removing the 10% Diversion option and focusing on options capable of conveying 15%, 20%, 25%, and 30 % of the river flow.
>
> (2) We recognize the limitations of the 1-dimensional HEC-RAS model, but additional data related to the shear flow, mixing zone, and attraction flow at the fish entrance to the bypass channel are essential. Future analysis will be improved with additional data depicting the fish-way entrance and its orientation relative to the base of the dam and the main river thalweg.
>
> (3) A possible low weir to divert additional attraction water was discussed, and it would be good to review and evaluate some possible alignments as soon as possible.
>
> (4) Future analysis will be improved with the addition of model cross-sectional data at the water entrance and exit. Specifically, the BRT requests details on anticipated depths at the modeled discharges for these locations.
>
> (5) The bypass channel should be constructed such that 2 meters of water depth is possible at discharges exceeding 10,000 ft^3/s to better mimic those habitat parameters that coincide with adult pallid sturgeon locations (Bramblett 1996; Bramblett and White 2001; MFWP unpublished data).

The proposed bypass channel would extend from immediately downstream of the diversion weir to approximately 2 miles upstream of the diversion, Figure 1. Bypass channel entrance and exit used herein are referenced to upstream fish movement. The bypass entrance and exit refer to the downstream and upstream end of the channel respectively, opposite that of flow direction.

Split-Channel Bypass Alternative - Design Data Assumptions

Preliminary design data for the bypass were established based on applicable design data from the rock ramp fishway studies and recommendations of the BRT. Table 1 presents design data used for the basis of the designs presented in this report.

Table 1 - Considerations for the fish bypass design

Split-channel Bypass Flow	The bypass conveys a minimum of 15 percent of river flow at the dam for river flows larger than10,000 ft^3/s. Bypass flows of greater than the minimum are considered highly desirable for increased fish attraction and passage.
Average Fishway Velocity	Average flow velocity of about 1 m/s (~3 ft/s) at 10,000 ft^3/s river flow increasing to about 2 m/s (~6 ft/s) at 70,000 ft^3/s river flow. This range is similar to the mean river velocity measured about 1000 ft downstream of the dam and BRT recommendations.
Channel slope	Average bypass channel slope should be similar to that of the river below the dam which is about 0.00055.
Bypass Entrance Shape	Information from sturgeon tracking and habitat use studies were compiled with river cross section data below the dam. These data support a channel shape with a wide, nearly flat invert at the center of the channel transitioning to shallow sloping banks. The invert slope should gradually increase toward the bank lines.
Bypass Channel Entrance Depth	A thalweg depth of about 2 m (~6 ft) at 10,000 ft^3/s increasing to about 5 m (~16 ft) at 70,000 ft^3/s. Depth at the bypass entrance should be similar to the thalweg depth downstream of the dam.
Bypass Channel Exit Depth	A minimum thalweg depth of about 2 m (~6 ft) for river flows above 10,000 ft^3/s.

Bypass Entrance Orientation to the River	Flows from the bypass should merge with river flow in a downstream direction avoiding large eddies and strong shear zones.
Irrigation Diversion Criteria	Diverting water into the bypass must not impact the ability of the irrigation diversion to meet established diversion criteria. A minimum water surface of 1991.1 is required at Intake diversion headworks.
Channel Bed Roughness	The bypass channel entrance should be designed to support large areas of silt/sand and small gravel bed materials. Riprap required on the channel bed should be set below design grade and choked with fines.

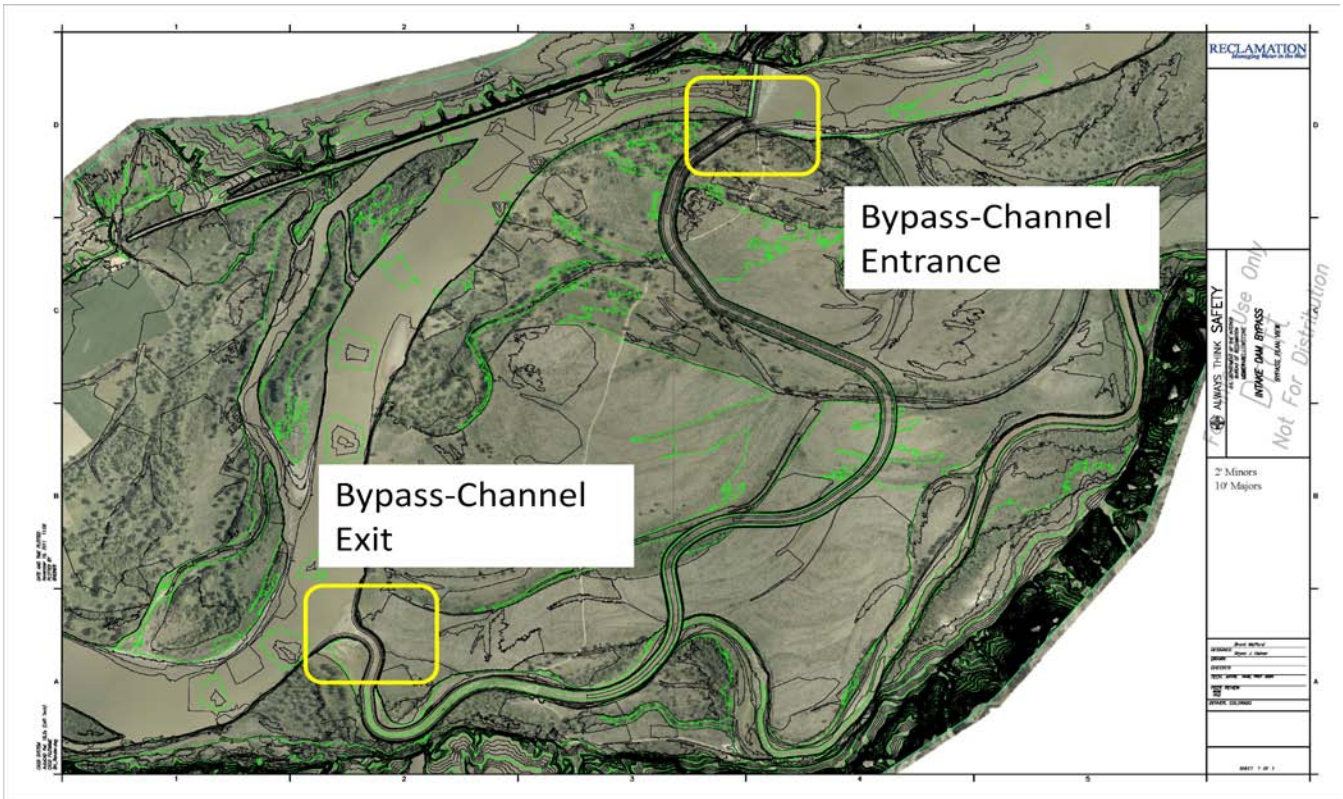


Figure 1 - Preliminary split-channel bypass design showing passage entrance and exit locations.

Bypass Channel Shape

A characteristic shape for the bypass channel was developed assuming the channel should approximately emulate the main stem river downstream from the influence of the diversion dam. The bypass channel shape chosen has a flat invert with shallow side slopes that become steeper closer to the banks, Figure 2. The bypass channel side slopes are similar to the natural bank slopes found in river transitions between bends downstream of the diversion dam. The importance of providing shallow sloping banks off the channel invert were presented by the BRT and are supported by studies of channel habitat utilization by sturgeon in the Yellowstone River, (Bramblett, R. 1996, DNRC, 1977).

The bypass channel shape given in Figure 2 was used in this study to evaluate the channel entrance and exit transition shapes, alignments and hydraulic performance. As the bypass channel design advances, the shape of the bypass channel between the entrance and exit will likely include attributes of bends, transitions and straighter runs. The length of the outer bank slope (1V:2H) shown is approximate. For all drawings and flow simulations conducted for this study the outer bank slope was carried to daylight at the elevation of the natural topography.

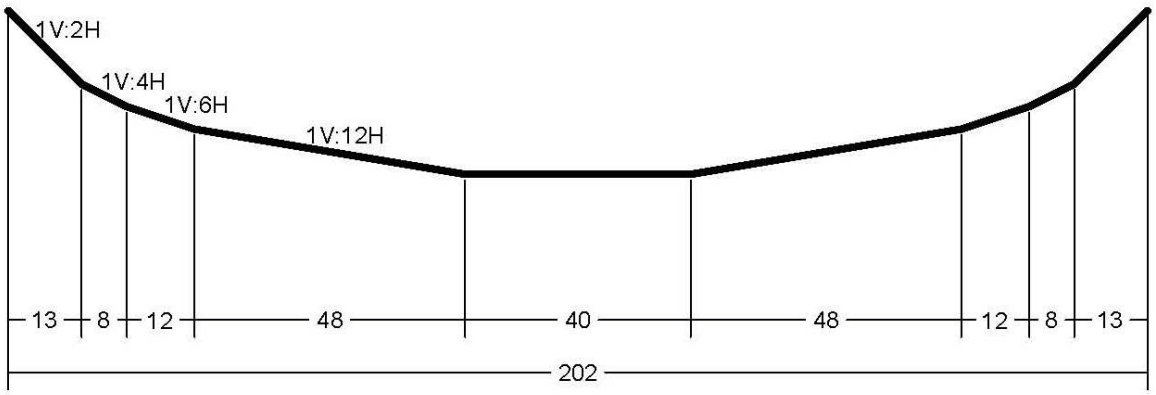


Figure 2 - Typical bypass channel section showing slopes and slope widths. Note: the plot's vertical scale is exaggerated by a factor of two.

Bypass Channel Entrance

The entrance to the bypass channel should be located approximately adjacent to the right abutment of the diversion dam. For this study, a new dam at the existing dam location with a crest geometry matching that developed for the design of the fish screens/headworks was assumed. Future selection of an upstream dam location should not significantly alter the findings of this study if the bypass entrance and dam are relocated together.

HEC-RAS Modeling

A HEC-RAS 1 dimensional numerical model of the Lower Yellowstone River around the Intake diversion dam was given to Reclamation from USACE. The model boundaries extended approximately 5 miles upstream and downstream of Intake dam. It also included approximately 4 miles of the irrigation canal and the proposed headworks structure. This existing model was modified to model various bypass alternatives, primarily focusing on the hydraulic characteristics of the bypass relating to fish passage and the percentage of flow in the bypass without affecting the ability to divert irrigations flows. Alternatives were not evaluated with respect to sediment transport capabilities, ice stability, or cut and fill. For all bypass alternatives the following parameters were assumed; channel roughness represented by a manning's n of .028, an invert elevation at the channel entrance of 1981.0 and a bypass channel length of 15500 ft. The sensitivity of the flow split between the river and bypass channel to higher roughness values was not analyzed. A Manning's n of .028 was considered a conservative low value for the purpose of guaranteeing diversion water.

Six bypass alternatives were modeled with varying slopes and channel widths. Major hydraulic parameters for each alternative are presented in Table 2. Alternatives 1 and 2 simulated 202 ft wide channels (assuming a reference depth of 14.5 ft) with slopes of 0.0005 and 0.0006, respectively. The steeper slope results in a higher invert elevation of the bypass channel at the upstream junction. In bypass alternatives 3 through 6, the horizontal invert of the bypass channel was increased by 50 ft, giving a reference channel width of 252 ft. These four alternatives then vary in channel slope from 0.0005 to 0.0007. Based on the HEC-RAS simulation results given in Table 2, Bypass 2 was carried forward for the development of bypass channel entrance and exit designs to a pre-appraisal level (no cost estimates). Bypass 2 was chosen as it represents the minimum excavation of the alternatives studied that meets the design data objectives. Bypass 2 meets all objectives with the exception of depth at the exit for a river flow of 10,000 ft^3/s. This was considered acceptable as the exit depth is similar to downstream river thalweg depths and exceeds the target depth prior to river flows reaching 20,000 ft^3/s.

A plot of average channel velocity in the bypass channel and downstream river is presented in Figure 3 for Bypass 2. Flow velocity for normal depth conditions in the upper reach of the bypass channel is similar to that of the downstream river. Tailwater inundation of the bypass entrance and lower channel reach results in a gradual reduction in bypass channel velocity from upstream toward the entrance. The entrance of the channel is designed to provide optimum flow depth, velocity and bed substrate for sturgeon habitat and movement as described by Bramblett, 1996. Plan and sections for the proposed bypass entrance are given as drawings 1 – 4 at the end of the report.

