ST. MARY DIVERSION and CONVEYANCE FACILITIES

Failure and O&M Reference Guide

WATER Resources Division

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FAILURE AND O&M REFERENCE GUIDE
ST. MARY RIVER DIVERSION AND CONVEYANCE FACILITIES

1.0 DNRC FOREWORD

In 2006, the St Mary Rehabilitation Working Group (SMRWG) introduced federal legislation (SB-3563) that was unsuccessful, signaling that the rehabilitation of the St. Mary Facilities was going to take much longer than anticipated. This led to concerns that, due to the aging and deteriorated state of the facilities, failures will increase in frequency and severity with time, and possibly a catastrophic failure of a vital structure that would require an emergency response will occur. Concerns were also leveled about spending large sums of money on structures that will likely be replaced in a few years.

These concerns, expressed by the Milk River Project Joint Board of Control (JBOC), SMRWG, and the State of Montana, led to formation of the SMRWG Contingency Planning Committee. The committee determined that to be successful, the U. S. Bureau of Reclamation (Reclamation),and the JBOC needed to be active partners in contingency planning. Reclamation and the JBOC were briefed on the concepts behind contingency planning, and amenable to the idea. Informally, this group of stakeholders came to be known collectively as the Catastrophic Failure Planning Team.

Contingency planning is a low-cost, cooperative and practical approach to the challenges presented by aging and deteriorating infrastructure. The shared interests of stakeholders are:

- Avoiding failures if possible,
- Cost containment,
- Identifying low-cost alternatives and temporary repairs that keep failing structures safe and operable while working through the processes toward rehabilitation,
- Developing a menu of temporary fixes for structures slated for replacement or rehabilitation, and
- Prioritizing structure replacement when rehabilitation funds are secured.

The Catastrophic Failure Planning Team agreed that a document providing an overall description of the facilities, their conditions, potential failure modes, risks and impacts, and a means of assessing failures would be a useful tool. This document provides that tool.

On September 25 and 26, 2007, an engineering walkthrough of the St. Mary Facilities was performed involving representatives of the SMRWG, Blackfeet Tribe, Reclamation, DNRC, and TD&H Engineering. The conditions of the individual structures were evaluated, potential failure modes were identified, and the severity of the failure modes were characterized, providing the material for this document. Also, recommended levels of contingency and emergency response planning for each component and identified failure modes were discussed.

The goals of this document are to provide the necessary background information to optimize the use of limited O&M funds and contain O&M costs while maintaining the viability of the St. Mary Facilities; manage failure threats; and, if possible, perform O&M that will complement the future rehabilitation.

This report offers a Proposed Failure Impact Severity Matrix that can be used to quantify the impacts of potential failures and helps identify likely responses. The impact parameters that affect severity are:

- Time of failure
- Demand for water
- Storage in Fresno Reservoir
- Downtime
- Repair costs
- Environmental impact
- Property damage
- Risk to human life

From these parameters, severity levels can be assessed, which in turn categorize response levels. Based on these results, a prudent and strategic use of O&M funds can be implemented and a determination if emergency funds are required can be made. Also, proactive contingency planning can be implemented that will either avoid a failure or minimize damage in the event of failure.

The question that often arises is: How much should be invested in facilities that are going to be replaced? This guide cannot answer that question, but it can help to address it in a proactive and practical manner. This reference guide is a tool to assist contingency and emergency response planning, which will help control the variables and minimize failure risks until the rehabilitation occurs.

Using this Document:

The review draft of the document drew numerous comments regarding its reversed order; therefore, an explanation is in order. Given the intent of this document, DNRC felt it prudent to reverse the normal order so that recommended actions for specific failure scenarios would be the first thing the reader encountered when opening the document thereby stressing the importance of contingency planning. The Condition of Individual Components and Background sections were moved to the back as a result.

Tables 1 and 2 in Section 2 offer pertinent recommendations. Planning contingencies are covered in Section 3. The failure impacts and failure impact ranking matrix are presented in Section 4. The results of the engineering walkthrough along with failure modes, likely damage and contingencies are summarized in Section 5. Section 6 provides background information. We hope this reference guide is instrumental in obtaining the stakeholders' goals.

Respectfully submitted,

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December 5, 2009

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It goes without saying that the document would not be where it is today but for the two-year effort put forth by Erling Juel and his staff at TD&H Engineering.

Vital document production assistance was provided by Cheryl O'Connor and Martha Hodder.

Thank you, all!!!

2.0 FINDINGS

2.1 OVERVIEW

Many hydraulic components of the St. Mary River Diversion and Conveyance Facilities have an elevated risk of failure with potential damages ranging from minor to catastrophic. Minor failures are those that can be absorbed into the normal O&M budget with little impact to irrigators. Catastrophic failures would have severe impacts on any combination of the environment, local residents of the Blackfeet Nation, or the Milk River Basin economy.

Greatest Potential For Catastrophic Failure

The St. Mary River Siphon, Hall Coulee Siphon and the five hydraulic drops pose the greatest catastrophic failure threats. In addition to property and environmental damage, tremendous economic impacts associated with repair and restoration costs and lost income would be felt throughout the Milk River Basin.

Most Probable Failures

Portions of the St. Mary Facilities most likely to fail in the near future are canal backslopes, fill embankments, and the diversion dam weir. Backslope failure would result in lost capacity and potential over-topping. Overtopping at dedicated grassy spillways would result in minor damage. Overtopping at other areas could initiate a breach, causing erosional down-cutting of the fill or downslope embankments and possible headcutting of the canal prism. Loss of the downslope bank could also occur due to slope instability and internal piping. Embankment failures could be sudden and progressive, resulting in severe damage and downtime. The probability of a diversion dam failure is high due to the poor condition of the fixed weir concrete. Collapse of the diversion dam would result in minor damage and diversion flow could be quickly restored with a temporary fix.

Overall Rehabilitation

The preferred solution to avert failure is a comprehensive rehabilitation of the St. Mary Facilities with estimated costs exceeding $150 million and perhaps as much as 10 years of construction to complete. Any federal action must comply with the National Environmental Policy Act (NEPA) of 1969. NEPA documents are developed to evaluate and identify the potential environmental issues and impacts associated with the proposed project. The engineering designs would be prepared in compliance with environmental studies.

Partial Rehabilitation

In the absence of a comprehensive rehabilitation, a prudent action would be to complete the replacement designs for major structures (e.g. siphons and hydraulic drops). These structures are considered critical since they pose a catastrophic failure risk. In the event of a catastrophic failure, reinstating service as soon as possible is crucial. Availability of partial replacement designs would expedite repairs.

Replacement design must incorporate a mechanism for partial implementation and adaption to existing grades and alignments while allowing for potential future changes in grade. The draft Preliminary Grade and Alignment proposed by DNRC has all three siphons proposed for replacement by parallel structures. New siphons can be proactively designed to be adapted to a potentially higher grade near the existing alignment. A total realignment of the canal to bypass the existing drops with a single drop structure at the terminal end could be designed regardless of the final grade if the alignment is assumed to follow the existing alignment at the Emigrant Gap Bridge.

Continue Diligent Inspections and Increased Monitoring

Early detection is crucial to averting or minimizing failure damages. Early detection can be achieved thorough frequent and thorough year-round inspections – especially of components that pose a catastrophic or likely failure risk.

Reclamation conducts facility inspections three times per week during the diversion season. Landslides and the steel siphons are inspected and assessed annually. Plunge pools of the hydraulic drops are inspected every 5 or 6 years. Additional inspections and monitoring of the chute floors and walls of the drops should be performed whenever the St. Mary Facilities are shut down.

During heavy precipitation events, the canal and known landslides should be inspected and monitored more frequently until the threat of slope and embankment movements has subsided.

Proactive Mitigative Tasks

The following activities can be performed to help lower failure risks or severity of impacts:

- Install stop log guides on the St. Mary River and Hall Coulee Siphon outlet transitions to allow continued diversion should a failure be limited to one barrel. Premade stop logs should be constructed and ready to put into service.
- Identify typical repair scenarios for minor failures of the diversion dam, Kennedy Creek Siphon and Wasteway, and select portions of the drop structures. Provide repair/construction details and specifications to expedite the repair.
- Identify and stockpile repair materials to facilitate and expedite repair.
- Develop agreements with local landowners and State, Federal, and Tribal entities to expedite the compliance and clearance activities for anticipated repair activities.
- Invoke Reclamation's streamlined contractor solicitation process as necessary.

Table 1 summarizes the recommended contingency planning activities for the major components of the St Mary Facilities.

Table 1 - Recommendations for Contingency Planning and Activities

Priority	Component	Issues	Recommended Actions
High	St. Mary River Siphon	Ground Slope & Siphon Movements	1) Establish reference points to be surveyed 2) Perform internal inspections annually 3) Reduce seepage and leakage introduced to slopes 4) Install horizontal drains on south slope
High	Hydraulic Drops	Deteriorating Concrete	1) Regular and thorough inspections of chutes and plunge pools both during and between operations
Moderate - High	Turnouts, Underdrains & Canal Prisms	Seepage, Piping, & Slope Stability Issues	1) Monitor changes in seepage rates and patterns as an indicator of internal changes 2) Canal lining, minor alignment shifts, and embankment reconstruction
Moderate	Hall Coulee Siphon	Ground Slope & Siphon Movements	1) Establish reference points to be surveyed 2) Perform internal inspections annually 3) Reduce seepage and leakage introduced to slopes
Low	Diversion Dam & Canal Headgates	Deteriorating Concrete	1) Develop typical repair scenarios for loss of diversion head
Low	Kennedy Creek Siphon, Wasteway and Check	Deteriorating Gates & Concrete	1) Develop typical repair scenarios for loss of containment

2.2 RECOMMENDATIONS

Table 2 summarizes the recommended activities and tasks that help avoid/minimize catastrophic failures of the St. Mary Facilities.

