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St. Mary Diversion Dam – Case Study of a 100 year Old Diversion

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ABSTRACT

After 100 years of service, the St. Mary Diversion Dam is being replaced with a new design that will provide more effective fish passage and protection. The diversion is located in northern Montana, adjacent to the east side of Glacier National Park. It diverts water from the St. Mary River 1.21 km (0.75 mile) downstream of Lower St. Mary Lake. The existing 60.35-meter-long and 1.83-meter-high (198-foot-long and 6-foot-high) concrete weir diverts up to 24 cubic meters per second (850 cubic feet per second) design flow from the St. Mary River into the North Fork of the Milk River through a 46.67-km (29-mile) long canal, siphon, and drop system. The existing facility, which is maintained and operated by the U.S. Bureau of Reclamation (Reclamation), was completed in 1915 and is in need of replacement. The Endangered Species Act (ESA) listed species that have been adversely affected by limited passage and entrainment into the canal. The St. Mary Diversion and Milk River Irrigation project have been identified as the primary threat to Bull trout habitat in the St. Mary River drainage. Recovery efforts to restore Bull trout habitat in the St. Mary River drainage requires that Reclamation provide effective Bull trout passage and protection at the St. Mary Diversion. This paper presents a short history of the St. Mary Diversion and Milk River Irrigation project, which includes collaborations with all interested parties as well as modeling efforts that were used to enhance the design of the replacement structure to provide the best situation for Bull trout recovery without limiting diversion capability.

***Keywords:** fish passage, protection, diversion, canal, screen, dam, physical modeling*

1. INTRODUCTION

The St. Mary Diversion Dam is part of the Bureau of Reclamation's (Reclamation) Milk River Project in north-central Montana. Located near Babb, Montana, the diversion and canal were constructed in 1915 on the St. Mary River, 1.21 km (0.75 mile) downstream from Lower St. Mary Lake. The dam consists of a 60.35-meter-long and 1.83-meter-high (198-foot-long and 6-foot-high) concrete weir and sluiceway. A design discharge of 24 cubic meters per second (850 cubic feet per second) of water is diverted from the west side of the river upstream of the dam through a 46.67-km (29-mile) long canal. The canal transports the water through two large steel-plated siphons and five large concrete drop structures before it discharges into the North Fork Milk River (Figure 1).

In 1999, the U.S. Fish and Wildlife Service (FWS) listed Bull trout (*Savelinus confluentus*) as a threatened species under the Endangered Species Act (ESA). When listed, FWS concluded that Bull trout native to the St. Mary River drainage are negatively affected by operation of the Reclamation Milk River Irrigation Project (Mogen 2011). More specifically, the St. Mary Diversion dam was cited as a known seasonal barrier to upstream migration of Bull trout (Mogen and Kaeding 2005a, 2005b and 2008) and a threat to the species due to the entrainment of fish during the irrigation season (Wagner and Fitzgerald 1995, Mogen and Kaeding 2000 and 2002). Fish entrained into the canal are either passed to the North Fork of the Milk River or remain in the canal until the gates are shut and the canal is dewatered during the non-irrigation season.