Table 2 - Bypass Alternatives with varying slopes and widths

Plan Name	Bypass 1	Bypass 2	Bypass 3	Bypass 4	Bypass 5	Bypass 6
Channel Length	15500	15500	15500	15500	15500	15500
Slope	0.0005	0.0006	0.0005	0.0006	0.00065	0.0007
Downstream Invert El.	1981	1981	1981	1981	1981	1981
Upstream Invert El.	1988.75	1990.3	1988.75	1990.3	1991.08	1991.85
Bypass width	202	202	252	252	252	252
Bypass Flow						
5 KCFS	1044	559	1544	894	613	366
10 KCFS	2024	1311	2867	1956	1524	1134
20 KCFS	3897	2905	5318	4099	3503	2902
30 KCFS	5618	4481	7535	6123	5555	4721
40 KCFS	7417	6151	9749	8245	7469	6684
70 KCFS	12814	11304	16304	14545	13658	12720
Main Channel Flow (Downstream of Bypass and Upstream of Irrigation Diversion)						
5 KCFS	3957	4442	3457	4107	4388	4635
10 KCFS	7977	8690	7134	8045	8477	8867
20 KCFS	16104	17096	14683	15902	16498	17099
30 KCFS	24383	25520	22466	23878	24446	25280
40 KCFS	32584	33850	30252	31756	32532	33317
70 KCFS	57187	58697	53697	55456	56343	57281
Main Channel Flow (Downstream of Irrigation Diversion)						
5 KCFS	2562	3041	2120 *	2708	2987	3234
10 KCFS	6579	7290	5733	6645	7077	7467
20 KCFS	14707	15694	13284	14502	15098	15698
30 KCFS	22983	24121	21067	22479	23047	23880
40 KCFS	31181	32451	28853	30357	31132	31915
70 KCFS	55787	57297	52298	54059	54944	55878
Bypass Flow/ Total Flow (Upstream of Bypass)						
5 KCFS	20.9%	11.2%	30.9%	17.9%	12.3%	7.3%
10 KCFS	20.2%	13.1%	28.7%	19.6%	15.2%	11.3%
20 KCFS	19.5%	14.5%	26.6%	20.5%	17.5%	14.5%
30 KCFS	18.7%	14.9%	25.1%	20.4%	18.5%	15.7%
40 KCFS	18.5%	15.4%	24.4%	20.6%	18.7%	16.7%
70 KCFS	18.3%	16.1%	23.3%	20.8%	19.5%	18.2%

Plan Name	Bypass 1	Bypass 2	Bypass 3	Bypass 4	Bypass 5	Bypass 6
Bypass Flow/ Flow Downstream of Dam						
5 KCFS	40.7%	18.4%	72.8%	33.0%	20.5%	11.3%
10 KCFS	30.8%	18.0%	50.0%	29.4%	21.5%	15.2%
20 KCFS	26.5%	18.5%	40.0%	28.3%	23.2%	18.5%
30 KCFS	24.4%	18.6%	35.8%	27.2%	24.1%	19.8%
40 KCFS	23.8%	19.0%	33.8%	27.2%	24.0%	20.9%
70 KCFS	23.0%	19.7%	31.2%	26.9%	24.9%	22.8%
Bypass Data						
10 KCFS						
Avg Velocity, upstream channel	3.0	2.8	3.2	3.0	2.8	2.6
Max Depth, upstream channel	6.1	4.8	5.8	4.6	4.0	3.3
% cross-section with 1.5-3 m depth	34%	0%	30%	0%	0%	0%
Avg Velocity, downstream channel	3.0	1.9	2.9	2.0	1.5	1.1
Max Depth, downstream channel	6.2	6.2	6.2	6.2	6.2	6.2
20 KCFS						
Avg Velocity, upstream channel	3.8	3.7	3.9	3.8	3.7	3.6
Max Depth, upstream channel	8.3	6.9	7.9	6.6	6.0	5.4
% cross-section with 1.5-3 m depth	59%	43%	55%	40%	33%	25%
Avg Velocity, downstream channel	3.6	2.6	3.5	2.7	2.3	1.9
Max Depth, downstream channel	8.6	8.7	8.6	8.7	8.7	8.7
30 KCFS						
Avg Velocity, upstream channel	4.3	4.2	4.4	4.3	4.3	4.2
Max Depth, upstream channel	9.8	8.5	9.4	8.1	7.6	6.9
% cross-section with 1.5-3 m depth	72%	62%	70%	58%	51%	43%
Avg Velocity, downstream channel	3.9	3.1	3.8	3.1	2.8	2.4
Max Depth, downstream channel	10.5	10.5	10.5	10.5	10.5	10.6
40 KCFS						
Avg Velocity, upstream channel	4.7	4.7	4.8	4.8	4.7	4.7

Plan Name	Bypass 1	Bypass 2	Bypass 3	Bypass 4	Bypass 5	Bypass 6
Max Depth, upstream channel	11.2	9.8	10.8	9.5	8.8	8.2
% cross-section with 1.5-3 m depth	45%	73%	48%	71%	66%	59%
Avg Velocity, downstream channel	4.3	3.5	4.2	3.5	3.2	2.8
Max Depth, downstream channel	12.0	12.1	12.0	12.1	12.1	12.1
70 KCFS						
Avg Velocity, upstream channel	5.7	5.7	5.7	5.8	5.8	5.8
Max Depth, upstream channel	14.6	13.2	14.1	12.7	12.1	11.4
% cross-section with 1.5-3 m depth	21%	29%	23%	33%	38%	43%
Avg Velocity, downstream channel	5.1	4.5	4.9	4.4	4.1	3.8
Max Depth, downstream channel	15.8	15.9	15.8	15.9	16.0	16.0
All simulations assume a canal diversion of 1400 cfs.						
* For the given bypass design and river flow the max irrigation diversion is 1338 cfs.						

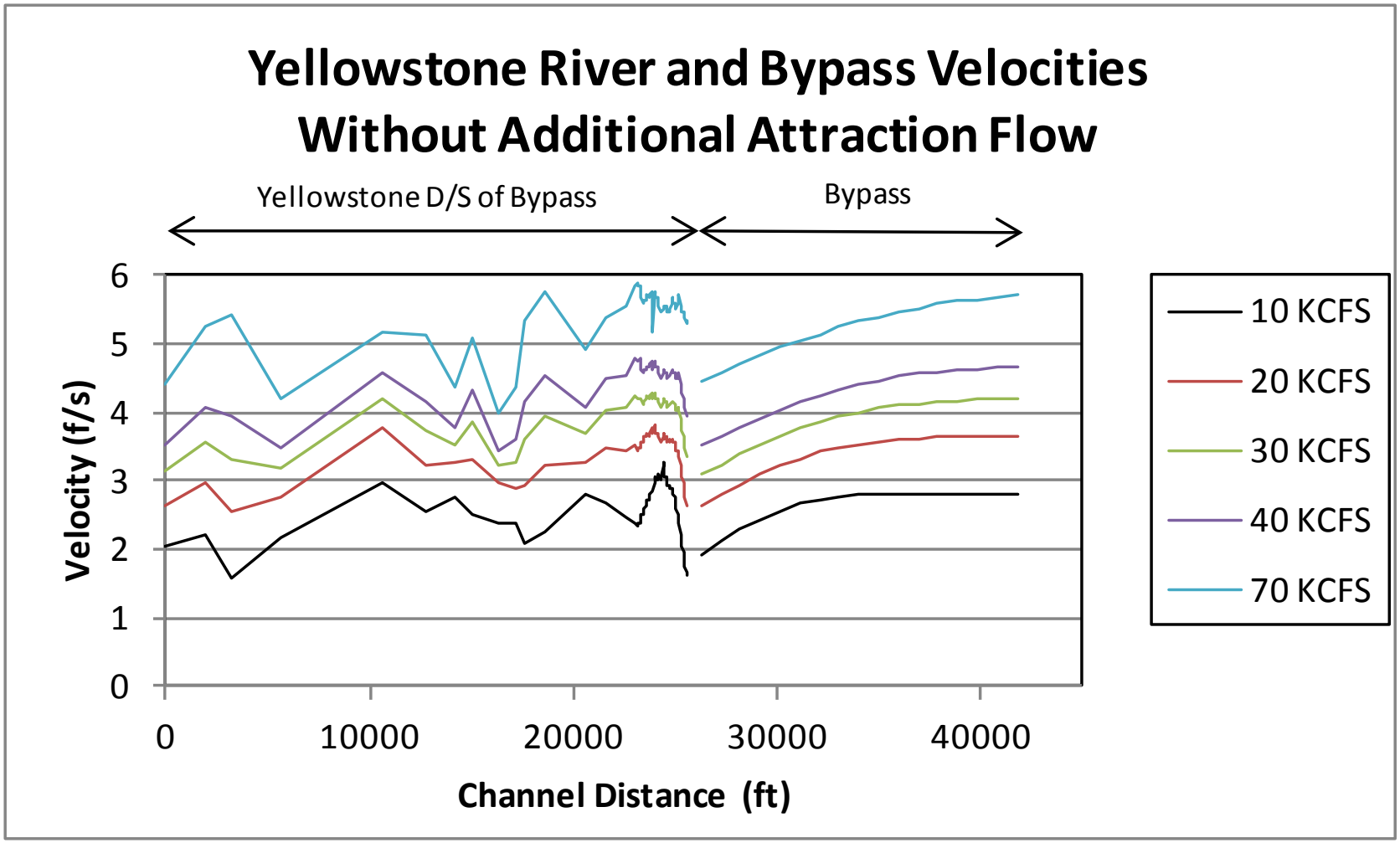


Figure 3 - Average channel velocity in the Yellowstone River downstream of the bypass entrance (left side) and in the bypass (right side).

Split-Channel Bypass Exit Design

The bypass channel exit (fish passage exit) is shown at approximately the location of the existing natural high flow channel bifurcation, Figure 1. For pre-appraisal, this location was selected as it provides sufficient separation from the diversion dam to permit a large meandering bypass channel to be constructed at a slope similar to the river. The site is located on the outside of a shallow bend and supports a natural bifurcation to a high flow channel. These factors suggest the location is favorable for achieving a stable bypass channel design. However, further sediment and flow modeling of the bifurcation will be needed to confirm the location. The bypass exit (flow entrance) shown is shaped as a gradual contraction to minimize zones of sharp flow acceleration and shear lines within the flow that could cause upstream migrating fish to become disoriented at the flow split. Behavioral reactions of sturgeon negotiating flow transitions are poorly understood, therefore, the design of the bypass channel exit attempts to make the flow split as hydraulically smooth as possible. Plan and sections for the proposed bypass exit are given as Drawings 5-8.

Auxiliary Flow Lateral Weir Option

Two alternatives that include a lateral weir located in the entrance of the bypass channel were developed as options for increasing bypass channel flow for fish attraction. The lateral weir alternatives presented are designed as an extension of the right abutment of the diversion dam. Proper alignment of the lateral weir to the bypass channel and effective dissipation of flow energy passing over the weir are necessary to achieve improved attraction without creating shear flows that may misguide or significantly delay fish movement.

Several weir crest elevations, weir lengths and weir alignments were investigated for this study. A weir crest elevation of 1992.1 matching the elevation of the diversion dam at the right abutment was selected for the lateral weir. Flow over the weir crest commences at a river flow measured upstream of the bypass exit of about 10,000 ft^3/s. This crest elevation prevents the side-channel flow from impacting the ability of the diversion headworks to divert at full capacity for all river flows above 5,000 ft^3/s (measured upstream of the bypass exit). Plan and section views of the two lateral weir options developed are shown on Drawings 9-11 (Option 1) and 12-14 (Option 2). The options vary only in their alignment to the diversion dam. Option 1 is aligned at an angle to the diversion dam and approximately parallel with the bypass channel. This alignment attempts to reduce false attraction to the weir flow for fish by minimizing channel length between the bypass and weir. The option 2 weir is aligned at a right angle to the diversion dam providing greater length for dissipation of flow energy, but may increase false attraction for fish to the weir flow.

HEC-RAS Modeling of Lateral Weir for Auxiliary Attraction Flow

A lateral weir located on river right immediately upstream of Intake dam was added to the HEC-RAS Model for Bypass 2 (see Table 2). Various lengths and elevations of the weir were analyzed. A weir with a crest length of 150 ft at elevation 1992.1 was selected to achieve between 5 percent and 10 percent auxiliary flow augmentation to the bypass channel entrance without impacting irrigation diversion. The default coefficient for a broad crested lateral weir in

HEC-RAS is 2.0. Assuming an ogee crest, the lateral weir discharge coefficient can increase to around 3.3. For this study, simulations were conducted with discharge coefficients of both 2.0 and 3.0 to determine the possible range of auxiliary attraction flow. Results of model runs with lateral weir coefficients of 2.0 and 3.0 are presented in Table 3.

A plot of average channel velocity in the bypass channel, through the bypass channel entrance with a 150 ft lateral weir and continuing along the downstream river is presented in Figure 4. Flow over the lateral weir at river flows above about 20,000 ft^3/s yield a strong increase in bypass channel velocity in the bypass mouth. With the addition of weir flow, flow velocity at the mouth of the entrance rises to about the level of that of the downstream river. The 150 ft long weir provides from 2 percent (10,000 ft^3/s river) to 7 percent (70,000 ft^3/s river) additional river flow to the bypass channel entrance using a weir coefficient of 2.0.