Table 2 - Recommendations to Help Avoid Catastrophic Failure

Priority	Recommended Actions	Comments
High	Initiate & Complete Overall Rehabilitation	The entire process including NEPA, engineering, and construction may take 10 to 15 years.
High	Develop Replacement Design of Critical Structures	Have replacement designs of the critical structures prepared. Structures include the St. Mary River and Hall Coulee Siphons and the hydraulic drops. In the event of a catastrophic failure, replacement designs would expedite restoration of service while ensuring compatibility with overall rehabilitation objectives.
High	Monitor and Stabilize St. Mary River Siphon	Implement horizontal drain program on south slope. Establish survey targets on siphon to track movements. Perform internal inspections annually. Continue monitoring of slope inclinometers and observation wells.
Mod	Increase/Maintain Inspections of the Hall Coulee Siphon	Establish survey targets on siphon to track movements. Perform internal inspections annually. Continue monitoring of slope inclinometers and observation wells.
Mod	Increase/Maintain Inspections of Hydraulic Drops	Monitor flow regime during operations. Inspect drop chutes during off-season and when midseason shut-downs occur.
Mod	Install Instrumentation to Monitor Canal Flow & Levels	Install water level recorders and telemetry at strategic locations (In progress). Drastic or abnormal drops or rises in canal levels provides an indication of lost containment.

3.0 EMERGENCY RESPONSE AND CONTINGENCY PLANNING

3.1 REPAIR VS. REPLACEMENT

The primary goal of the St. Mary Rehabilitation Working Group is to cost-effectively rehabilitate the St. Mary Facilities before a catastrophic failure occurs. Rehabilitation of the St. Mary Facilities would incorporate canal modernization and enhancements that improve efficiency, future operations, and management.

For minor failures, the objective would be to reinstate diversion service as soon as possible with little consideration for future rehabilitation plans. The SMRWG is concerned that in the event of a catastrophic failure, large sums of O&M money would be spent to rebuild the structure similar to its 100-year-old design without consideration for the future overall rehabilitation.

As the rehabilitation process progresses, the new canal grade and alignment should be finalized, and replacement designs for the critical structures developed as a matter of priority. In the event of a catastrophic failure, having replacement designs for critical structures would provide the opportunity to integrate emergency repairs with the rehabilitation, which would reduce the service interruption and minimize impacts to the O&M budget.

Disruption of water deliveries due to construction must be avoided as much as practicable during the rehabilitation effort. An alignment shift would allow summertime construction when weather conditions are favorable, which would reduce construction costs and minimize service disruptions.

3.2 ACCELERATED EMERGENCY RESPONSE

3.2.1 Emergency Facility Shutdown

Rapid shutdown of the St. Mary Facilities may cause problems such as canal prism failure. The speed at which dewatering is implemented should be a function of failure severity. If a minor failure occurs, the canal should be stepped down safely. If the failure is catastrophic or threatens the environment or property, dewatering should be rapid without regard to secondary failures internal to the prism.

A copy of Reclamation's shutdown procedures should be reviewed with respect to the goals of the Catastrophic Failure Planning Team (Reclamation, JBOC, and SMRWG). Written procedures should reflect a range of different failure scenarios. If written procedures do not exist, they should be prepared by Reclamation's maintenance staff.

3.2.2 Replacement Plans

Preparing replacement plans for the major structures for the St. Mary Facilities should be a priority in the rehabilitation effort, which could be implemented in the event of a catastrophic failure. The plans should include partial adaptation contingencies that are compatible with final implementation of the ultimate alignment and grade.

For minor failures, typical repair standards could be developed and implemented as funding becomes available. Repair standards, such as prism reconstruction and concrete repairs, could be prepared in advance. Preparation of typical repair standards would expedite the repair and reduce service disruptions. Standardized repair details, construction drawings, and specifications could encompass the following failure scenarios:

- Failure of the diversion dam, fixed weir, or sluiceway
- Failure of the Kennedy Creek, St. Mary River, or Hall Coulee Siphons and transitions;
- Failure of a canal drain turnout or underdrain
- Failure of the downslope fill embankment
- Chute floor or sidewall failures of the hydraulic drops
- Plunge pool and wingwall failures of the hydraulic drop stilling basins.

Depending on the nature of the failure, the repair plans could be temporary in order to quickly reestablish service and salvage the remaining diversion season. A permanent fix could then be planned for implementation during the off-season if necessary. Some failures, such as a drop chute floor or sidewalls, may require a permanent fix to be implemented prior to resuming diversion service.

3.2.3 Expedited Contracting Procedures

Emergency repairs warrant expedited solicitation procedures when contracted services are needed. Reclamation has the authority to trim the contractor selection time from the typical 6 weeks or more to 5 or 6 days when warranted. Reclamation's existing good working relationship with the Blackfeet Tribal Historic Preservation Officer assures compliance with THPO ordinances in a timely manner.

3.2.4 Environmental and Cultural Clearances

Along with typical repair scenarios, regulatory clearances and environmental compliance documentation could be completed, which would save time in the event of a failure. Some documentation may be time sensitive and require periodic updates such as the existing report on the Class 3 pedestrian survey of cultural resources along the canal. The Tribal Historic Preservation Officer has recommended that a Traditional Uses study be performed in the near future. Much of this information would be completed as part of the NEPA requirements for St. Mary Facilities rehabilitation.

3.2.5 Agreements with Local Landowners

In addition to expediting procurement, regulatory, and tribal requirements, coordination with adjacent local landowners is also important. Access to the necessary repair area may require approval from local landowners. Advanced access permission can be obtained through agreements with potentially affected landowners.

3.2.6 Stockpiling Repair Materials

Stockpiles of typical repair materials near sites with elevated risks of failure would save time and expense in the event of failure. Typical repair materials would include various aggregates such as drainage rock, structural gravel fill, and large riprap stone. These types of materials and others should be identified and quantified as part of the designs for typical failure repairs. Existing and potential borrow pits for use during the future rehabilitation were identified and summarized in the *Phase I Borrow Resource Study* (TD&H, 2008).

Notes

4.0 FAILURE IMPACTS

4.1 POTENTIAL DAMAGE

Damages from the failure of any of the canal facilities can vary as to type and severity. The types of damages can be grouped into three broad categories: environmental, economic, and loss of life and property. Major component failures can cause damage under each category while minor failures of smaller components may exhibit only one type of damage.

The severity of impact resulting from the different failure modes and types of damage vary widely. Minor failures can be absorbed into normal O&M activities with minimal impact on Project beneficiaries, while catastrophic failures would result in severe impacts. The SMRWG has proposed the following working definition of "Catastrophic Failure":

> The term "Catastrophic Failure" shall mean a failure of the infrastructure of the St. Mary River Diversion and Conveyance Facilities that causes a significant disruption in operations that threaten:
>
> - The environment;
> - The lives, health, or property of the residents of the Blackfeet Reservation; or
> - The Milk River Basin economy.

The different types of damage are discussed in detail below.

4.1.1 Environmental Damage

Environmental damage is damage that harms the water, land, air, vegetation, fish, or wildlife. In general, failures of the St. Mary Facilities would entail an uncontrolled release of the diverted water. Failure related releases may range from minor, temporary canal bank overtopping to complete and sudden loss of containment of the full diversion discharge.

An uncontrolled release could involve damages associated with erosion and sediment. Erosion can remove the protective soil cover on slopes thereby exposing it to progressive degradation associated with subsequent runoff events. When the eroded material is deposited, it can impact or destroy wildlife habitat. Inordinate amounts of sediment into streams can have adverse impacts on fisheries.

Many environmentally-sensitive species, both terrestrial and aquatic, exist near the St. Mary Facilities. Environmental damage could invoke State, Federal, and Tribal regulatory action. The St. Mary Facilities' proximity to Canada could also have international implications. Environmental damage could involve cleanup and restoration costs, regulatory fines, and legal fees. Environmental damage associated with specific component failures is summarized in Table 3 below.