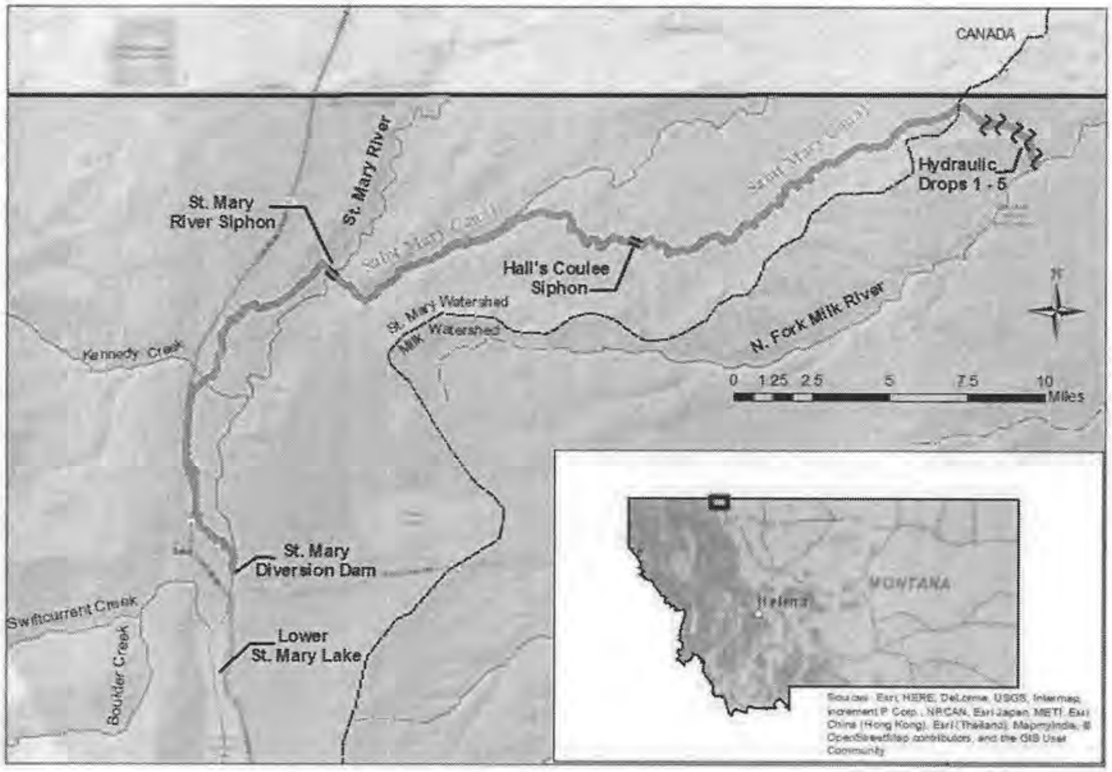

Figure 1. Overview map of the St. Mary Diversion and related features.

To help aid growth of Bull trout and other species in the Milk River System, Reclamation began investigations on how to reduce the impact the St. Mary Diversion Dam and Canal has on Bull trout in the Milk River System. This paper discusses the history of the St. Mary Diversion Dam and Headworks including the condition of the existing facility and several of the recommended mitigation plans to provide fish screening and passage at the facility while still maintaining diversion flow rates. This paper is not a comprehensive list of all design options that have been evaluated over the past 15 years.

2. DESCRIPTION OF EXISTING FACILITY

The St. Mary Diversion Dam is a concrete ogee weir with an overhead abandoned 3-span truss bridge (one span has been removed Figure 2). The spillway is a concrete overflow structure that consists of an uncontrolled weir and downstream horizontal slab. The spillway is ungated and has no mechanical features but is subdivided into two equal sections by a concrete bridge pier on which two abandoned 29.72-meter (97.5-foot) Pratt trusses span the crest of the spillway. Each section of the spillway weir is 28.9 meters wide (94 feet 10 inches). The concrete spillway weir crest is elevation 1362.76 m (4471.0 ft). The weir crest elevation was raised to elevation 1363.07 m (4472.0 ft) by mounting 0.31 m (1 ft) high weir-boards on top of the entire spillway crest. Figure 3 provides an overhead view of the spillway from the upstream channel. The sluiceway is located to the left of the spillway and consists of six openings with inverts at elevation 1361.24 m (4466.0 ft) controlled by 0.1- by 0.1-meter (4- by 4-inch) stop planks (Figure 4). The St. Mary Canal headworks is located on the left abutment and is controlled by eight 1.52- by 1.68-meter (5- by 5.5-foot) headgates with gate sills at elevation 1361.24 m (4466.0 ft) (Figure 6). The headworks are a concrete structure 17.98 meters (59 feet) wide and 6.71 meters (22 feet) long, with an upstream weir in front of the gates with a crest at elevation 1361.54 m (4467.0 ft).