Table 3 - Bypass channel and weir flows with a weir coefficient of 2 and 3

Weir Elevation=	1992.1
Weir Length=	150
Weir coefficient=	**2**

River Flow, ft^3/s	Bypass Flow, ft^3/s	Weir Flow, ft^3/s	Canal Flow, ft^3/s	Bypass Flow as % of River Flow	Weir Flow as % of River Flow	Bypass & Weir Flow as % of River Flow
5000	558.9	0.0	1399.3	15.5%	0.0%	15.5%
10000	1305.8	145.5	1400.0	15.2%	1.7%	16.9%
20000	2884.0	843.8	1400.8	15.5%	4.5%	20.0%
30000	4428.4	1608.6	1400.0	15.5%	5.6%	21.1%
40000	6037.6	2401.4	1400.3	15.6%	6.2%	21.9%
70000	11052.1	4755.7	1400.0	16.1%	6.9%	23.0%

Weir Elevation=	1992.1
Weir Length=	150
Weir coefficient=	**3**

River Flow, ft^3/s	Bypass Flow, ft^3/s	Weir Flow, ft^3/s	Canal Flow, ft^3/s	Bypass Flow as % of River Flow	Weir Flow as % of River Flow	Bypass & Weir Flow as % of River Flow
5000	552.2	0.0	1401.4	15.3%	0.0%	15.3%
10000	1304.8	210.1	1400.2	15.2%	2.4%	17.6%
20000	2883.8	1208.3	1402.2	15.5%	6.5%	22.0%
30000	4414.4	2301.1	1401.7	15.4%	8.0%	23.5%
40000	6018.9	3433.8	1400.0	15.6%	8.9%	24.5%
70000	10976.6	6774.9	1400.1	16.0%	9.9%	25.9%

Both options are shown with 1 ft high stepped aprons on the downstream side of the weir. The stepped aprons were included assuming roller compacted concrete construction would be used for the weir. The steps will help dissipate a portion of the flow energy on the apron and breakup the flow nappe before it merges with bypass channel flow. However, weir height to critical depth on the weir is less than 10 and therefore, the steps contribute relatively little to energy dissipation of flow on the apron. Table 4 presents the elevation drop between the river and bypass channel water surfaces, weir unit discharge, head on the weir and the estimated residual energy at the bypass water surface.

Table 4 - Lateral weir flow parameters

Weir Elevation= 1992.1
Weir Length= 150
Weir coefficient= 2

River Flow	River WSEL	Bypass WSEL	Difference	Unit Discharge	Head on Weir	$H_{residual}/H_{max}$ [1]
ft^3/s	ft	ft	ft	ft^3/s	ft	
10000	1992.8	1987.2	5.6	0.97	0.7	0.5
20000	1994.2	1989.7	4.5	5.62	2.1	0.83
30000	1995.3	1991.6	3.8	10.7	3.2	0.94
40000	1996.3	1993.1	3.2	16.0	4.3	0.95
70000	1998.8	1997.0	1.8	31.7	4.9	~1

Weir Elevation= 1992.1
Weir Length= 150
Weir coefficient= 3

River Flow	River WSEL	Bypass WSEL	Difference	Unit Discharge	Head on Weir	$H_{residual}/H_{max}$ [1]
ft^3/s	ft	ft	ft	ft^3/s	ft	
10000	1992.8	1987.2	5.5	1.4	0.7	0.52
20000	1994.2	1989.7	4.5	8.0	2.1	0.86
30000	1995.3	1991.6	3.7	15.3	3.2	0.95
40000	1996.2	1993.1	3.0	22.9	4.3	0.97
70000	1998.6	1997.0	1.6	45.2	4.9	~1

[1] Reference Boes and Hager (2003) "Design of stepped spillways", ASCE Journal of Hydraulics Engineering, Sept.
* River data at station 28062 (50 ft upstream of dam), bypass data at station 194.7 (station where LW flow enters).

This study does not provide detail on the merging of flows from the bypass channel, lateral weir and river. This will need to be investigated using physical and three dimensional numeric models. Limited 3-dimensional numerical flow modeling was conducted for this study to identify major flow patterns for developing the initial alignment of the bypass entrance and lateral weir option.

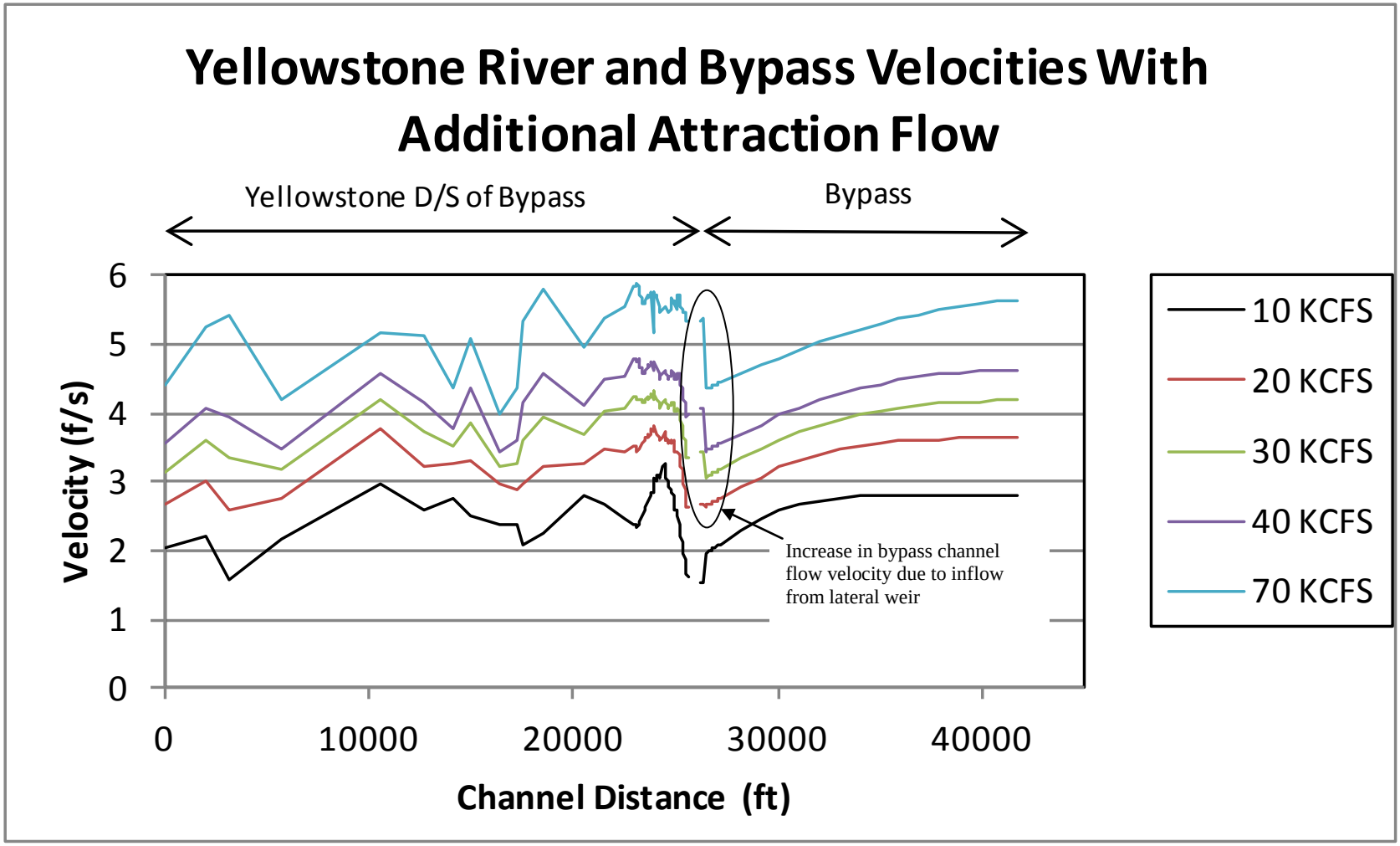


Figure 4 - Average channel velocity in the Yellowstone River downstream of the bypass entrance (left side) and in the bypass (right side) with additional attraction flow from lateral weir

CFD Modeling

Preliminary Flow3D[1] modeling of the bypass entrance with a lateral weir was conducted to determine major flow patterns associated with merging bypass channel flow, lateral weir flow and river flow. The model was not run to stabilization and results should not be used to make any quantitative conclusions. Figure 5 shows a plan view of the velocity magnitudes in ft/s that occur at a river flow of 40,000 ft^3/s (upstream of the bypass exit). Although a course-grid model was used containing many assumptions, the complex interaction that occurs when the bypass re-enters the river for lateral weir option 1 suggests that favorable approach conditions to the bypass can be achieved with further analysis. Due to the limitations of CFD modeling to quickly look at multiple weir alignments it is recommended that a physical model be used to further analyze the bypass entrance conditions.

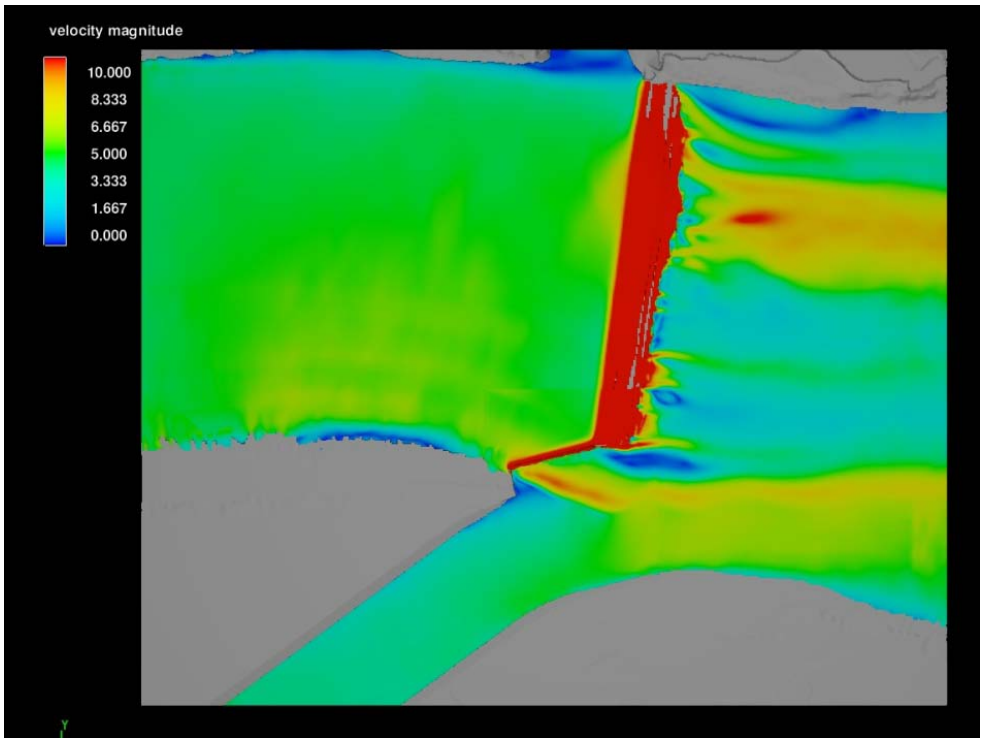


Figure 5 - Flow3D model of the fish bypass entrance and river confluence (flow is from left to right)

Drawings

Preliminary bypass channel alignments were provided by the Corps. Reclamation used the initial layouts and created a dynamic AutoCAD Civil3D model which allowed refinement of the entrance and exit geometries. Considering that the Corps uses different modeling programs and cannot open Civil3D files, the dynamic models were converted to standard AutoCAD files and

[1] a commercially available computation fluid dynamics (CFD) program

PDF's. Drawings include plan and section views for the bypass entrance without a lateral weir, bypass exit and two different configurations of the bypass entrance with a lateral weir. For the drawings, it was assumed that the new crest geometry will be placed in approximately the same location as the existing dam. All drawings can be found at the end of the report.

References

Bramblett, G.R., 1996, "Habitats and Movements of Pallid and Shovelnose Sturgeon in the Yellowstone and Missouri Rivers, Montana and North Dakota," PhD thesis, Biological Sciences, Montana State University-Bozeman

Elser, A. A., et al., July 1977, "The Effect of Altered Streamflow on Fish of the Yellowstone and Tongue Rivers, Montana," Montana Department of Natural Resources and Conservation Water Resources Division, Technical Report No. 8.