Table 3 - Anticipated Environmental Damage from Various Component Failures

Relative Damage Ranking	Facility Component	Potential Environmental Damage
Catastrophic	St. Mary River Siphon	Failure of the existing siphon would: cause progressive slope erosion, discharge sediment into the St. Mary River, impact the bull trout fishery, and cause Blackfeet and Canadian water quality issues.
Catastrophic	Drop No. 5 or Approach Canal	Catastrophic failure and subsequent head-cutting of Drop No. 5 would cause serious erosion, discharge sediment into the North Fork Milk River, impact local fisheries, and cause Blackfeet and Canadian water quality concerns.
Severe	Drops No. 3 and 4	Failure of either of these two drops would cause sediment and turbidity in the North Fork Milk River. The canal and stilling basins between Drops No. 3 and No. 4 and between Drops No. 4 and No. 5 would capture much of the sediment before reaching the North Fork Milk River.
Severe	Canal from Former Spider Lake Check to Big Cut Slide	Embankment failure along this reach would cause severe erosion and environmental damage to Willow Creek drainage, wetlands, and riparian habitat.
Severe	Canal From Memorial Bridge to Spider Lake	Embankment failure in this segment could cause significant environmental damage due to the relatively steep terrain and could lead to a catastrophic failure of the St. Mary River Siphon.
Moderate	Drops No. 1 and 2	Similar to a failure of Drops No. 3 and 4. The damage would be less due to two more stilling basins, which increases the opportunity to capture more sediment before reaching the North Fork Milk River.
Moderate	Hall Coulee Siphon	Failure of this siphon on either slope would cause severe erosion and deposit sediment in Hall Coulee – an intermittent stream.
Minor	Kennedy Creek Check & Wasteway	Failure of this structure would result in localized erosion of the natural channel extending to the St. Mary River. Due to the coarse alluvial soils and the structure's design, environmental damage is assumed to be minor.
Minor	Diversion Dam/Canal Headgates	Failure of the diversion dam would represent a loss of diversion; however, flows would remain in the natural channel of the St. Mary River causing minor, localized environmental damage.
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Relative Damage Ranking	Facility Component	Potential Environmental Damage
Minor	St. Mary River Bridge	Failure of the bridge would result in catastrophic failure of the siphon. The coarse alluvial soils and the capacity of the natural channel would likely result in minor environmental damage, possibly in the form of localized scouring.
Minor	Hall Coulee Wasteway	Failure of the nonfunctional wasteway may cause localized erosion to the intermittent stream channel. The wasteway was designed for a capacity of over 900 cfs, which exceeds the current canal capacity.
Minor	St. Mary Canal From the Diversion Works to Memorial Bridge	Embankment failure along this reach would most likely cause minor damage due to relatively flat slopes and coarse alluvial soils.
Minor	Kennedy Creek Siphon	Failure of this siphon and/or transition structures would release diversions to the Kennedy Creek drainage. Environmental damage is anticipated to be minor and localized.
Minor	Canal from Big Cut Slide to Drop No. 1	This stretch of canal is characterized by low rolling terrain with discrete drainage swales. Environmental damage in this segment would likely be minor.
Minor	Canal from Drop No. 1 to Drop No. 4	A canal breach in this stretch would likely cause minor damage since flows would reenter the system at the next downstream stilling basin.

4.1.2 Loss of Life and Property Damage

Certain failures of the St. Mary Facilities may result in the loss of human life or property damage. Loss of life refers to the general public, Reclamation staff, and emergency responders as a direct result of failure. Property damage includes public and private property as a direct result of failure. Property loss and damage may include fencing, livestock, vehicles, equipment, crops, buildings, land improvements, or degradation of property value. Table 4 below summarizes the relative risk regarding loss of life and property damage from select component failures.

Table 4 - Relative Risk Regarding Loss of Life and Property Damage Related to Potential Component Failure

Facility Component	Loss of Life	Property Damage
Diversion Dam & Canal Headgates	Highly Unlikely	Very Low
Kennedy Creek Siphon	Highly Unlikely	Very Low
Kennedy Creek Check & Wasteway	Highly Unlikely	Very Low
St. Mary River Siphon	Highly Unlikely	Low
Hall Coulee Siphon	Highly Unlikely	Low

Facility Component	Loss of Life	Property Damage
Hydraulic Drops	Highly Unlikely	Low
Canal from the Diversion to Memorial Bridge	Highly Unlikely	Moderate
Canal from Memorial Bridge to Spider Lake	Highly Unlikely	Moderate
Canal from Spider Lake to Big Cut Slide	Very Low	Moderate
Canal from Big Cut Slide to Drop No. 1	Very Low	Moderate
Canal from Drop No. 1 to Drop No. 5	Highly Unlikely	Very Low

4.1.3 Economic Losses

An extended period of lost diversion water during a crucial time would have direct economic impacts on the Milk River Basin. The immediate impacts would affect agricultural producers through reduced crop production. The delayed and possibly more severe economic impact to producers would result from the costs of failure repairs and environmental mitigation. If a failure results in a protracted service disruption, these economic impacts would extend to local businesses, communities, regional distributers that serve north central Montana, and possibly the local tax base. In extreme cases, State and Federal tax bases would be detrimentally impacted from lower revenues and an increased need for social services. Table 5 below summarizes the relative risk of economic losses from various failure scenarios.

Table 5 - Relative Risk of Economic Losses Resulting From Various Failure Scenarios

Facility Component	Potential For Economic Losses
Diversion Dam & Canal Headgates	Very Low
Kennedy Creek Siphon	Very Low to Moderate
Kennedy Creek Check & Wasteway	Very Low
St. Mary River Siphon	Low to Catastrophic
Hall Coulee Siphon	Low to Catastrophic
Hydraulic Drops	Moderate to Catastrophic
St. Mary Canal from the Diversion Works to Memorial Bridge	Very Low
Canal from Memorial Bridge to Spider Lake	Low to Moderate
Canal from Spider Lake to Big Cut Slide	Low to Severe
Canal from Big Cut Slide to Drop No. 1	Low to Moderate
Canal from Drop No. 1 to Drop No. 5	Very Low to Low

4.2 PARAMETERS AFFECTING FAILURE SEVERITY

4.2.1 Parameters

The damage severity of a failure can be exacerbated by additional parameters that affect the economic impact. The individual parameters are discussed below.

Timing of Failure

The timing of failure during the irrigation season directly impacts severity. For example, a late–season failure (except catastrophic), could be repaired with little or no impact on the current growing season. A failure during June or July when demand for diverted water is typically high would have a far more detrimental impact.

Demand for Water

A failure during periods of high demand would increase the impact severity. Variables that affect demand include soil-moisture, precipitation, temperature, and wind. An ill-timed failure (i.e. drought conditions) would represent a high level of severity. Conversely, severity is reduced if a failure occurred during a period when precipitation was satisfying crop water requirements.

Level of Fresno Reservoir

The severity of a failure is correlative to storage in Fresno Reservoir. If Fresno Reservoir were full at the time of failure, it would serve to buffer its severity. St. Mary River diversions have averaged 170,530 Ac-Ft. per year – approximately double the active storage capacity of Fresno Reservoir. If Fresno Reservoir storage were low at the time of failure, the impact would be much more severe.

Duration

Severity increases with respect to the duration of lost diversions. Minor failures may last a few days while a catastrophic failure may span multiple irrigation seasons. Duration of lost diversions is compounded by the timing, demand, and storage parameters. Recent past failures included an 11-day shutdown in 2004 to weld a section of the St. Mary River Siphon; 54 days in 2003 to fix a small portion of Drop No. 2; and most of the 1995 diversion season was lost due to canal bank and backslope failures.

Repair Costs

The repair costs of a failure represent a portion of the financial impact to be borne by irrigators. Costs increase with respect to complexity and the emergency effort required, which in turn increases impact severity. Repair costs may be exacerbated by environmental, private property mitigation, or legal expenses.

4.2.2 Severity Matrix

Potential failures of the St. Mary Facilities can be quantified by using a rating system that evaluates the various parameters that influence impact severity. Potential failures could also be evaluated using the matrix to plan a likely emergency response. The matrix could be tested using the parameters from past failures. A proposed Failure Impact Severity Matrix is presented in Table 6 for future discussion and additional consideration.

Table 6 - Proposed Failure Impact Severity Matrix

Failure Impact Parameter	Matrix Ranking			Impact Score (1-3)
	1	2	3	
Time of Failure	August or Later	March to May	June and July	
Demand for Water	Low	Moderate	High	
Level of Fresno Reservoir	Full	Normal	Low	
Loss of Diversion Time	< 1 week	Up to 1 month	> 1 month	
Repair Costs	<$100K	$100K - $750K	>$750K	
Environmental Impact	Low	Moderate	Severe	
Personal Property Damage	<$10K	$10K to $100K	>100K	
Risk of Human Life	None	Potential	Elevated	
			Total	

4.3 FAILURE IMPACT LEVELS

The results of a severity matrix evaluation could be used to quickly characterize the impact of a potential or actual failure and help guide a timely and appropriate response. Failure impact levels and the corresponding responses would range from normal O&M repair to a catastrophic failure that requires emergency action. For the purpose of the proposed Failure Impact Severity Matrix, four response levels have been developed and are discussed below.

Category 1 - Normal O&M Activity

A Failure Impact Severity Matrix score of less than 10 and one or more of the following would constitute a Category 1 level:

- No irrigation allotment reductions in the Milk River Basin.
- Poses no threat to loss of life.
- Poses no threat of environmental or property damage.
- Repair costs within O&M budget.

Response: Planned as part of normal maintenance activity or completed in off-season using Reclamation crews.

Category 2 - Emergency Mode I

A failure Impact Severity Matrix score from 10 to 13 and one or more of the following would constitute a Category 2 level:

- Would result in irrigation allotment reductions up to 20% in the Milk River Basin.
- Potential for loss of life.
- Minor threat of either environmental damage or property damage.
- Repair costs impact O&M budget.

Response: Planned shut-down and immediate repair using Reclamation crews.

Category 3 - Emergency Mode II

A failure Impact Severity Matrix score from 14 to 18 and one or more of the following would constitute a Category 3 level:

- Would result in irrigation allotment reductions up to 50% in the Milk River Basin.
- Potential for loss of life.
- Elevated threat of either environmental damage or property damage.
- Repair costs exceed water users' ability to pay.

Response: Emergency shutdown and immediate repair. Additional resources and crews may be required. May require financial assistance.

Category 4 – Catastrophic

A Failure Impact Severity Matrix score of 19 or greater and one or more of the following would constitute a Category 4 level:

- Would result in irrigation allotment reductions greater than 50%.
- Potential for loss of life.
- Severe threat of either environmental or property damage.
- Repair costs are extraordinary and exceed the water users' ability to pay.

Response: Emergency shutdown and indefinite loss of diversion. Repairs would require additional resources and outside financial assistance.