The 46.67-km-long (29-mile) St. Mary Canal was constructed between 1907 and 1915. The unlined canal was designed to convey 24 cubic meters per second (850 cubic feet per second) at a flow depth of 2.74 meters (9 feet). The canal was excavated to a bottom width of 7.92 meters (26 feet) with 2:1 side slopes at a channel invert slope of 0.000095 (Interior 1981). The dam is used to divert water into the canal from March through September. During the non-diversion period, the sluiceways are opened and canal headgates are closed. The canal was designed to convey 24 m^3/s (850 ft^3/s); however, the condition of the canal limits diversion to a maximum of 18.41 m³/s (650 ft³/s). During March and early April, all river flow in excess of about 2.83 m³/s (100 ft³/s) is typically diverted. From June to August, diversions often reach 75 percent of total river flow. Diversion decreases sharply in late August and September (Mefford 2003).

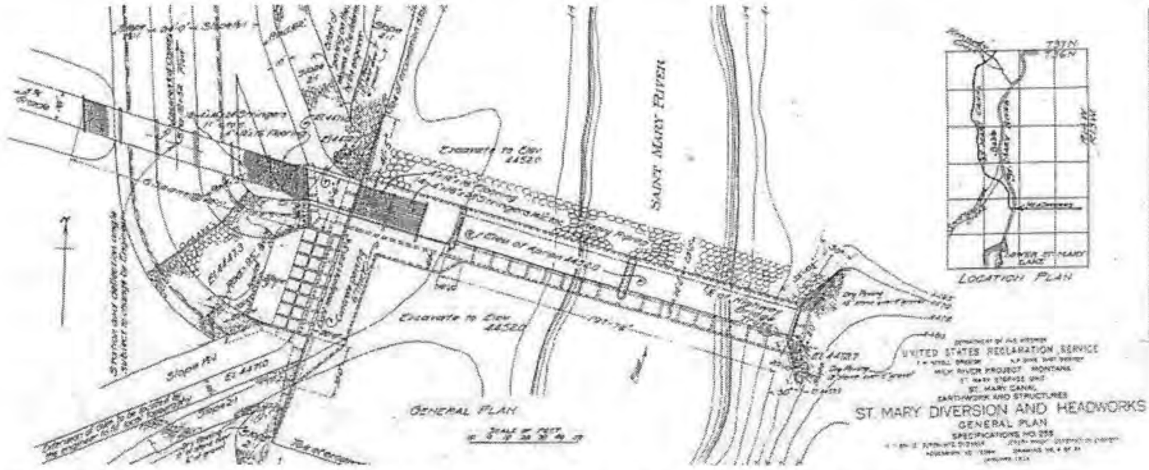

Figure 2. Original plan view drawing of the existing St. Mary Diversion Dam and Headworks (January 1914 – note: elevations are based on project datum that is approximately 4.27 meter (14 feet) lower than NAVD88)

Figure 3. Existing St. Mary Dam Diversion weir, sluiceway and abandoned bridge during low flow fall season (view is from upstream left bank)

Figure 4. St. Mary Diversion sluiceway gates (view is from upstream left bank, standing on top of the headworks structure)

Figure 5. St. Mary Diversion headworks structure (view of from downstream of the headworks, flow is towards reader)

Recent examinations of the 100-year-old diversion dam, headworks, and canal revealed substantial freeze-thaw damage to exposed concrete surfaces. Concrete core samples taken from the piers on the dam and sluiceway indicated that the condition of the concrete is very poor where exposure to ice and frequent freeze-thaw cycles have degraded the strength (Mefford 2003). Based on available inspection data and visits to the structure, the weir (Figure 6), abutments (Figure 7), piers (Figure 8), sluiceways (Figure 9), and diversion headworks will likely all require demolition and replacement in the near future. Recently, some modifications and repairs to the facility have been made that will prevent catastrophic failure of the structures.

Figure 6. St. Mary Diversion weir concrete failure and exposed rebar.

Figure 7. St. Mary Diversion right abutment damage and exposed rebar.

Figure 8. Concrete degradation on the downstream end of piers surrounding sluice bays.

Figure 9. Concrete degradation upstream end of piers surrounding sluice bays.

3. TIMELINE OF PROJECT DECISIONS

Over the past 15 years, Reclamation has been working with all interested stake holders to help protect the threatened Bull trout at the St. Mary Diversion. This section describes some of the early concepts that were evaluated along with some of the design decisions that have shaped the project. This is not a comprehensive list of events and concepts.