List of Drawings

Bypass Channel Entrance with no Lateral Weir

1. Fish Passage Inlet Sheet 1 – Plan
2. Sheet 2 – Sections 0+00 to 1+50
3. Sheet 3 – Sections 2+00 to 3+50
4. Sheet 4 – Sections 4+00 to 4+50

Bypass Channel Exit

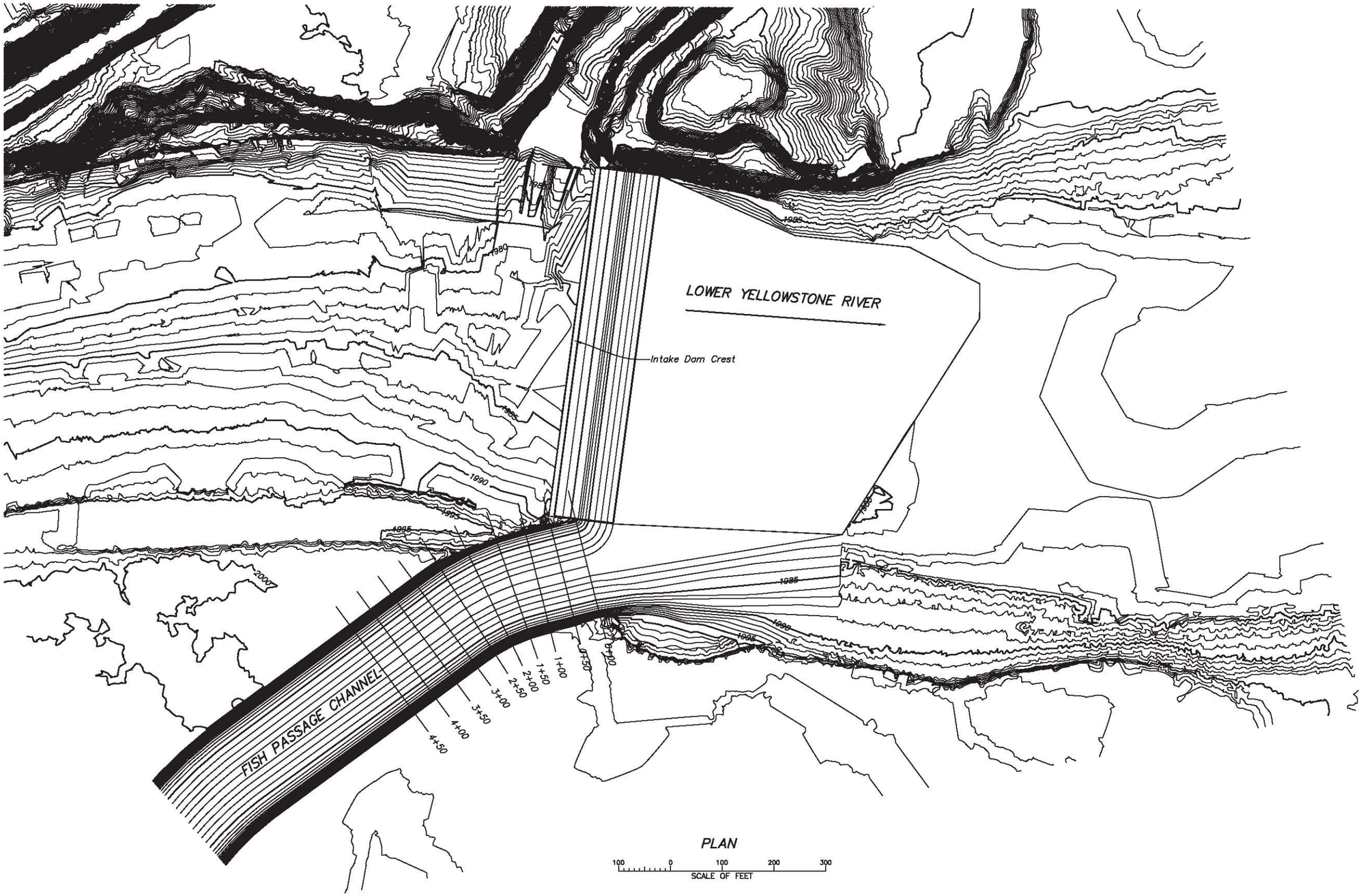
5. Fish Passage Outlet Sheet 1 – Plan
6. Sheet 2 – Sections 155+50 to 157+00
7. Sheet 3 – Sections 157+50 to 158+50
8. Sheet 4 – Sections 159+00 to 159+50

Bypass Channel Entrance with Lateral Weir Option 1

9. Fish Passage Option 1 Sheet 1 - Plan and Typical Section
10. Sheet 2 – Sections 0+00 to 0+75
11. Sheet 3 – Sections 1+00 to 1+50

Bypass Channel Entrance with Lateral Weir Option 2

12. Fish Passage Option 2 Sheet 1 - Plan and Typical Section
13. Sheet 2 – Sections 0+00 to 0+75
14. Sheet 3 – Sections 1+00 to 1+50



PLAN

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE INLET

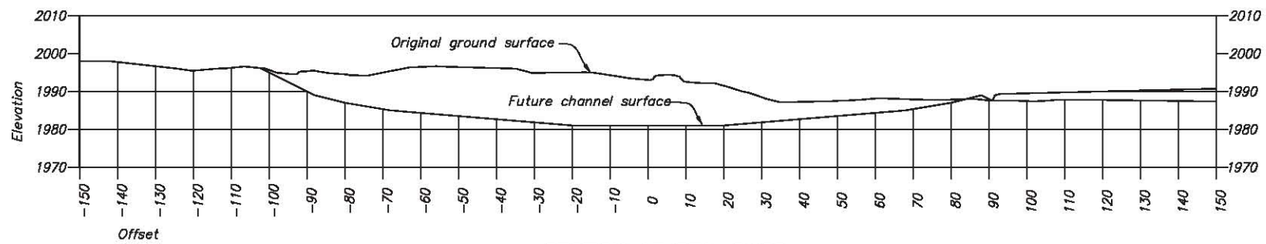
Use Only
Not For Distribution

DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME – TITLE
APPROVED PEER REVIEWER – NAME – TITLE
DENVER, COLORADO Dec. 20, 2011

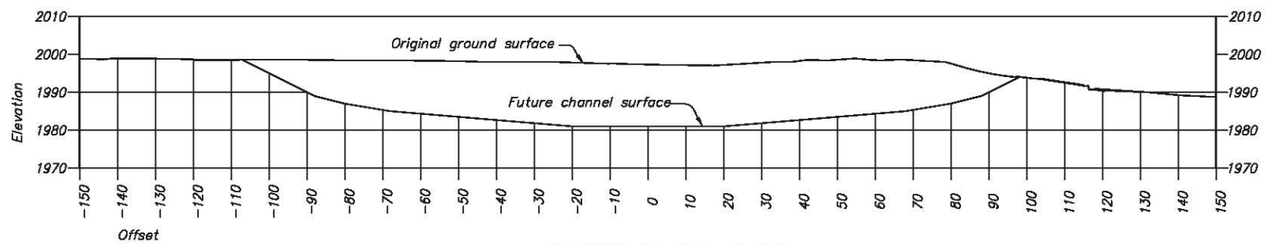
Drawing No. 1
SHEET 1 OF 4

DATE AND TIME PLOTTED
January 5, 2012 09:36
PLOTTED BY
JMORTENSEN

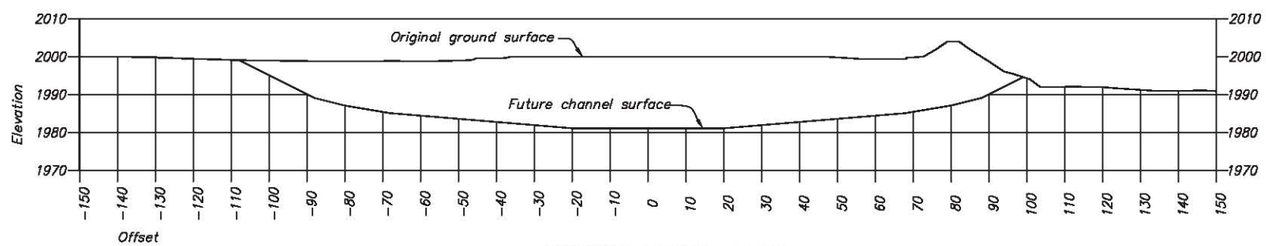
CADD SYSTEM
AutoCAD Rel. 18.0s (LMS Tech)
CADD FILENAME
Passage Channel Inlet.dwg



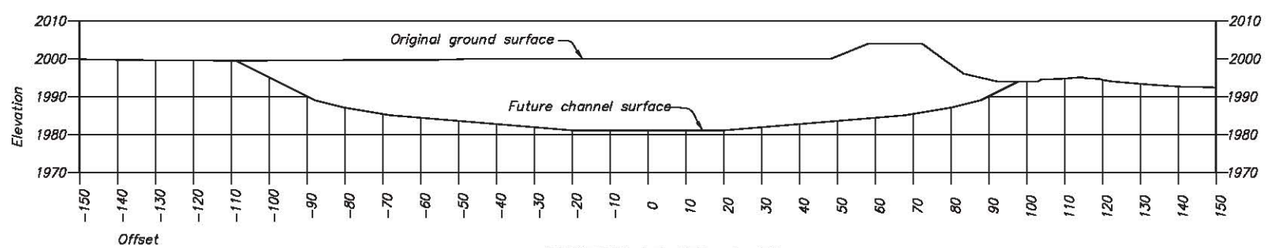
SECTION AT STA. 0+00



SECTION AT STA. 0+50



SECTION AT STA. 1+00



SECTION AT STA. 1+50

20 0 20 40 60
SCALE OF FEET

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE - INLET

Not For Distribution
For Use Only

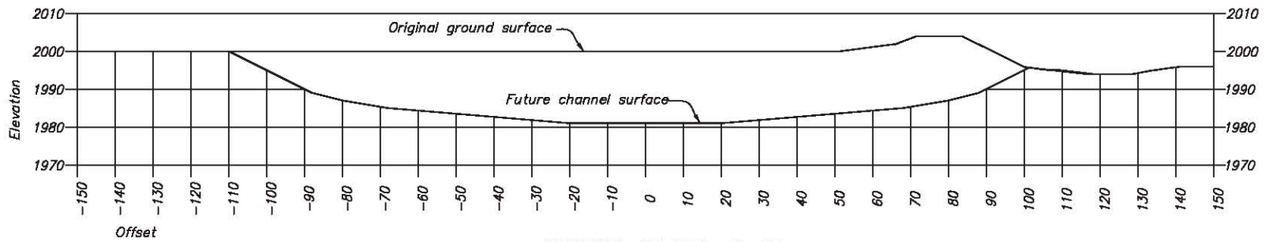
DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME – TITLE
APPROVED PEER REVIEWER – NAME – TITLE

DENVER, COLORADO Dec. 20, 2011

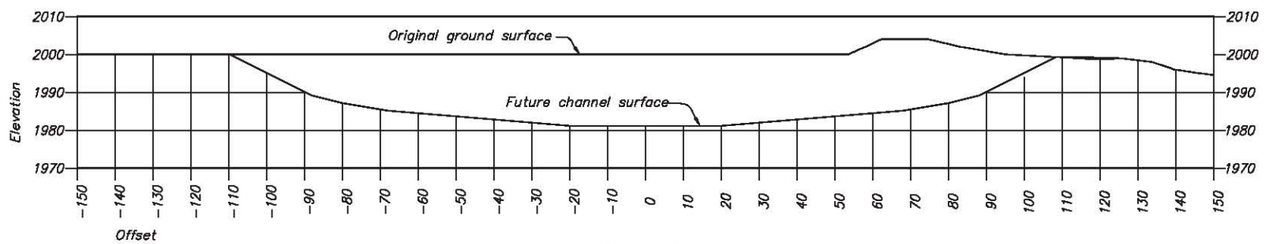
Drawing No. 2
SHEET 2 OF 4

DATE AND TIME PLOTTED
January 5, 2012 09:36
PLOTTED BY
JMCHRISSEN

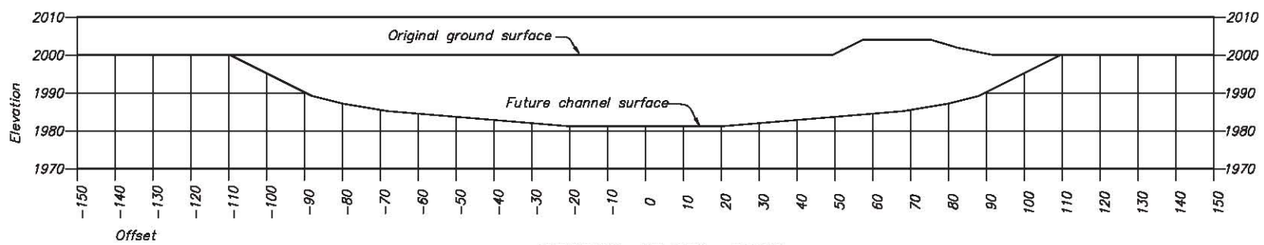
CADD SYSTEM
AutoCAD Rel. 18.0a (LMS Tech)
CADD FILENAME
Passage Channel Inlet.dwg



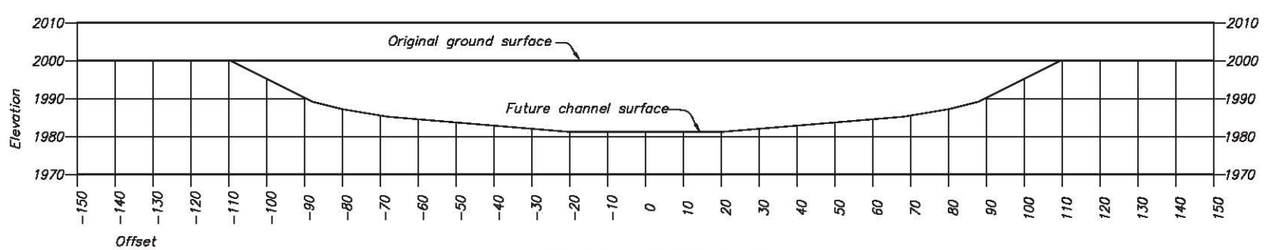
SECTION AT STA. 2+00



SECTION AT STA. 2+50



SECTION AT STA. 3+00



SECTION AT STA.3+50

20 0 20 40 60
SCALE OF FEET

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. Department of the Interior
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE - INLET