Table 7 - Failure Impact Severity Levels

Matrix Impact Score	Impact Severity	Likely Emergency Response Level	Likely Failure Impact
<10	Category 1	Normal O&M	Minor Financial Impact
10 - 13	Category 2	Emergency Mode I	Moderate Financial Impact
14 - 18	Category 3	Emergency Mode II	Severe Financial Impact& outside funding may be necessary
>19	Category 4	Catastrophic	Catastrophic Financial Impact - State & Federal Financial Assistance Likely

5.0 CONDITION OF INDIVIDUAL COMPONENTS

5.1 INTRODUCTION

On September 25-26, 2007 an engineering walkthrough was performed to characterize the condition of the hydraulic components of the St. Mary Facilities for likelihood, modes, and severity of failure. The observations and information gleaned from the engineering walkthrough are provided in this section and represent the core of this Reference Guide. This section provides crucial information on the individual components that comprise the St. Mary Facilities, which includes existing conditions, background data, operations and issues, estimated replacement costs, potential failure modes, and contingency planning considerations.

5.1.1 Ranking Methodology

Due to the complexity of calculating numerical failure probabilities, a relative system was developed to rank the likelihood of failure and implemented as follows:

Very Low - The chance of failure is very low, nearly negligible.
Low - The chance of failure is unlikely.
Moderate - moderate credible risk of failure exists.
High - The chance of failure is likely or imminent.

Likewise, a relative ranking system was developed to describe the severity of damage from a failure. The terms used to qualify potential damage are described below and coincide with the terminology used in Section 4.3.

Minor - Normal O&M Activity (Category 1)
Moderate - Emergency Mode I (Category 2)
Severe - Emergency Mode II (Category 3)
Catastrophic- Catastrophic (Category 4)

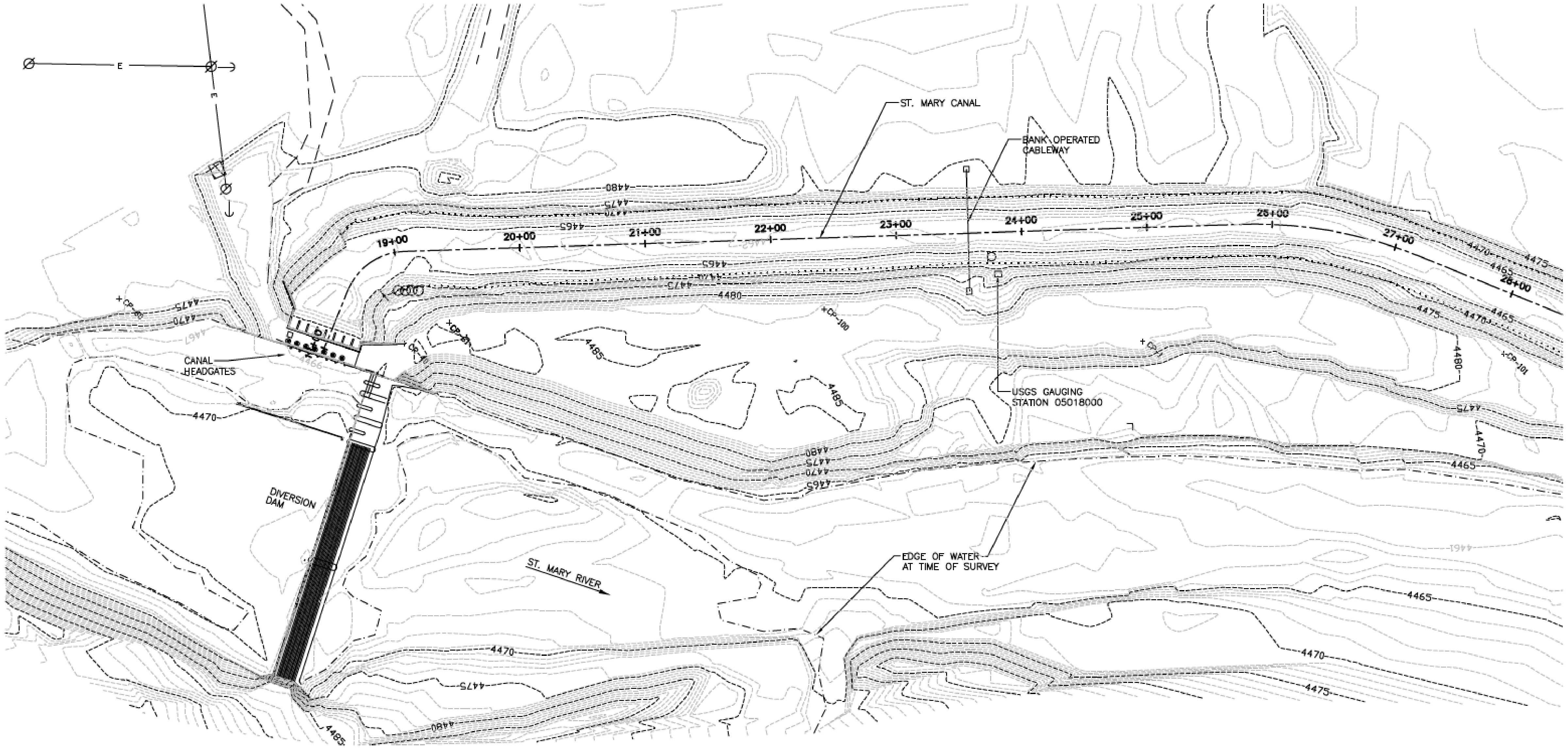
5.2 DIVERSION DAM/CANAL HEADGATES

5.2.1 Existing Conditions

The existing diversion dam (Figures 1 and 8) is a sharp-crested, concrete, overflow dam (See Photo 1). The eastern portion of the dam has a crest length of 190 feet. The western portion of the dam includes a 6-bay, three-sluiceway segment with a total width of 56 feet. Four bays contain removable timber stop logs. Two bays of the western most sluiceway are equipped with cable-operated, timber gates. The sluiceways are shown in Photo 2. Portions of a partially demolished steel truss bridge with timber decking remain. The remaining portion has rotted timber decking and is unsafe.

Photo 1. Looking east across St. Mary River during the off-season at the two fixed weir segments below the remaining bridge spans. Note condition of concrete, magnitude of sediment deposition upstream of dam and timber plank added to fixed weirs (10/06/04).

The diversion headworks facility has eight steel slide gates set in a concrete wall approximately 20.7 feet high and 105 feet long (Photo 3). A floating boom is normally deployed in front of the headgate structure to deflect floating debris from the canal gates (Photos 4 and 5). Some of the gates and/or stems are bent and inoperable. The diversion dam and headgate facility is in extremely poor condition (Photos 6 and 7) with plans for replacement underway. Fish entrainment into the canal and fish passage at the diversion dam are issues due to the presence of bull trout. Bull trout are list as a threatened species under the Endangered Species Act of 1973. Additional details and descriptions of the facility can be found in previous reports (USBR, 2003; TD&H, 2005 and TD&H, 2006). Reclamation had at one time an electric fish barrier installed at the gate entrances to help deter fish from entering the canal.



LEGEND

---------3415---------	MAJOR CONTOUR
	MINOR CONTOUR
×CP-102	CONTROL POINT
— — — — —	EDGE OF GRAVEL
□	ELECTRICAL BOX
→	GUY WIRE
——— E ———	OVERHEAD ELECTRIC
⦰	POWER POLE
—·—·—·—	EDGE OF WATER

0 50' 100' 150'
SCALE

FIGURE 1

ERLING A. JUEL 10740PE
REGISTERED PROFESSIONAL ENGINEER
MONTANA

REVISIONS

BY ____	DATE ____	DESCR ____
BY ____	DATE ____	DESCR ____
BY ____	DATE ____	DESCR ____

TD&H
THOMAS, DEAN & HOSKINS, INC.
ENGINEERING CONSULTANTS
GREAT FALLS—BOZEMAN—KALISPELL—HELENA MONTANA
SPOKANE WASHINGTON
LEWISTON IDAHO

DRAWN BY: WAB
DESIGNED BY: EAJ
QUALITY CHECK:
DATE: 11.20.08
JOB NO. 04-167
FIELDBOOK

DNRC - WATER RESOURCES DIVISION
ST. MARY DIVERSION FACILITIES

EXISTING DIVERSION DAM AND CANAL HEADGATES

CAD NO. 04167-8F2 .DWG
SHEET 1 OF 1

Notes

Photo 2. Looking downstream (north) at three sluiceways and 6 bays on the west side of diversion dam. Canal headgates are left of photo. Note two manually operated lift gates used to regulate flow and permit passage of off-season flow (10/06/04).

Photo 3. Looking at downstream end (canal side) of headgate structure. Diversion dam is located behind headgates (10/13/04).

Photo 4. Upstream view of headgates showing trash boom, electric fish barrier, and dam sluiceways (11/11/04).

Background Data Summary

The following data summarizes pertinent specifications of the diversion facilities.

Diversion Dam -

- Concrete buttress weir with hydraulic height of 6.5 feet
- 12-inch wooden flashboards added
- Estimated 20,000 cfs discharge at elevation 4468'
- Abutment crest elevation – 4471'
- Weir crest elevation – 4457.5'
- Sluiceway invert elevation – 4452'
- 190 ft. of fixed weir; two bays (95' each) and 5' bridge pier
- 6 sluiceways total length – 56'
- Western sluiceway is gated with two hoist-operated, timber panels

Canal Headgate Structure -

- 8 steel gates, 5' x 5.5' (Photo 5)
- 7 hydraulic operators, 1 manual
- Concrete gate wall 20' high by 60' long
- Floating trash boom
- Backup power in adjacent shed to operate hydraulic actuators

Photo 5. Upstream view of gate openings (11/11/04).