3.1. Early Design Concepts

Mefford (2003) conducted a conceptual design study and outlined two different concepts. Concept 1 recommended rehabilitating the diversion weir and replacing the headworks and sluiceway (Figure 10). Concept 2 recommended replacing all the existing structures (Figure 11). Both concepts included fish screens to prevent entrainment in the canal and a rock type fishway to allow passage over the dam. Both concepts proposed using a flat plate fish screen in the canal with a bypass at the end of the screen to return fish to the river. Main features were intended to maintain approach velocities of 0.12 m/s (0.4 ft/s), provide a 0.31-m (1-ft) sill on the bottom of the screen, and limit fish exposure to the screen to 60 seconds or less. The 0.31 m (1-ft) sill was meant to provide better protection to the bottom-oriented behavior of Bull trout (Beyers and Bestgen 2002). The rock-type fishway for both options would provide passage on river right by extending a rock fishway at a 3.5 percent slope to approximately 45.72 meters (150 feet) downstream of the weir. The difference between the two options was the extent to which the existing weir structure was rehabilitated or replaced. Each design was sized to allow flows of 18.41 m^3/s (650 ft^3/s) (current canal maximum), 24.07 m^3/s (850 ft^3/s) (original design), and 28.32 m^3/s (1000 ft^3/s) (increased capacity) into the canal. 2003 costs for construction of each concept was estimated to between \$6.9M and \$10M, depending on which was chosen.

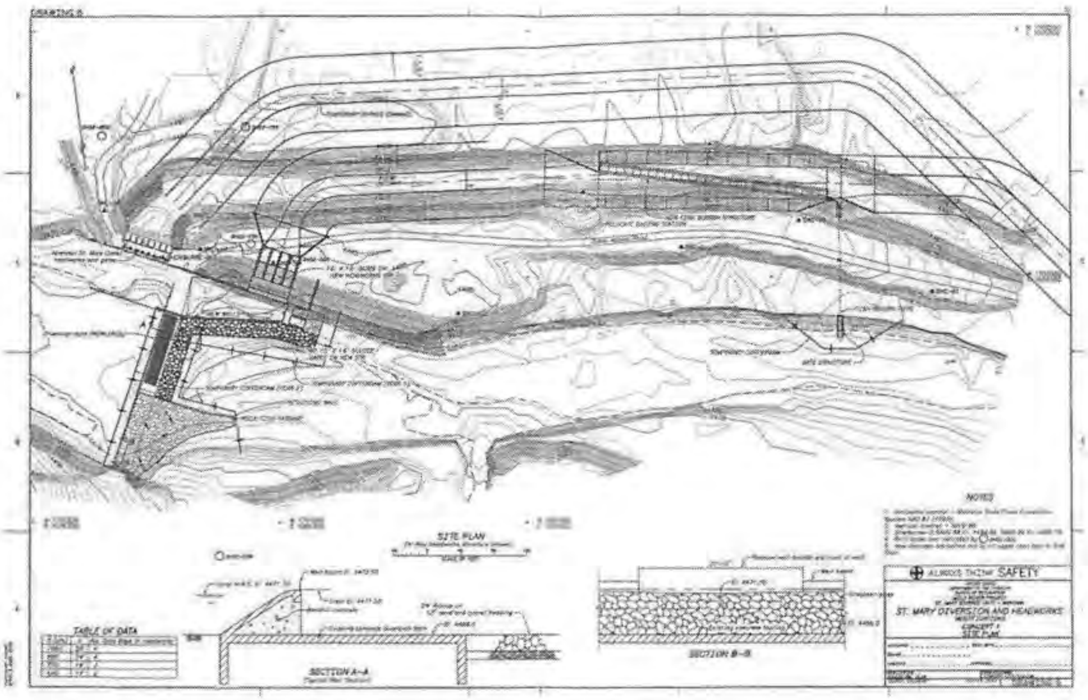

Figure 10. St. Mary Diversion rehabilitation concept 1 as presented by Mefford (2003).