For Use Only
Not For Distribution

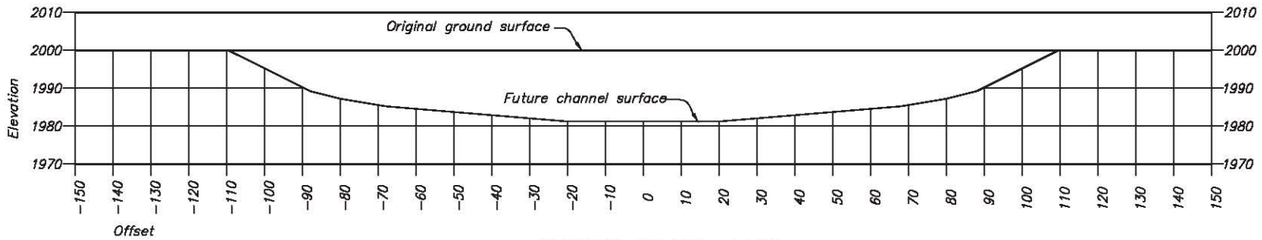
DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME – TITLE
APPROVED PEER REVIEWER – NAME – TITLE

DENVER, COLORADO Dec. 20, 2011

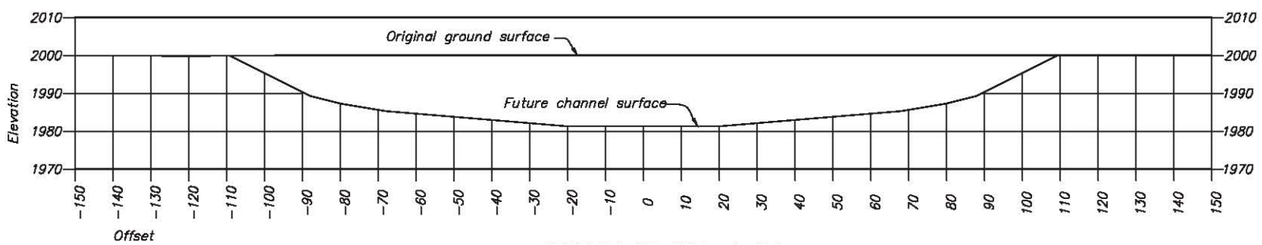
Drawing No. 3
SHEET 3 OF 4

DATE AND TIME PLOTTED
January 5, 2012 09:37
PLOTTED BY
JMCPETERSEN

CADD SYSTEM
AutoCAD Rel. 18.0s (LMS Tech)
CADD FILENAME
Passage Channel Inlet.dwg



SECTION AT STA. 4+00



SECTION AT STA. 4+50

20 0 20 40 60
SCALE OF FEET

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE / INLET

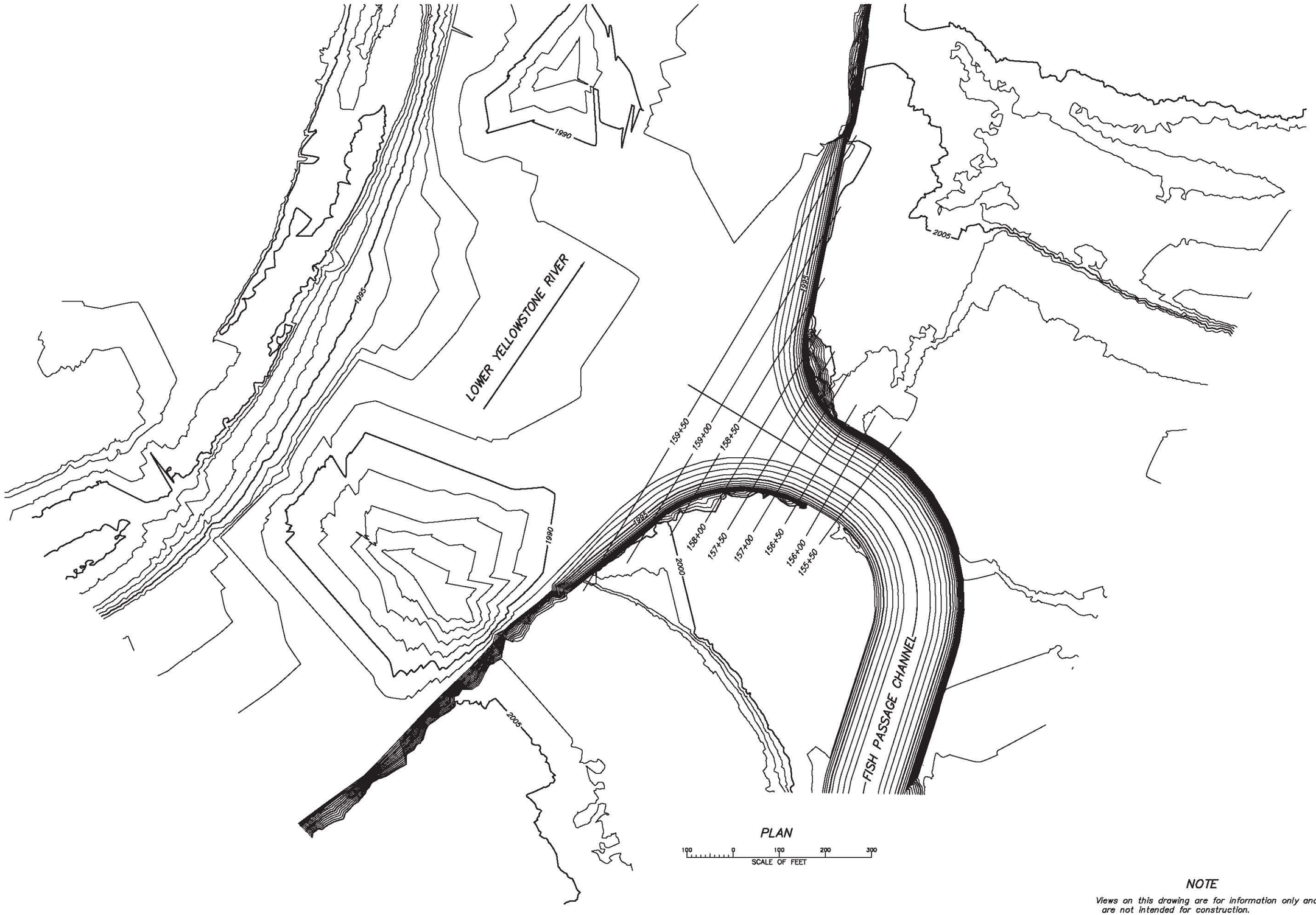
For Use Only
Not For Distribution

DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME - TITLE
APPROVED PEER REVIEWER - NAME - TITLE
DENVER, COLORADO Dec. 20, 2011

Drawing No. 4
SHEET 4 OF 4

DATE AND TIME PLOTTED
January 5, 2012 08:39
PLOTTED BY
JARTENSEN

CADD SYSTEM
AutoCAD Rel. 18.0a (LMS Tech)
CADD FILENAME
Passage Channel Inlet.dwg



PLAN

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE - OUTLET

Not For Use Only
For Distribution

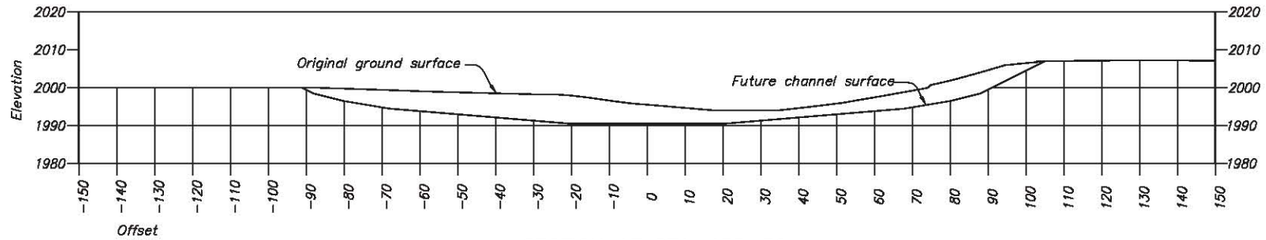
DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME – TITLE
APPROVED PEER REVIEWER – NAME – TITLE

DENVER, COLORADO Dec. 20, 2011

Drawing No. 5
SHEET 1 OF 4

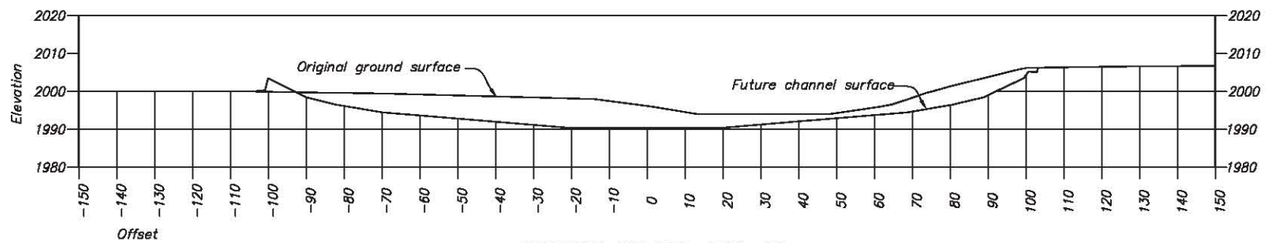
DATE AND TIME PLOTTED
January 5, 2012 08:32
PLOTTED BY
JAKRITENSEN

CADD SYSTEM
AutoCAD Rel. 18.0b (LMS Tech)
CADD FILENAME
Passage Channel Outlet.dwg



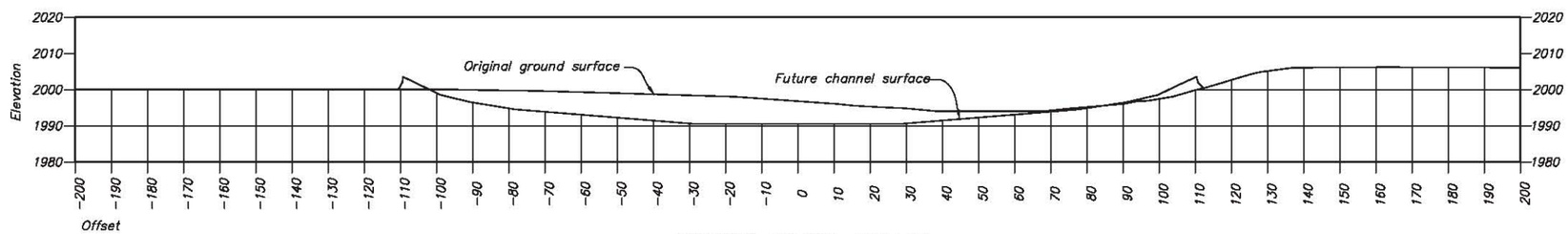
SECTION AT STA. 155+50

20 0 20 40 60
SCALE OF FEET



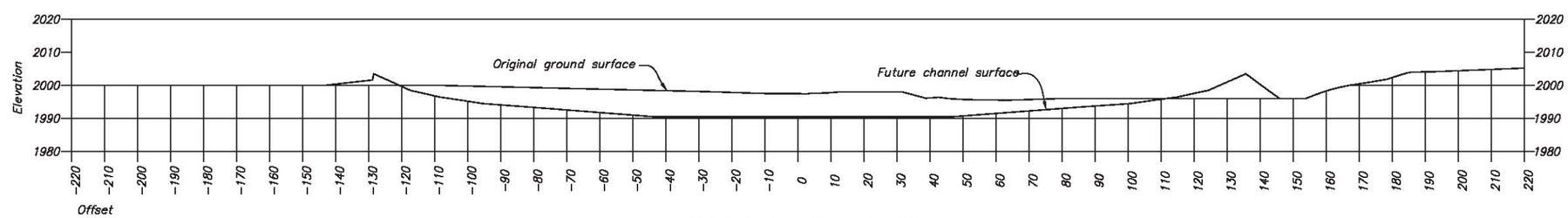
SECTION AT STA. 156+00

20 0 20 40 60
SCALE OF FEET



SECTION AT STA. 156+50

20 0 20 40 60
SCALE OF FEET



SECTION AT STA. 157+00

20 0 20 40 60
SCALE OF FEET

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER INTAKE DAM
FISH PASSAGE - OUTLET