Operations and Issues

The typical operations and maintenance issues of the diversion facilities are summarized below:

Diversion Dam-

- Severe concrete deterioration (Photos 6 and 7)
- Sluiceway gates are typically closed during diversion
- Gates raised during off-season
- Prevents fish passage during diversions
- Occasional midseason trash removal required
- Requires manual monitoring and operation
- Limited safety features

Canal Headgates-

- Gates adjusted throughout season depending on desired canal flow
- Manually monitored and adjusted
- Closed during off-season but do not seal adequately resulting in leakage and ice problems (Photos 8 and 9)
- Concrete deterioration
- No effective fish deterrent to reduce canal entrainment
- Trash buildup
- Limited safety features

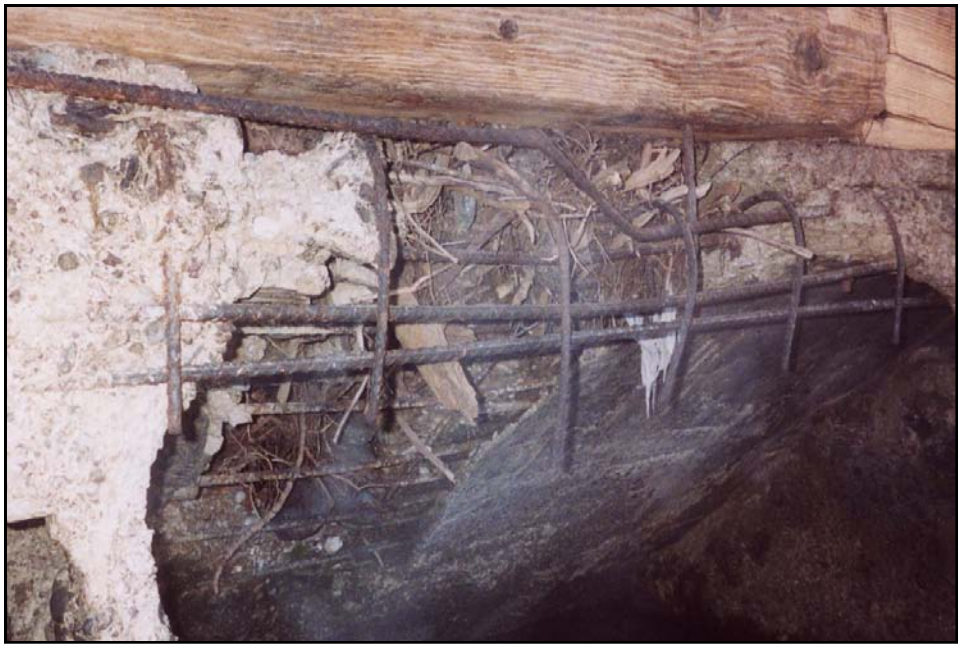


Photo 6. View of concrete condition of the underside of fixed weir portion of diversion dam (11/11/04).

Photo 7. Looking west at upstream edge of sluiceway piers. Note concrete condition and exposed reinforcement (11/11/04).

Photo 8. Downstream view of headgate structure during the off-season. Note heavy leakage through Gates 3 and 5 (10/13/04).

Photo 9. Close-up (downstream) of heavy leakage and debris at Gate 3 (10/13/04).

Estimated Replacement Costs

The estimated replacement cost, depending on diversion capacity, varies from $16.5 to $18.5

million (TD&H, 2006). This price includes both the diversion dam and the canal headgate structure. The replacement structures would address fish passage at the dam and canal entrainment issues.

5.2.2 Potential Failure Modes

The diversion facilities are low hydraulic head structures. Damages associated with failures of this type of structures are typically minor. Failure of the fixed weir, sluiceway, or abutment would be confined to the natural river channel with only minor localized erosion possible. Each of these failure modes would result in a loss of diversion head. Due to its present condition, the fixed weir portion of the diversion dam poses the most likely failure mode (Photo 6).

The likelihood of structural collapse, foundation failure, and embankment failure of the headgate structure due to erosion and progressive piping are very low. Damages, if any, would be confined to the river channel with severity levels likely to be low. The gates and gate operators pose the most likely failure modes. During the diversion season, gate or gate operator failure would result in a closed position and the inability to re-open them. During the off-season, gate or gate-operator failure would occur in the open position thereby preventing closure. Damages associated with off-season gate and gate-operator failures would be related to icing in the canal during the winter time. Potential failure modes, likelihood of failure, and relative damage of the diversion facilities are summarized in Table 8 below.

Table 8 - Potential Failure Modes and Corresponding Damage for the Diversion Dam and Canal Headgates

Diversion Dam

Potential Failure	Likelihood of Failure	Relative Severity of Damage
Collapse of Fixed Weir	Moderate	Minor
Foundation-Piping/Erosion	Very Low	Minor
Flashboard Sluiceway	Low	Minor
Sluiceway Gate	Low	Minor
Rt Abutment - Piping/Erosion	Low to Very Low	Moderate

Canal Headgates

Potential Failure	Likelihood of Failure	Relative Severity of Damage
Structural Collapse	Very Low	Moderate
Foundation/Abutment	Very Low	Minor
Piping/Erosion	Very Low	Minor
Gates	Low	Minor
Operators & Stems	Low	Minor

5.2.3 Contingency Planning

Due to the low-head nature of the diversion facilities and the lack of storage, both temporary and permanent repairs to fix a failed weir would be relatively easy to implement. A diversion dam failure during the diversion season could be repaired using engineered riprap.

A canal headgate failure would be considered relatively minor.

5.3 KENNEDY CREEK SIPHON

5.3.1 Existing Conditions

Kennedy Creek Siphon is the first of three inverted siphons along the St. Mary Canal. The siphon conveys diversion water under Kennedy Creek (Figures 2 and 8). The siphon is a cast-in-place, reinforced concrete, horseshoe-shaped conduit. The siphon has concrete inlet and outlet structures designed to control the flow transitions in and out of the siphon (Photo 10). The siphon crosses under Kennedy Creek atop an active alluvial fan. Numerous armored dikes were built upstream of the siphon crossing to control stream migration of Kennedy Creek during flood flows.

The transition structures have areas of exposed reinforcement, delaminated concrete, spalls, and cracks (Photos 11 and 12). Downstream of the outlet transition, turbulence has eroded the bottom of the canal. The siphon barrel concrete is reportedly in good condition due primarily to the fact that the siphon remains full of water year around. This protects the concrete surfaces of the siphon barrel by reducing exposure to freeze-thaw action.