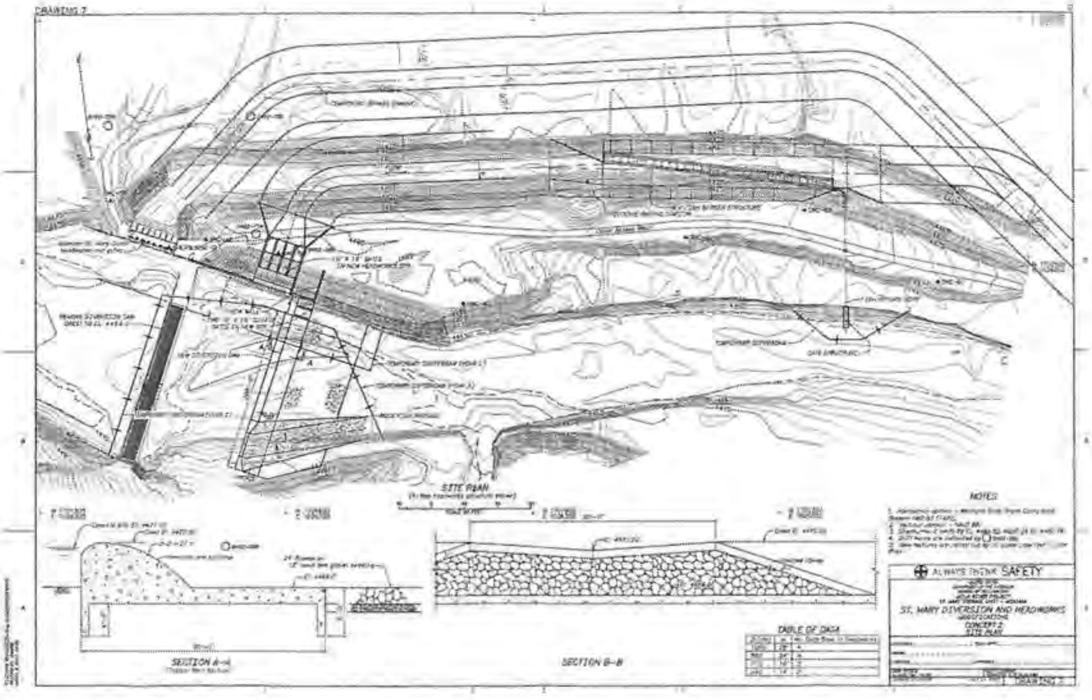

Figure 11. St. Mary Diversion rehabilitation concept 2 as presented by Mefford (2003).

Since the 2003 concepts, many other configurations were investigated by a wide range of individuals and groups. TD&H Engineering Consultants (2006) provided a wide range of alternatives to repair/replace the existing diversion and canal; included in their report are costs and recommendations.

More recently, Reclamation's Montana Area Office (MTAO) funded Reclamation's Technical Service Center (TSC) to develop a 100% design and specification package to allow replacement of the existing diversion facility. The TSC has worked in conjunction with MTAO, FWS, Blackfeet Nation Tribe, Montana Department of Natural Resources and Conservation (DNRC), Milk River Irrigators, St. Mary Rehabilitation Working Group, and many other stake holders to develop a design that met everyone's expectations and requirements. Team discussions and design reviews suggest as many as 6 different diversion and headwork options. Notable designs included a 0.91-meter (3-foot) dam raise, a rock ramp to provide passage, and many different configurations of concrete ladders and fish screen locations.

3.2. Original 60% Design Option – Physical Model 1

In January of 2014, MTAO and other stakeholders met to complete a 60% design review on the to-date plans for the St. Mary Diversion Dam and Headworks. The designs were developed by the TSC with a multidisciplinary team led by Jason Wagner. The 60% design was to be robust, simple, and easy to operate. The fish ladder and fish screen were designed appropriately for juvenile Bull trout. The screens were designed such that a maximum screen approach velocity would not exceed 0.24 m/s (0.80 ft/s) at 30.58 m^3/s (1080 ft^3/s) flow in the canal. Typical design criteria for salmonids would usually only allow 0.12 m/s (0.4 ft/s) approach velocity, but the multi-agency biological review team obtained an exception due to the species and life stages present at the facility.