For Not Use Only Distribution

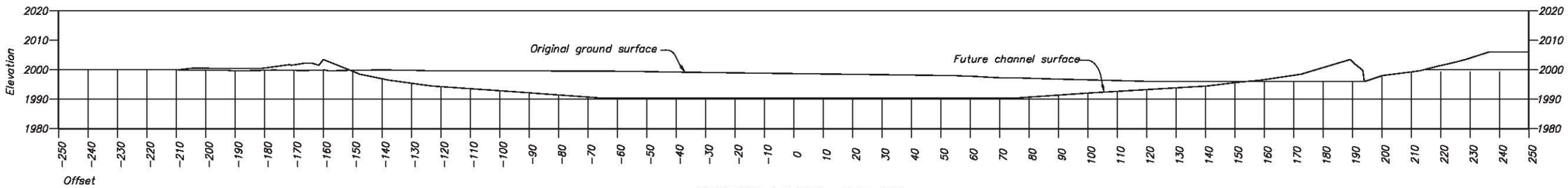
DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME - TITLE
APPROVED PEER REVIEWER - NAME - TITLE

DENVER, COLORADO Dec. 20, 2011

Drawing No. 6
SHEET 2 OF 4

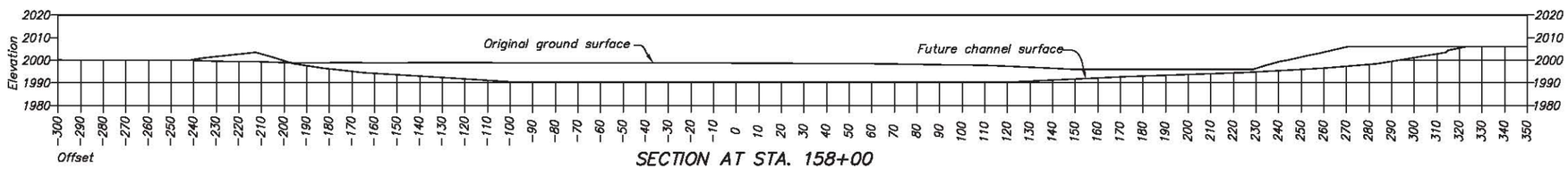
DATE AND TIME PLOTTED
January 5, 2012 09:51
PLOTTED BY
JMCHRISSEN

CADD SYSTEM
AutoCAD Rel. 18.0s (LMS Tech)
CADD FILENAME
Passage Channel Outlet.dwg



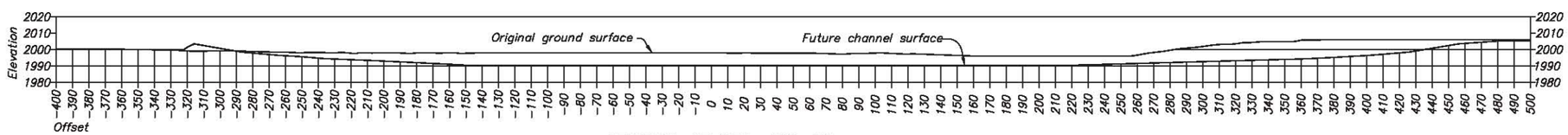
SECTION AT STA. 157+50

SCALE OF FEET



SECTION AT STA. 158+00

SCALE OF FEET



SECTION AT STA. 158+50

SCALE OF FEET

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. Department of the Interior
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE - OUTLET

For Use Only
Not For Distribution

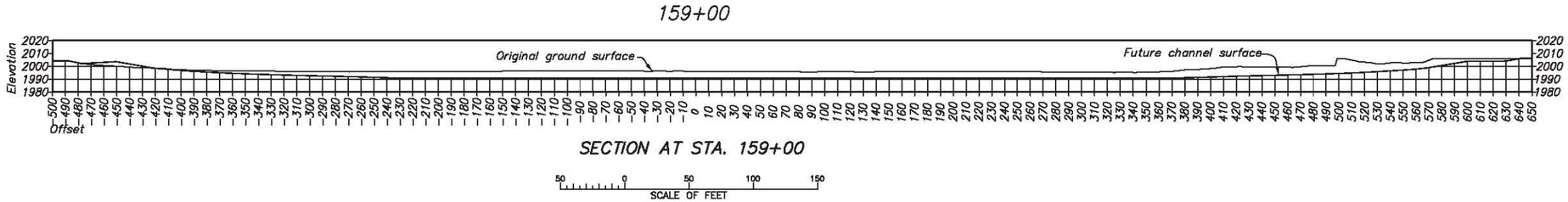
DESIGNED
DRAWN
CHECKED
TECH. APPR. — NAME – TITLE
APPROVED — PEER REVIEWER – NAME – TITLE

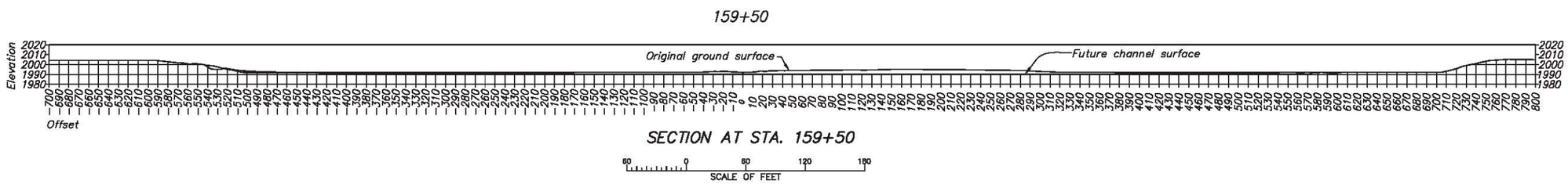
DENVER, COLORADO Dec. 20, 2011

Drawing No. 7
SHEET 3 OF 4

DATE AND TIME PLOTTED
January 5, 2012 09:52
PLOTTED BY
JMCHRISSEN

CADD SYSTEM
AutoCAD Rel. 18.0s (LMS Tech)
CADD FILENAME
Passage Channel Outlet.dwg





NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE - OUTLET

For Use Only
Not For Distribution

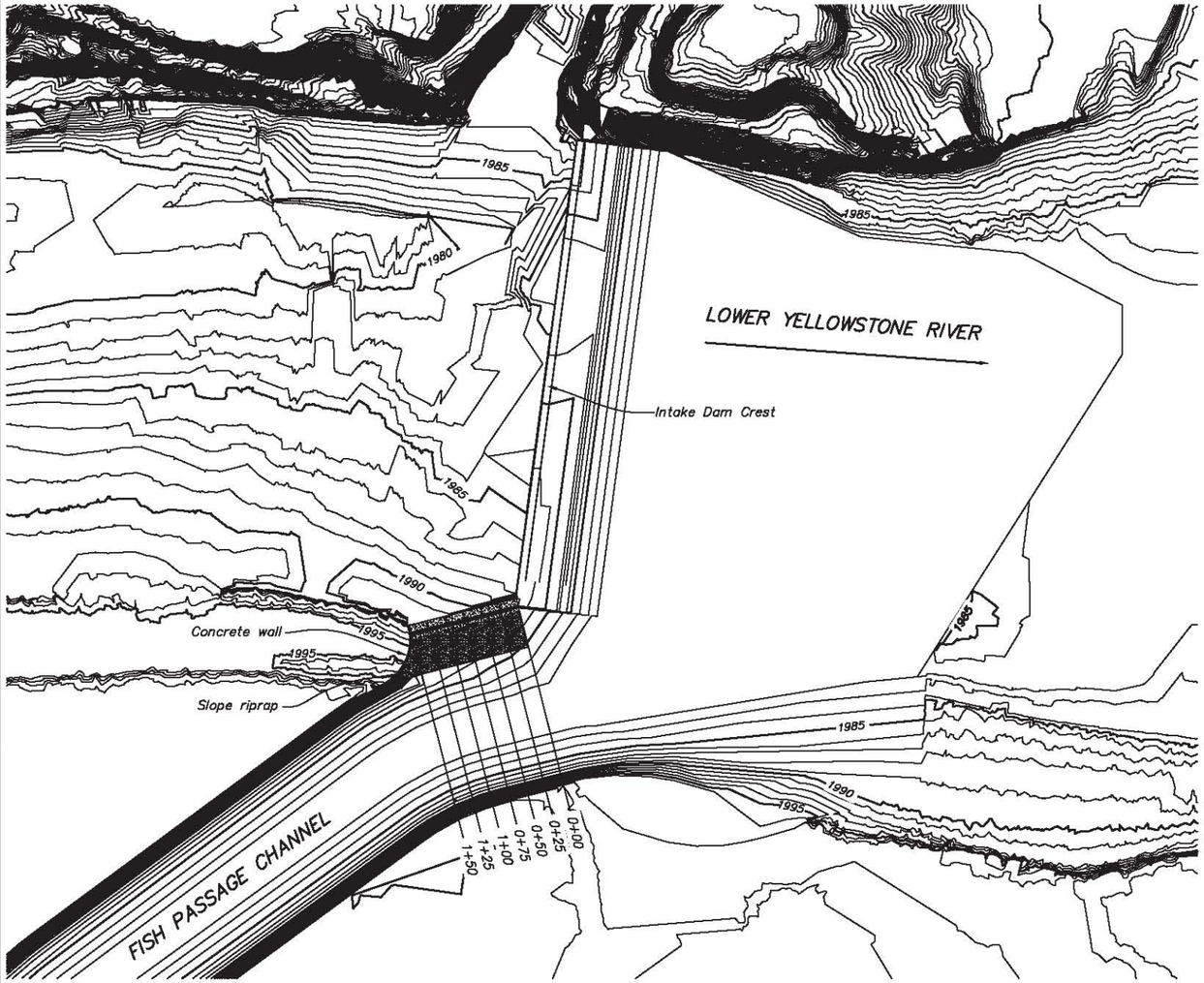
DESIGNED
DRAWN
CHECKED
TECH. APPR. — NAME – TITLE
APPROVED — PEER REVIEWER – NAME – TITLE

DENVER, COLORADO Dec. 20, 2011

Drawing No. 8
SHEET 4 OF 4

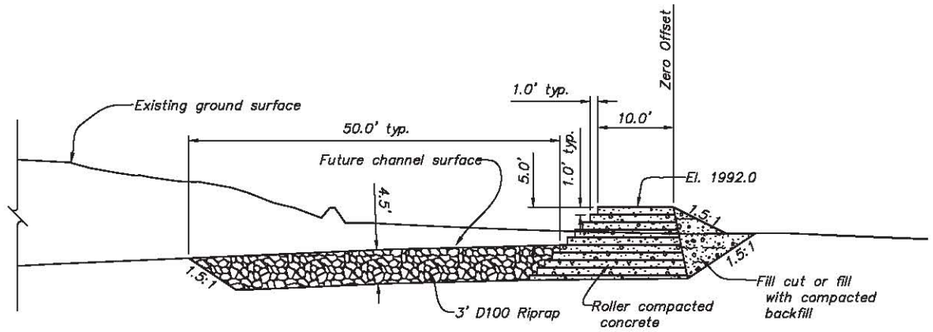
DATE AND TIME PLOTTED
January 5, 2012 09:52
PLOTTED BY
JMCHRISSEN

CADD SYSTEM
AutoCAD Rel. 18.0s (LMS Tech)
CADD FILENAME
Passage Channel Outlet.dwg



PLAN

100 0 100 200 300
SCALE OF FEET



TYPICAL SECTION

(Not to scale)