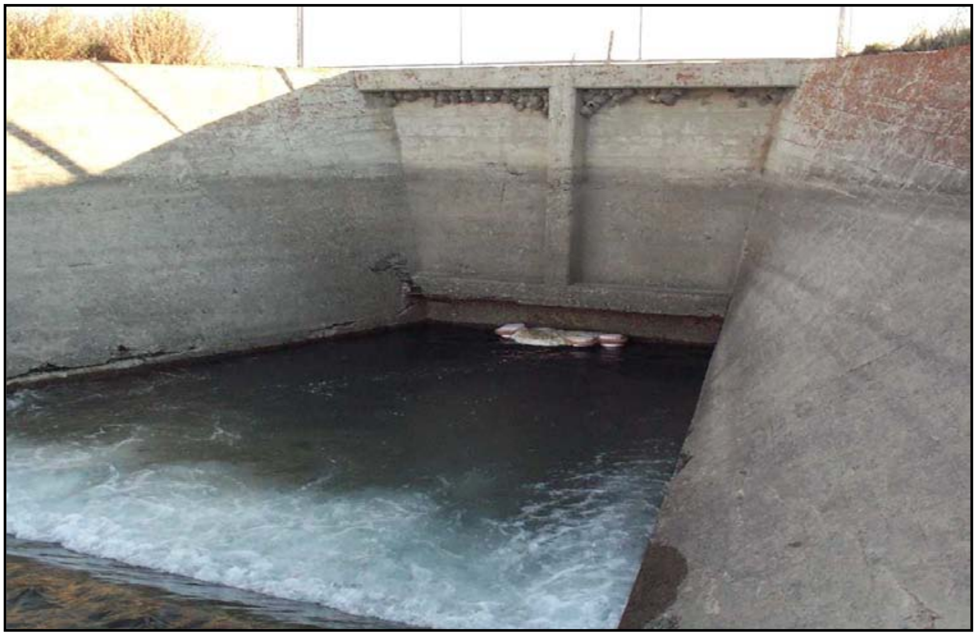


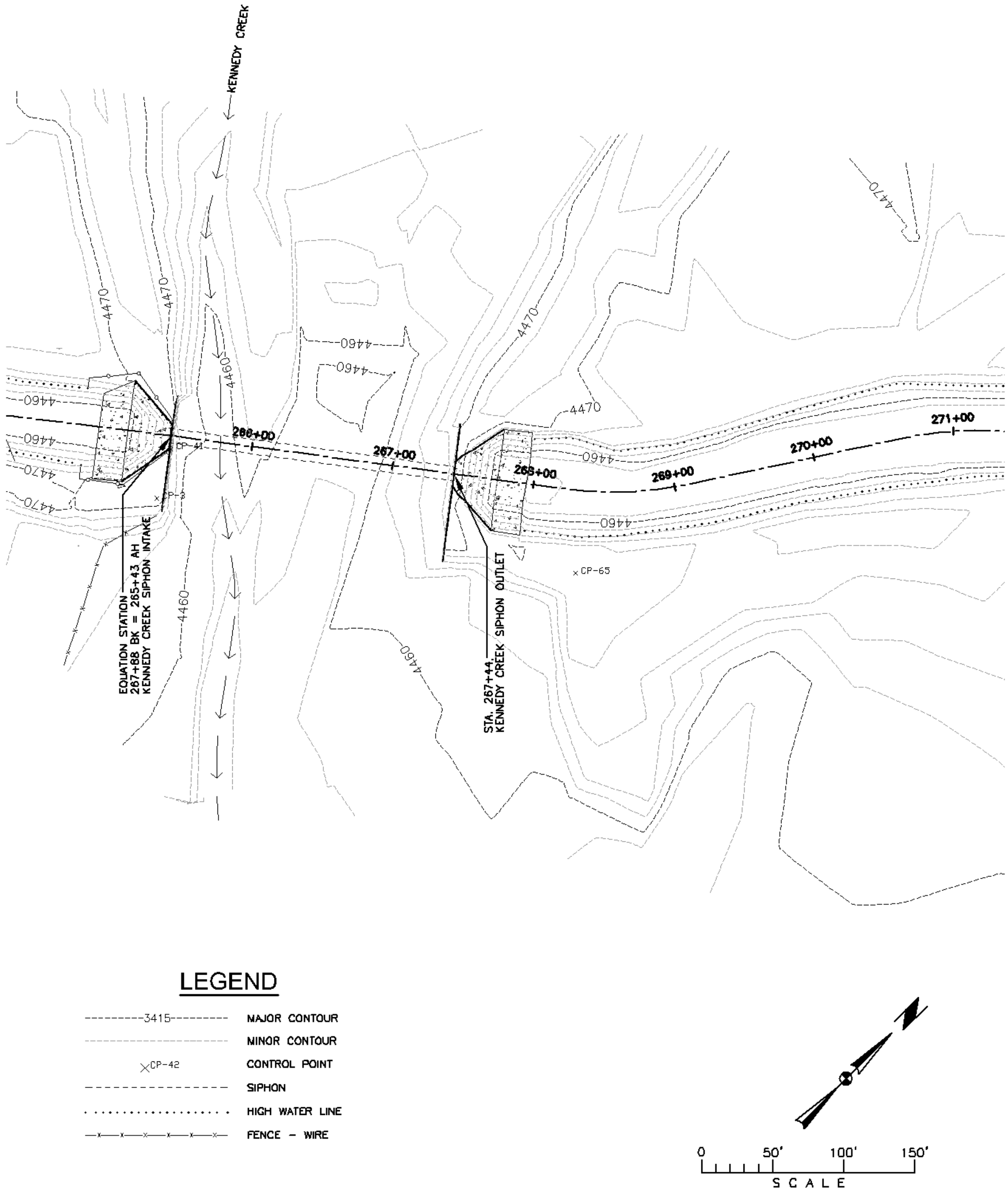
Photo 10. Inlet section (south side) of Kennedy Creek siphon during off-season (10/13/04).

The top of the siphon barrel is exposed in the channel of Kennedy Creek, which has caused minor scouring in the stream channel on its downstream side.

Background Data Summary

The following data summarizes pertinent specifications of the Kennedy Creek Siphon crossing.

- Siphon length 201’ with transition structures
- CIP horseshoe-shaped conduit, Height – 9.25’, Bottom Width – 8.5’
- 850 cfs design capacity
- Crosses under Kennedy Creek, atop active alluvial fan
- Numerous training dikes to control Kennedy Creek migration



DNRC-WATER RESOURCES DIVISION **ST. MARY DIVERSION FACILITIES**	TD&H	**THOMAS, DEAN & HOSKINS, INC.** **ENGINEERING CONSULTANTS** GREAT FALLS–BOZEMAN–KALISPELL SPOKANE LEWISTON MONTANA WASHINGTON IDAHO		
EXISTING KENNEDY CREEK SIPHON CROSSING	DRAWN BY: WAB DESIGNED BY: EAJ QUALITY CHECK:	DATE: 11.21.08 JOB NO. 04-167 CAD NO. 04167-SF2	**FIGURE**	**2**

Notes

Photo 11. Kennedy Creek side of inlet transition structure (11/11/04).

Photo 12. Kennedy Creek side of outlet transition structure. Note exposed steel reinforcement (11/11/04).

Operations and Issues

The following operational and maintenance issues should be addressed and incorporated into the designs of a future replacement structure.

- Potential hazard due to limited safety features
- No blow-off or drain outlet, remains full year around (Photo 10)
- Difficult to perform off-season inspections
- Top of conduit exposed in stream channel

Estimated Replacement Costs

Depending on capacity, the projected replacement cost estimates vary from $2.3 to $2.5 million (TD&H, 2006).

5.3.2 Potential Failure Modes

The potential failure modes of the Kennedy Creek Siphon were identified and evaluated during the engineering walkthrough. The likelihood and severity of potential damage from a failure is summarized in Table 9 below.

Table 9 - Potential Failure Modes and Corresponding Damage for Kennedy Creek Siphon

Potential Failure	Likelihood of Failure	Relative Severity of Damage
Conduit Collapse	Very Low	Moderate
Headwall Failure	Very Low	Moderate
Piping/Erosion	Very Low	Minor
Exposure in Creek	Low	Minor
Channel Jumping	Low	Moderate to Severe

The Kennedy Creek Siphon is a low-head, pressure siphon. Failure of the siphon would most likely release flow to the natural stream channel of Kennedy Creek.

The possibility of channel jumping due to failure of the diversion/deflector dikes is considered low. Potential damages associated with channel jumping would be moderate to severe – most likely by eroding the existing St. Mary Canal either upstream or downstream of the siphon. Channel jumping would likely be the result of a major flood. The repair would consist of rebuilding the canal and diversion dikes using locally available materials.

Failure of the siphon barrel or transition structures is considered to be low to very low with damages anticipated to be moderate.

5.3.3 Contingency Planning

The recommended contingency planning for this structure is to conduct a "dewatered" inspection of the siphon barrel interior in the near future. Continue to inspect the exterior portion of the siphon barrel exposed in Kennedy Creek and the transition structures. Regular inspections of the diversion/deflector dikes should be made following annual spring and precipitation runoff events. No extensive repairs or improvements are anticipated at this time.

5.4 KENNEDY CREEK CHECK AND WASTEWAY

5.4.1 Existing Conditions

The Kennedy Creek Check and Wasteway structure (Photo 13) is one of two wasteways located along the 29-mile canal. It is located about 1,000 feet downstream from the Kennedy Creek Siphon (Figure 3). It was intended primarily as an emergency discharge point in the event that Kennedy Creek breached or overtopped the canal bank, or to check and release the canal flow to the wasteway if a downstream failure occurred. The wasteway historically served as a discharge for off-season inflows and leakage from the canal headgates. The wasteway discharges into a previous channel of the Kennedy Creek alluvial fan complex making its way to the St. Mary River.

During the fall of 2009, Reclamation's maintenance crew installed a new turnout upstream of the wasteway to alleviate the need to use the wasteway during the winter. The new turnout discharges into the same channel as the wasteway.

Check

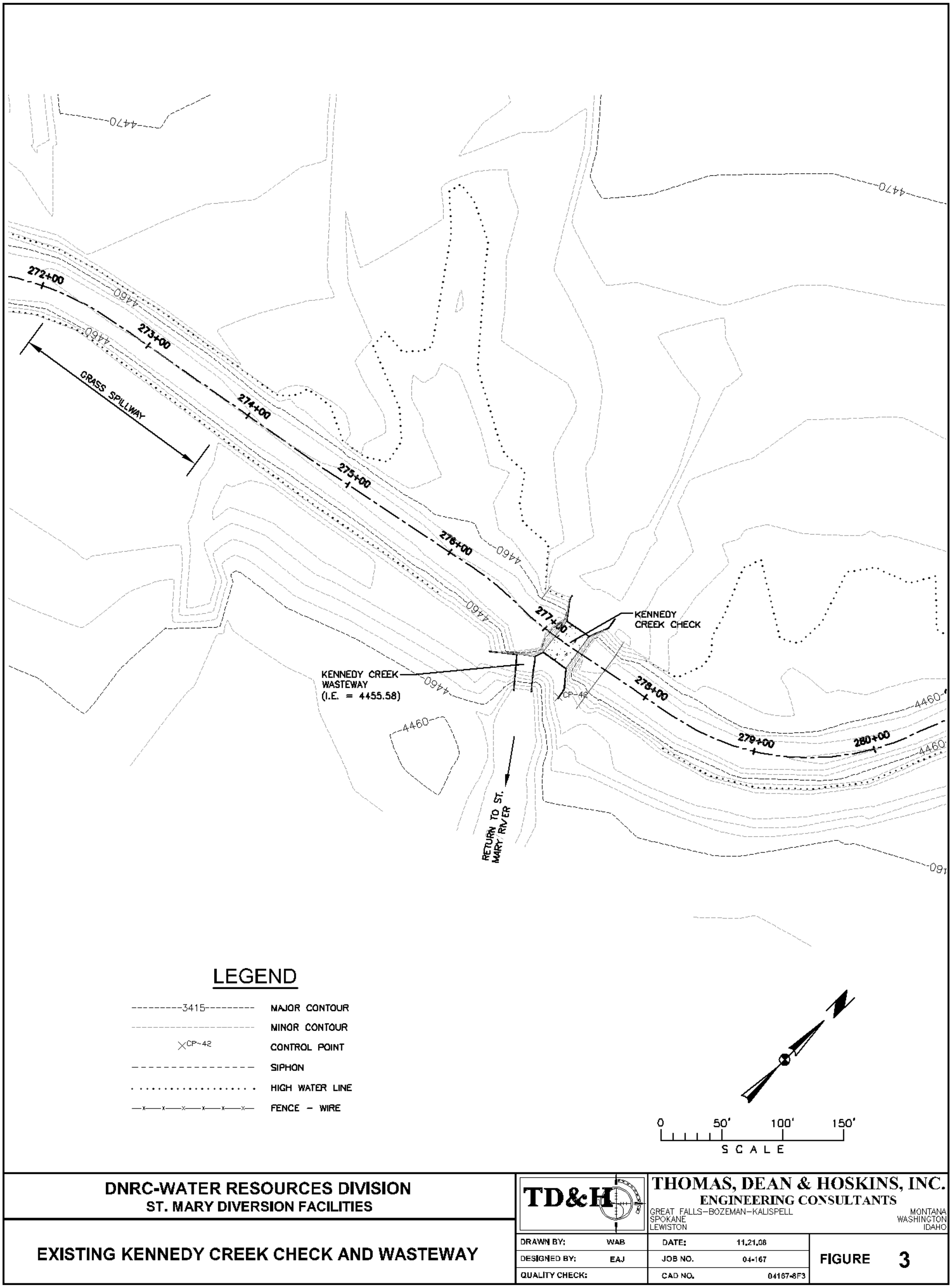
The check portion of the structure consists of three wooden-faced radial gates. The gates are secured in the open position with chains and wire cable to lock them open. They have not been operated in a long time. This most likely represents a safety measure to prevent unauthorized