Figure 12 provides a plan view drawing of the proposed 60% design. Included in the design are the following features: A) New diversion dam located downstream of the existing structure with a kinked ogee shape and an offset weir height to align flow and allow more flow on the right bank of the river. B) New sluice bays and overshot bays on both the right and left side of the dam adjacent to the abutments to allow sediment and floating debris removal and aid in ladder attraction. C) New headworks that consists of a trashrack with a maximum 0.61 m/s (2 ft/sec) approach velocity and nine 1.52- by 1.68-meter (5- by 5.5-ft) steel slide gates. D) New fish screen 54.86-m long by 2.3-m tall (180-ft long by 7.5-ft tall) and fish bypass to protect fish from entrainment.

E) All species fish ladder located on the right bank of the river. F) New lowered sluice channel on river left to allow non-irrigation flows to pass without inundating the headworks.

Due to the complexity of the project, TSC constructed a 1:12 physical model of the complete structure and several numerical models of individual components of the proposed 60% design to ensure that all the hydraulic and structural components would function as intended and that the project would succeed at both protecting Bull trout and providing the necessary diversion to the St. Mary canal. Figure 13 provides an aerial view of the physical hydraulic model with annotations. Testing the physical model helped the design team identify several areas of concern with the proposed design. The following items were noted from the physical and numerical models: A) The kinked ogee crest dam caused severe scour downstream of the apron, which resulted in an unstable river bed. B) The entrance to the fish ladder was going to be difficult for species to locate due to extreme turbulence and eddies. C) The headworks was too large, resulting in small gate openings to operate the canal at the desired flowrates. D) The overshot bays intended for flushing floating debris over the dam were not in ideal locations and would require excessive operation and maintenance. E) Operation of the facility on two sides of the river would be difficult due to the access limitations on the right bank. F) Having the fish ladder on the opposite side of the river as the headworks required maintaining two thalwegs, which created additional complexity and may increase operation and maintenance costs.

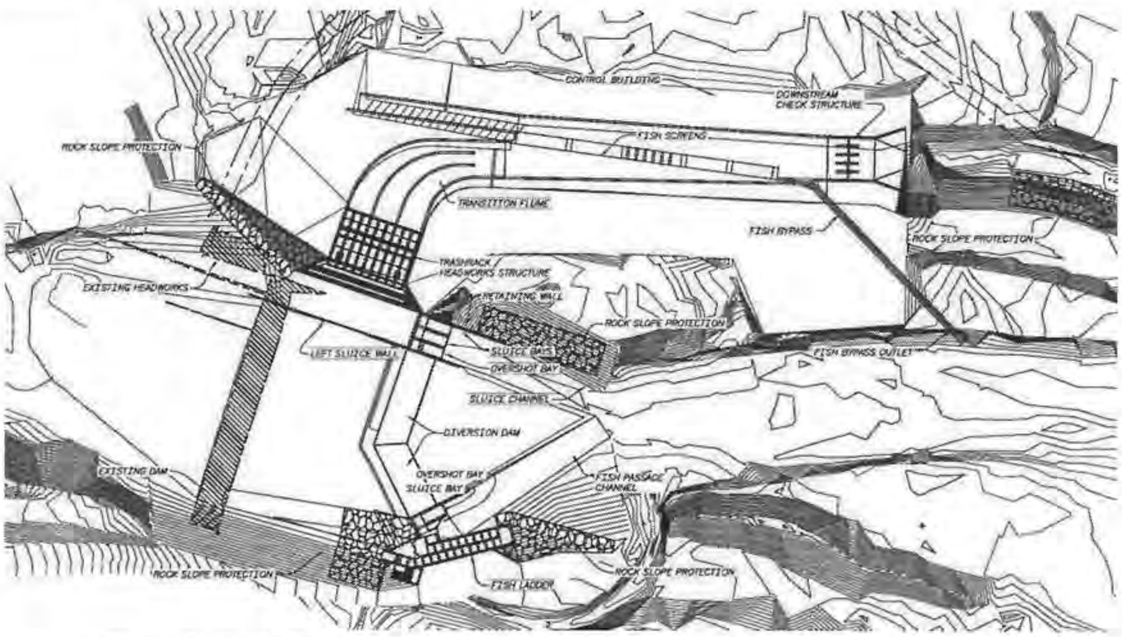

Figure 12. Originally proposed 60% design of the St. Mary Diversion Dam and Headworks.