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE - OPTION 1

Not For Distribution

For Use Only

DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME - TITLE
APPROVED PEER REVIEWER - NAME - TITLE

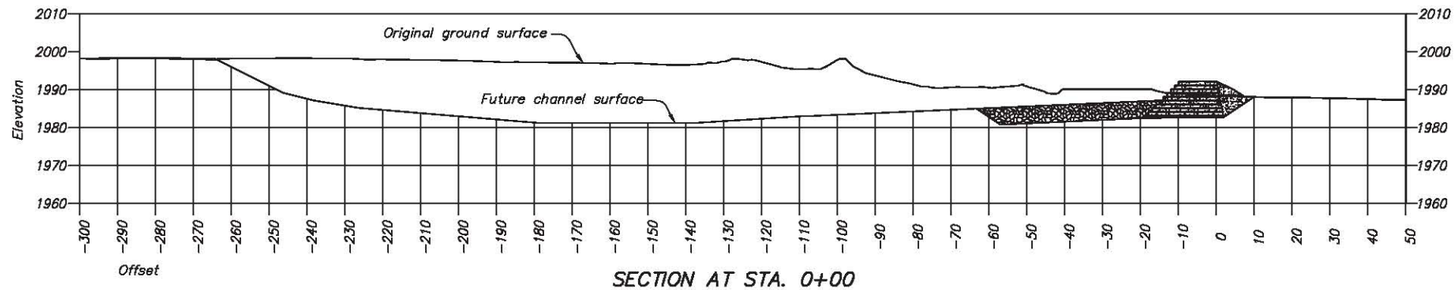
DENVER, COLORADO Dec. 20, 2011

Drawing No. 9

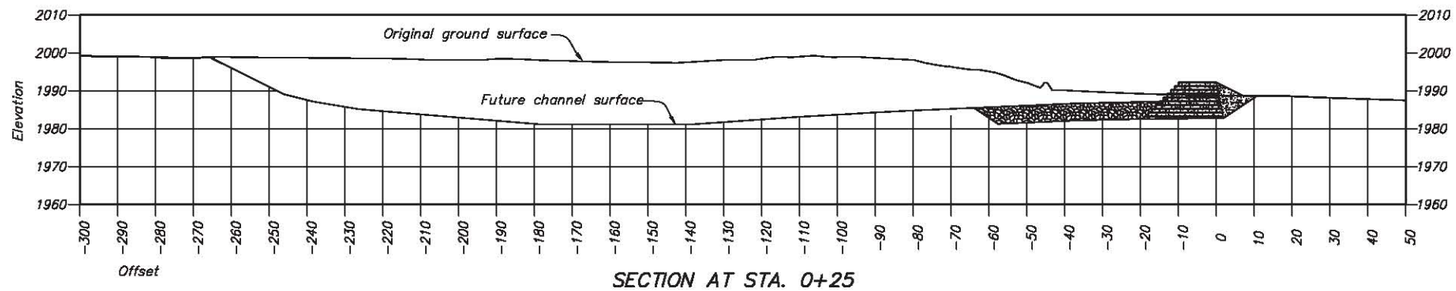
SHEET 1 OF 3

DATE AND TIME PLOTTED
January 5, 2012 10:10
PLOTTED BY
JMORTENSEN

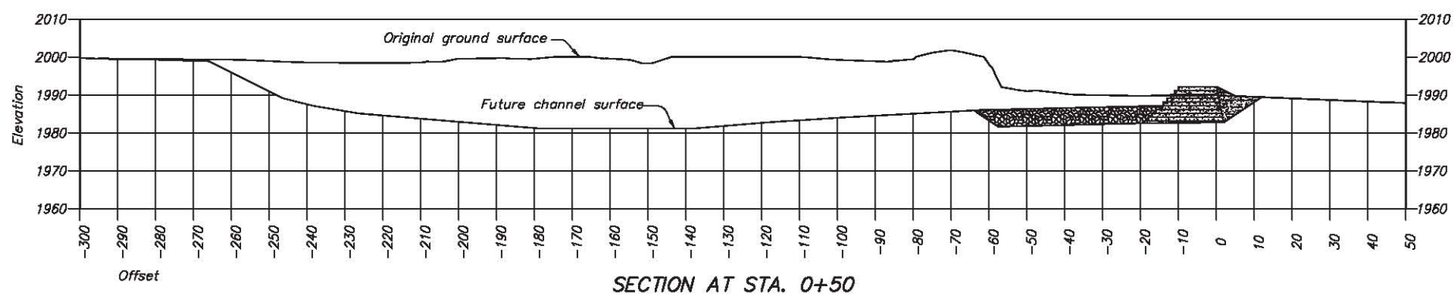
CADD SYSTEM
AutoCAD Rel. 18.0s (LMS Tech)
CADD FILENAME
Lot_Weir_Option1.dwg



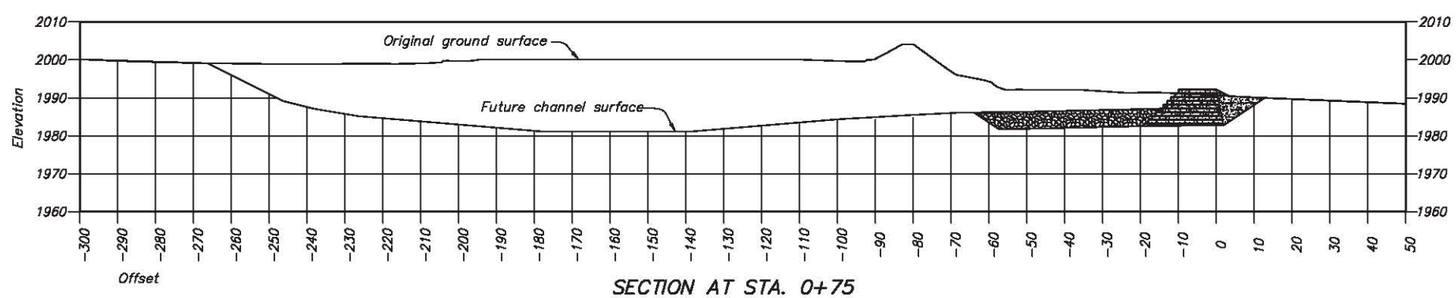
SECTION AT STA. 0+00



SECTION AT STA. 0+25



SECTION AT STA. 0+50



SECTION AT STA. 0+75

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE - OPTION 1

For Use Only
Not For Distribution

DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME - TITLE
APPROVED PEER REVIEWER - NAME - TITLE

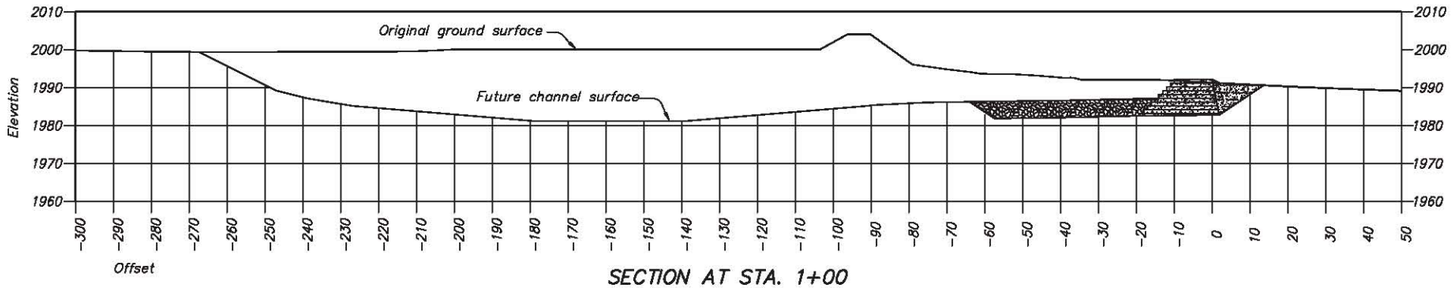
DENVER, COLORADO Dec. 20, 2011

Drawing No. 10

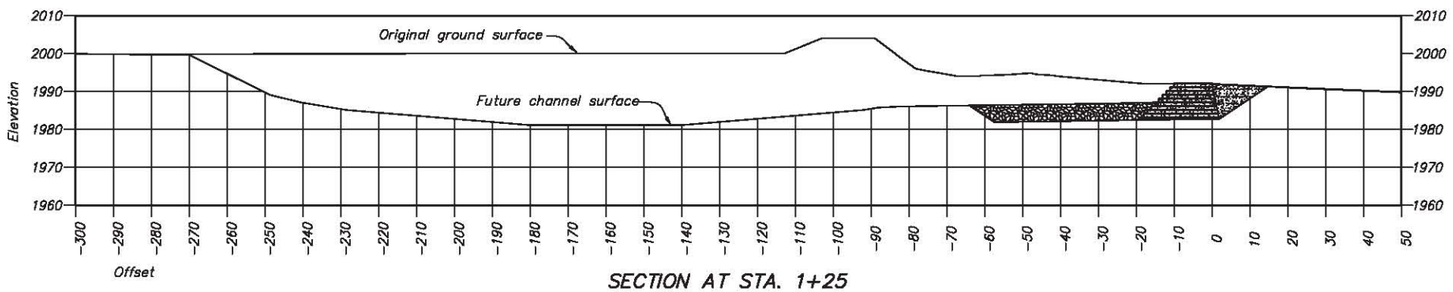
SHEET 2 OF 3

DATE AND TIME PLOTTED
January 5, 2012 10:11
PLOTTED BY
JMORTENSEN

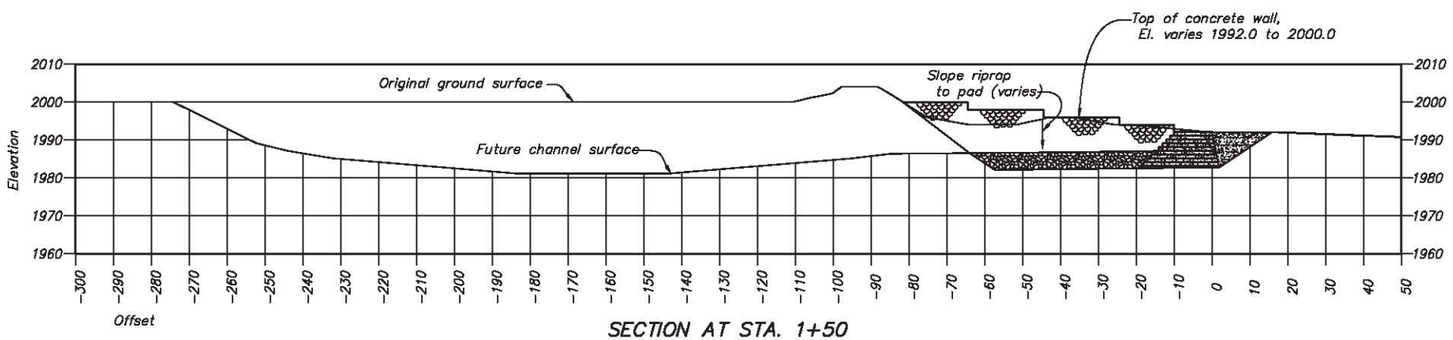
CADD SYSTEM
AutoCAD Rel. 18.0s (LMS Tech)
CADD FILENAME
Lot_Weir_Option1.dwg



SECTION AT STA. 1+00



SECTION AT STA. 1+25



SECTION AT STA. 1+50

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. Department of the Interior
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE - OPTION 1

For Not Use Only For Distribution

DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME - TITLE
APPROVED PEER REVIEWER - NAME - TITLE

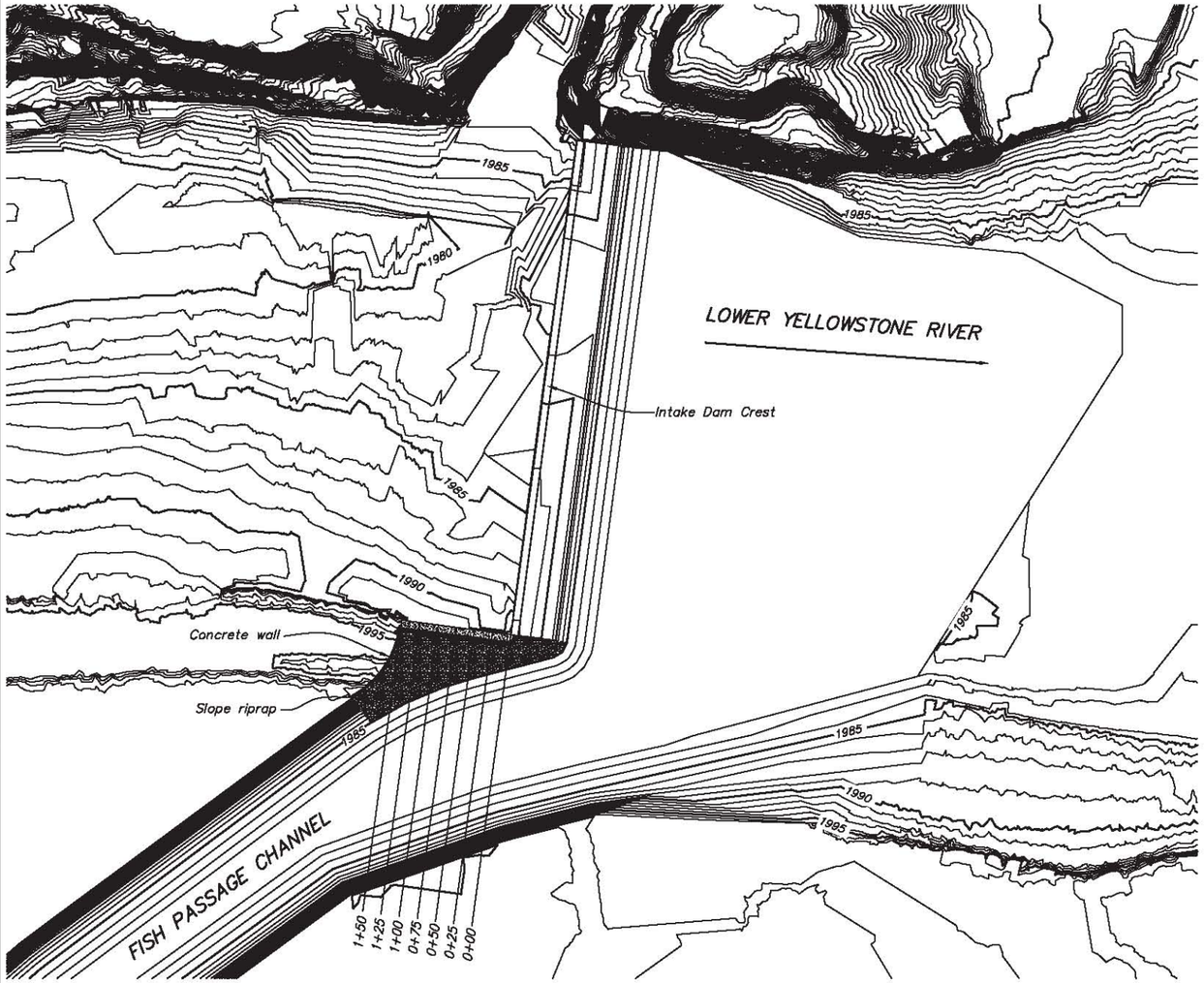
DENVER, COLORADO Dec. 20, 2011

Drawing No. 11

SHEET 3 OF 3

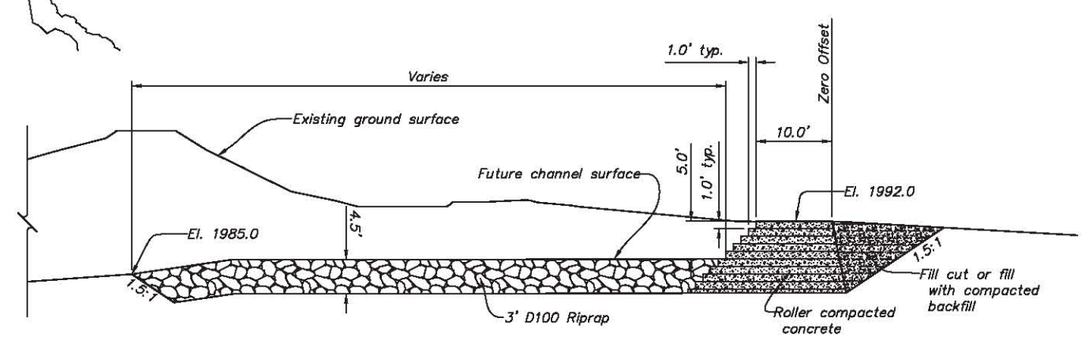
DATE AND TIME PLOTTED
January 5, 2012 10:11
PLOTTED BY
JAKRITENSEN