Photo 13. Upstream view of Kennedy Creek check structure during the off-season. Wasteway is located at right side of photo (10/13/04).

operation or accidental closure if the operating cables failed. The wooden gate faces are deteriorated. Each gate is equipped with a mechanical hoist and cable system to raise and lower the gate. Their deteriorated condition indicates that they would perform poorly if operated. The concrete structure overall is in fair to poor condition. The channel divider walls between the gates and the abutment wall have many areas of deteriorated concrete.

Wasteway

The wasteway invert is depressed approximately 2 feet below the invert of the check structure. The wasteway structure (Photo 14) contains two radial gates of similar construction to the check structure. Only one gate is operable while the second gate has wooden wedges driven between the gate and concrete sidewall to minimize leakage. The face of each gate has been covered with polyethylene plastic sheeting over the wood face to further reduce leakage.


4470
272+00
273+00
274+00
275+00
276+00
277+00
278+00
279+00
280+00
4460
GRASS SPILLWAY
KENNEDY CREEK CHECK
KENNEDY CREEK WASTEWAY (I.E. = 4455.58)
CP-42
RETURN TO ST. MARY RIVER
LEGEND
3415 MAJOR CONTOUR
MINOR CONTOUR
CP-42 CONTROL POINT
SIPHON
HIGH WATER LINE
FENCE - WIRE
N
0 50' 100' 150'
SCALE
DNRC-WATER RESOURCES DIVISION
ST. MARY DIVERSION FACILITIES
EXISTING KENNEDY CREEK CHECK AND WASTEWAY
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SPOKANE
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MONTANA
WASHINGTON
IDAHO
DRAWN BY: WAB
DESIGNED BY: EAJ
QUALITY CHECK:
DATE: 11.21.08
JOB NO. 04-167
CAD NO. 04167-8F3
FIGURE 3

Notes

Photo 14. Upstream view of Kennedy Creek wasteway structure during off-season. Note only one gate is open. Check structure is to left. (10/13/04).

The concrete on the wasteway portion of the structure is much more deteriorated than on the check structure (Photo 15). There is significant spalling and reinforcing steel exposed in each of the raceways above the low water line. The downstream walls and center wall are also in poor condition. The top slab is extremely deteriorated and can no longer support the reaction thrust produced by the gate operators. Steel beams have been placed beneath the operator for the only operable gate to support the gate reaction load (Photo 16).

Background Data Summary

The following data summarizes pertinent specifications of the Kennedy Creek Check and Wasteway structures.

- Check – 29’ wide by 11.5’ high with three, 9’ wide by 10’ high wooden-faced, radial gates
- wasteway – 2’ lower than check, 13’ wide by 13.5’ high with two, 6’ by ‘6 wooden-faced, radial gates
- Hand-lain, grouted rip rap upstream and downstream of both structures
- Grassy spillway located upstream of check structure (Figure 3)

Photo 15. Downstream view of Kennedy Creek wasteway structure. Note condition of concrete surfaces (09/25/07).

Photo 16. Kennedy Creek wasteway operators (09/25/07).

Operations and Issues

The operational issues and limitations of the Kennedy Creek Check and Wasteway are listed as follows:

- Check structure is not operational
- Only 1 of 2 wasteway gates has been used; the other is wedged-shut and has been sealed with PE sheeting to reduce leakage
- Ice buildup hinders closing of gate in March prior to diversions
- Operating wasteway gate could be used for emergency releases
- Deteriorated concrete structures
- Lacks automation and remote control
- Limited safety features

Estimated Replacement Costs

Depending on canal capacity, the estimated replacement cost varies from $1.1 to $1.4 million for the check structure and $0.6 to $0.7 million for the wasteway (TD&H, 2006).

5.4.2 Potential Failure Modes

The Kennedy Creek Check is not operational. Potential failure modes, identified during the 2007 engineering walkthrough, would not compromise the canal or its operation. Moderate damage resulting from erosion of the grassy spillway and foreslope of the canal embankment could occur if the radial gates of the check were to fail in a closed position during normal canal operations.

The wasteway structure is situated within the fill embankment and therefore structural collapse and failure due to progressive piping would be similar to a canal breach. Due to the relatively low head and coarse alluvial soils (USBR, 2001) the risk of progressive and internal erosion is very low. The most likely wasteway failure involves the two radial gates. During normal operations, loss of one or both gates would result in lost diversions. Physical damage would be limited to minor erosion since the discharge would be confined to the natural drainage and eventually flow to the St. Mary River.

The potential failure modes and associated damages are listed in Table 10 below.

Table 10 - Potential Failure Modes and Corresponding Damage For the Kennedy Creek Check and Wasteway

Potential Failure	Likelihood of Failure	Severity of Damage
Check Gates	Very Low	Moderate
Wasteway Gates	Low to Moderate	Minor
Concrete Collapse	Very Low	Minor
Piping/Erosion	Very Low	Minor

5.4.3 Contingency Planning

The recommended contingency planning for this structure is to continue with scheduled inspections of both structures – particularly the wasteway gates. No extensive repairs or improvements are recommended at this time.

5.5 ST. MARY RIVER SIPHON

5.5.1 Existing Conditions

The St. Mary River Siphon is the most significant feature of the St. Mary River Diversion and Conveyance Facilities (Figures 4 and 8). The 3,260-foot long inverted siphon consists of two riveted steel pipes ranging in diameter from 84 to 90 inches (See Photos 17 and 18). The discharge capacity of each pipe is 425 cfs for a combined capacity of 850 cfs. The maximum static head is 165 feet (71.5 psi) which is the approximate elevation difference between the siphon inlet and the bridge crossing. The siphon inlet and outlet are concrete transition structures (Photos 19 and 20).

Previous St. Mary River Siphon failures have occurred due to slope movement causing compression buckling and tensional separation of the pipe at expansion/contraction joints and the concrete transition structures (Photos 21 through 23).

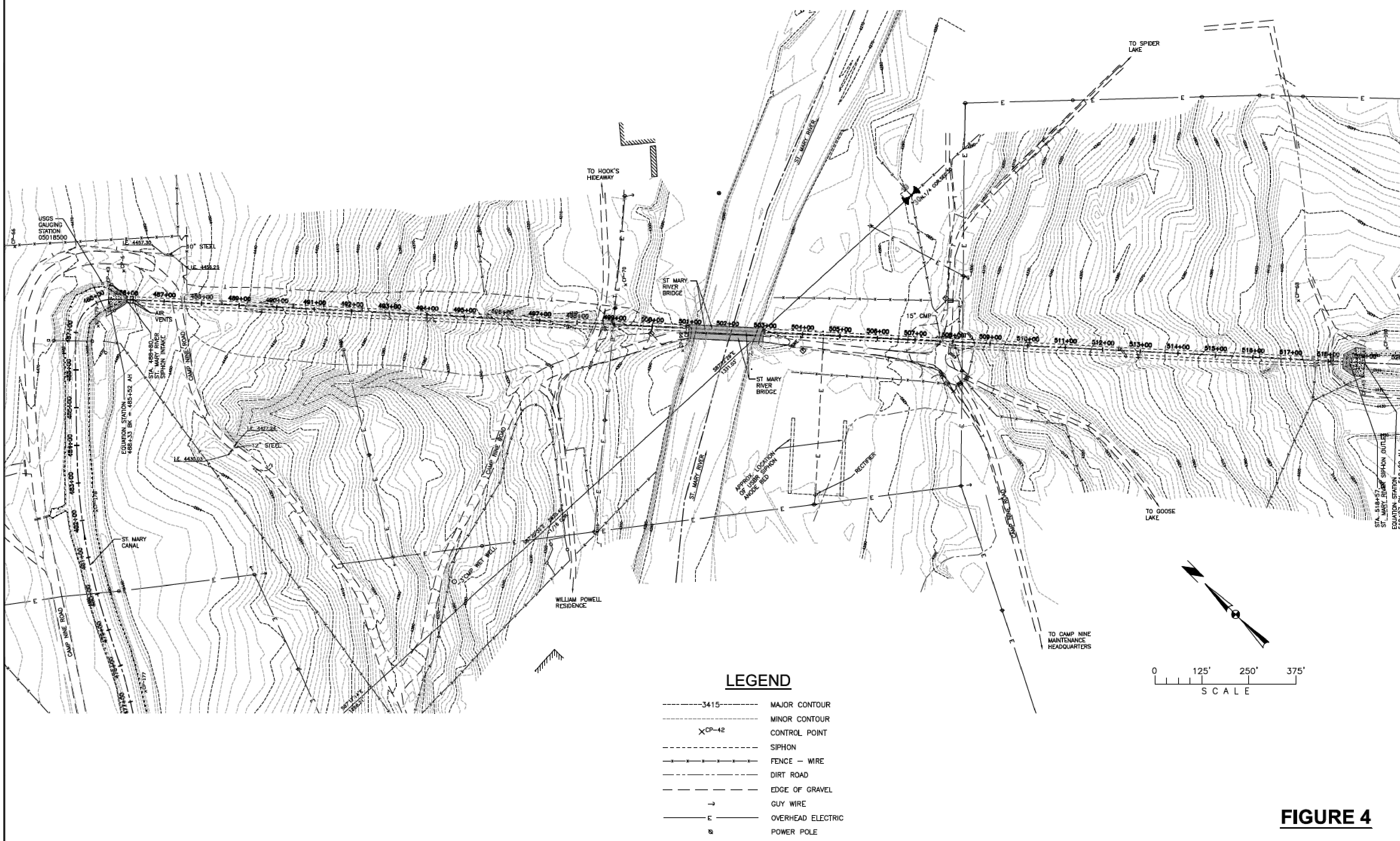

FIGURE 4

ERLING A. JUEL 10740PE REGISTERED PROFESSIONAL ENGINEER MONTANA

REVISIONS		
BY	DATE	DESCR
BY	DATE	DESCR
BY	DATE	DESCR

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EXISTING ST. MARY RIVER SIPHON CROSSING