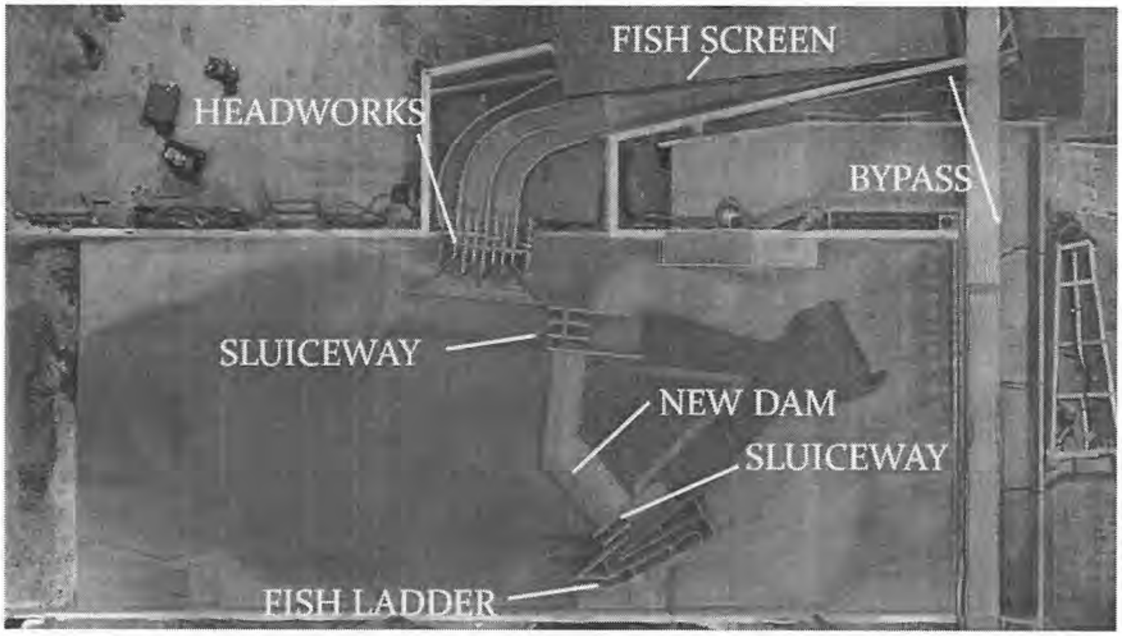

Figure 13. Aerial photograph of the original 60% design of the St. Mary Diversion Dam with annotations.

3.3. Modified 60% Design Option – Physical Model 2

Following the first modeling efforts, project members re-worked the 60% design and incorporated the changes shown in Figure 14. Modifications to the original 60% design include the following: A) A broad crested weir with reduced length (now 55.78-m (183-ft)) and a suitable energy dissipation basin downstream to prevent scour. B) The fish ladder located on river left to allow for easier operation, provide better attraction, and limit the access needed on the right bank. C) The headworks was reduced from nine to six 1.52- by 1.68-m (5- by 5.5-ft) gates. D) The overshot bays were removed on both sides of the diversion dam, and the right bank sluice gate was removed to reduce O&M requirements. Figure 15 provides an aerial view of the modifications to the physical hydraulic model with annotations. Additional information obtained during the model study enabled design team members to A) Set baffle configurations to allow uniform approach velocities for the fish screen at diversion flow rates of 18.41, 24.07, and 30.58 m^3/s (650, 850 and 1080 ft^3/s). Velocity uniformity was unachievable without baffling due to the screen's close proximity to upstream gates and channel curvature. B) Generate head discharge relationships for the dam with and without the fish ladder and headworks operational to verify that upstream water surface elevations were not too high and to provide a reasonable discharge curve for each structure. C) Verify the amount of headloss produced by the headworks and fish screens to ensure canal discharges could be met with adequate canal depths. D) Confirm that all flow during non-irrigation season can pass through the sluice gates without inundating the headworks with water.