CADD SYSTEM
AutoCAD Rel. 18.0s (LMS Tech)
CADD FILENAME
LoYc_Inter_Option1.dwg



PLAN

100 0 100 200 300
SCALE OF FEET



TYPICAL SECTION
(Not to scale)

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE - OPTION 2

For Use Only
Not For Distribution

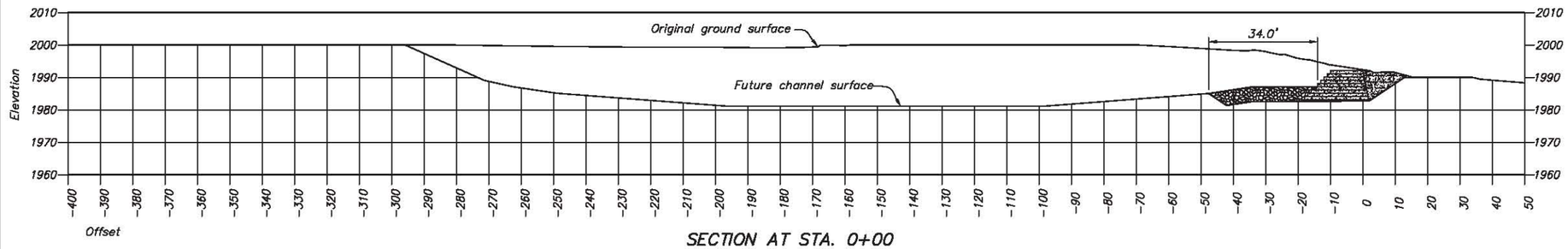
DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME – TITLE
APPROVED PEER REVIEWER – NAME – TITLE

DENVER, COLORADO Dec. 20, 2011

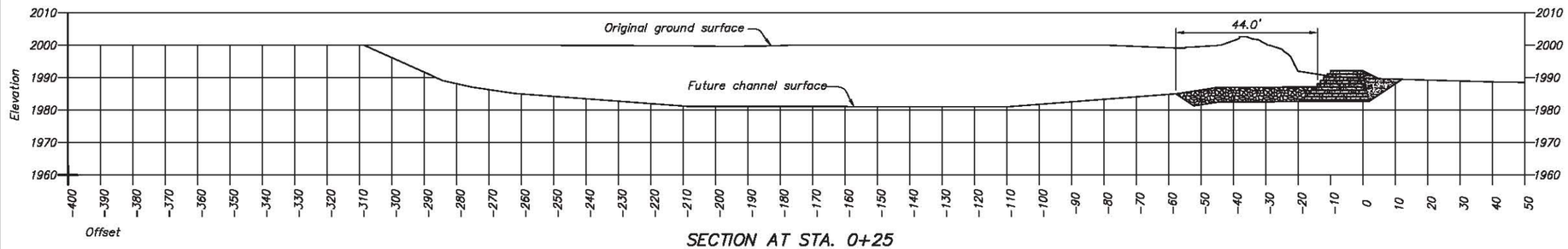
Drawing No. 12
SHEET 1 OF 3

DATE AND TIME PLOTTED
January 5, 2012 - 10:13
PLOTTED BY
JMORTENSEN

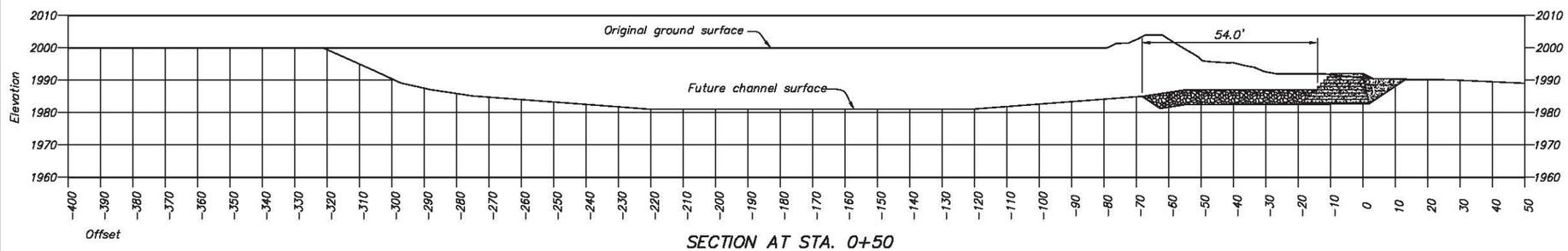
CADD SYSTEM
AutoCAD Rel. 18.0s (LMS Tech)
CADD FILENAME
LoC_Wer_Option2.dwg



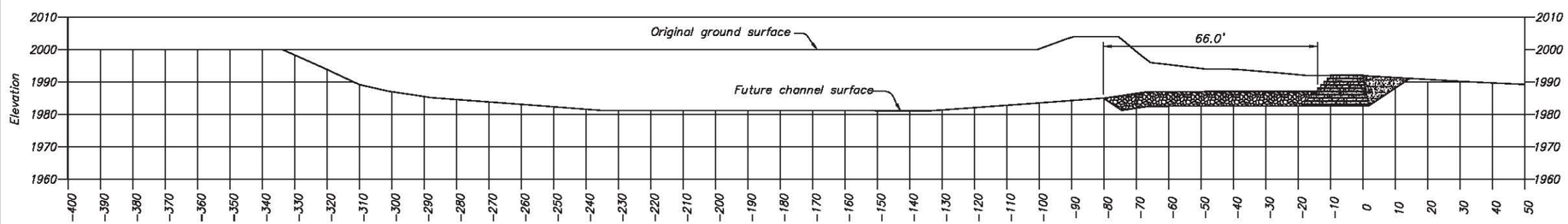
SECTION AT STA. 0+00



SECTION AT STA. 0+25



SECTION AT STA. 0+50



SECTION AT STA. 0+75

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE - OPTION 2

Draft
Not For Distribution
Use Only

DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME - TITLE
APPROVED PEER REVIEWER - NAME - TITLE

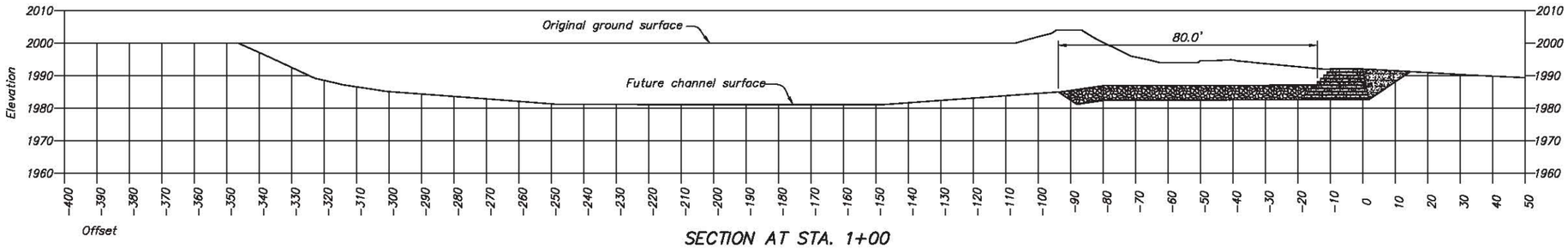
DENVER, COLORADO Dec. 20, 2011

Drawing No. 13

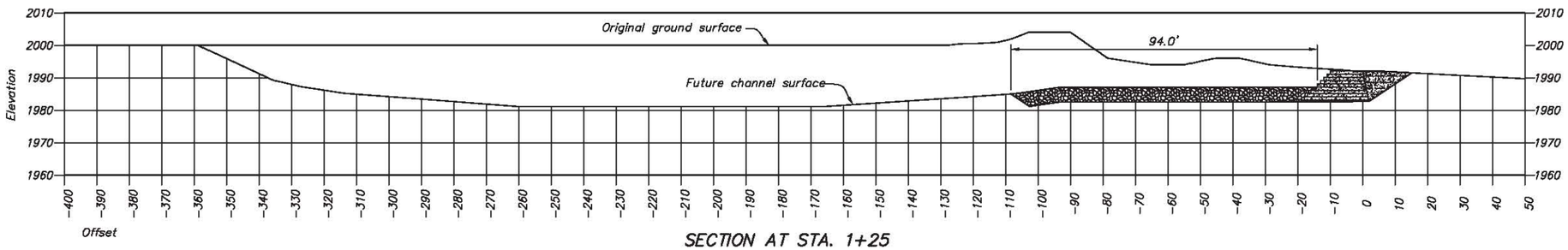
SHEET 2 OF 3

DATE AND TIME PLOTTED
January 5, 2012 10:14
PLOTTED BY
JMORTENSEN

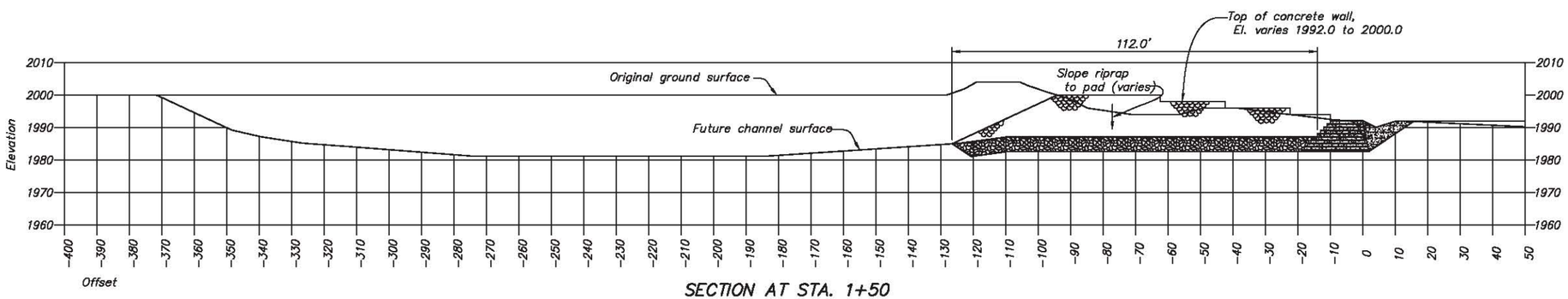
CADD SYSTEM
AutoCAD Rel. 18.0s (LMS Tech)
CADD FILENAME
Lot_Weir_Option2.dwg



SECTION AT STA. 1+00



SECTION AT STA. 1+25



SECTION AT STA. 1+50

NOTE

Views on this drawing are for information only and are not intended for construction.

RECLAMATION
Managing Water in the West

ALWAYS THINK SAFETY

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LOWER YELLOWSTONE RIVER
INTAKE DAM
FISH PASSAGE - OPTION 2

Not For Distribution

For Use Only

DESIGNED
DRAWN
CHECKED
TECH. APPR. NAME - TITLE
APPROVED PEER REVIEWER - NAME - TITLE

DENVER, COLORADO Dec. 20, 2011

Drawing No. 14

SHEET 3 OF 3

DATE AND TIME PLOTTED
January 5, 2012 10:14
PLOTTED BY
JMORTENSEN

CADD SYSTEM
AutoCAD Rel. 18.0s (LMS Tech)
CADD FILENAME
Lot_Weir_Option2.dwg