CAD NO. 04167-8F5.DWG
SHEET 1 OF 1

Notes

Photo 17. Looking downstream (southeast) along the St. Mary River Siphon crossing (07/04/05).

Photo 18. Looking upstream (northeast) along the St. Mary River Siphon crossing (07/04/05).

Photo 19. St. Mary River Siphon inlet structure (10/13/04).

Photo 20. St. Mary River Siphon outlet structure (10/13/04).

Past Reclamation efforts included exposing buried sections, supporting portions above ground on concrete piers, installing subsurface drains along buried sections, maintaining an impressed current cathodic protection system, and most recently, installing additional expansion-contraction joints (Photo 24).

Photo 21. Typical siphon repair due to deflection and/or corrosion at a riveted joint. (10/13/04).

Photo 22. Photo shows ground movements right to left causing rotation of concrete support and point-loading of siphon which can lead to localized buckling (10/13/04). Photo shows the left side of the right barrel on the north slope of the St. Mary River crossing. The arrow points downhill.

Photo 23. Photo shows buckled section of right pipe from the south slope that failed in 1996

Photo 24. A typical expansion/contraction joint installed by USBR staff on the right pipe (5/16/06).

Recent geotechnical monitoring studies performed by TD&H Engineering concluded that slope instabilities and ground movements impacting the siphon are seasonal and correlate to leakage from operations of the St. Mary Canal and naturally-occurring groundwater and storm water infiltrations (TD&H, 2008).

Background Data

Pertinent specifications of the St. Mary River Siphon crossing are summarized below.

- Siphon plan length – 3258'; including transitions – 3345'
- Overall hydraulic drop – 16.31'
- 2 riveted, mild steel barrels each with 425 cfs design capacity (Total capacity – 850 cfs)
- 9.6 to 11.0 fps velocity at full capacity
- Barrel diameter reduces from 90" to 84" at bridge crossing and then back to 90"
- Wall thickness varies from ¼" to ⅜"
- Approximate static head 165' (72 psi)
- Left barrel buried (1912 to 1915), Right barrel above ground (1925-1926)
- Concrete transition structures with grouted riprap aprons
- Crosses river on bridge
- Impressed current cathodic protection

Operations and Issues

The operation of this siphon is passive with no active controls. Dewatering the siphon involves dewatering the entire upstream canal and the majority of Spider Lake, which drains back towards the siphon outlet.

Ground slope movement increases during operations due to leakage from the siphon and adjacent canal. Most of the movement occurs on the south slope.

The operational issues of the siphon crossing are summarized below.

- No mechanism to isolate flow to one barrel
- Leaks at numerous locations, mainly at expansion/contraction joints
- Both slopes moving, south side more than north
- Corrosion
- Hazardous condition at inlet due to limited safety features
- Siphon blow-offs located on bridge

Estimated Replacement Costs

The estimated replacement cost varies from $29 to $40 million (TD&H, 2006) depending on design capacity, number of conduits, configuration, and type of pipe material.

5.5.2 Potential Failure Modes

Potential failure modes and damage for the St. Mary River Siphon that were identified during the engineering walkthrough are summarized in Table 11 below.

Table 11 - Potential Failure Modes and Corresponding Damage for the St. Mary River Siphon

Potential Failure	Likelihood of Failure	Severity of Damage
Slope Movements	High	Moderate
Concrete Transitions	Moderate	Catastrophic
Siphon Leaks	Moderate	Minor
Progressive Slope Failure	Moderate	Catastrophic
Siphon Supports	Very Low	Moderate
Corrosion/ Cathodic Protection	Very Low	Minor

Collapse of the concrete support piers and siphon failure due to corrosion pose a very low risk. Failure of the support piers would result in a slow, continual deterioration of the concrete; therefore, impending failure would be observed during routine inspections. Likewise, corrosion would be slow and would likely be identified during internal inspections of the individual barrels.

Slope and ground movements can cause a variety of failures ranging from relatively minor to catastrophic. Catastrophic failure would include severe environmental damage and an economic disaster due to loss of St. Mary River diversions for one or more seasons.

Ground movements impart forces on the siphon that cause either compressional or tensional stresses. Compressional stresses can result in failure of the siphon sidewalls and joints, especially when they become increasingly eccentric. Continual movement can result in buckling of the siphon. This type of failure has occurred numerous times during the life of the structure. Tensional forces can also stress riveted joints and expansion/contraction joints. Lateral separation can and has occurred at the concrete transition structures.

5.5.3 Contingency Planning

The majority of potential failure modes and damage severity for the St. Mary River Siphon are attributed to ground slope movements. Eliminating siphon leakage and canal seepage in the vicinity of the siphon crossing would eliminate ground movements. This is impractical due to the number of groundwater seepage pathways. A more practical option is to install internal slope drainage adjacent to and below the siphon to stabilize groundwater levels year-round. This would significantly reduce the hydrostatic forces that induce slope instability and improve shear strength.

Leakage and seepage can be reduced by:

- Identifying and repairing leaks in the pipes, at riveted joints, and at expansion/contraction joints
- Inspecting and sealing the interface at the steel pipe to concrete transitions
- Lining the approach and trailing canal within 400 feet of the transition structures
- Installing an effective drainage system alongside the buried siphons
- Grading the terrain to direct surface runoff away from the siphon
- Installing a series of horizontal drains on the south slope

Rehabilitating the St. Mary River Siphon would involve a new replacement structure near the existing crossing. Unknowns include:

- Alignment and grade
- Configuration
- Capacity

At the earliest possible time, the new siphon design should be developed and available in the event of a catastrophic failure. The new design will have a different alignment and most likely different invert elevations; therefore, the replacement design should have the flexibility of installing it to match current grade and alignment while being able to modify it in the future to match final grade and alignment.

Even minor failures to a single barrel require a system shutdown to make repairs. Stop log guides exist on the inlet transition (Photo 25), but not on the outlet transition (Photo 20). Installing stop log guides and constructing stop logs for both transitions to isolate the barrel needing repairs would allow diversions to continue through the other barrel hence avoiding a complete shutdown.

Photo 25. Close-up of St. Mary River Siphon inlet during diversion. Note stop log guides in concrete (07/18/08).

The most effective contingency planning is regular and thorough inspection of all siphon components and monitoring ground slope movement adjacent to the siphon barrels. Reference points should also be established on exposed sections of the siphon to regularly monitor and measure displacements.

For buried sections, internal inspections, as currently performed by Reclamation, are warranted to assess pipe movements, deflections, and changes in wall thickness due to corrosion. Regular, external and internal inspections provide an opportunity to monitor and document the on-going displacements and deterioration of the siphon.

5.6 ST. MARY RIVER BRIDGE

5.6.1 Existing Conditions

From 1915 to 2008, the St. Mary River Bridge has served the dual purpose of public access and supporting the steel barrels across the St. Mary River (Photo 26). In 2008, a new county bridge was constructed approximately 200 feet upstream of the original bridge (Photo 27). The original bridge location is shown in Figure 4.

Photo 26. Looking downstream along the St. Mary River Siphon at the existing bridge (07/04/05).

The bridge has experienced recent damage to the vertical trusses and top cords of the steel portal bracing from oversized equipment crossing the bridge (Photos 28 and 29). The posted 10-ton load limit was exceeded regularly, even when the siphon was full. The bridge is constructed of low tensile and yield strength, mild steel. The truss superstructure has a fractured critical member. The substructure exhibits deteriorating and spalling concrete, especially at the fixed bearing points. Expansion rollers are reportedly frozen and nonfunctional.

Photo 27. New Glacier County bridge under construction approximately 200 feet upstream of the existing St. Mary River Bridge (7/17/08).

Photo 28. Damage to top chord (5/10/07).

Photo 29. Damage to vertical truss (5/10/07).

Background Data Summary

The following data summarizes pertinent specifications of the existing siphon bridge:

- Two span, triple steel truss structure built in 1915 by the Minneapolis Bridge Company
- Two 100’ spans with 194’ clear span beneath
- 18’ of vertical hydraulic clearance
- Single lane traffic on 4”x16” stringers and 3”x12” transverse planks and longitudinal running boards—now closed to public use
- Concrete terminal abutments and center pier

Operations and Issues

The operational and maintenance issues of the St. Mary River Bridge are summarized below.

- Carries the St. Mary River Siphon
- Provides maintenance access

- 10-ton Load Limit
- Concrete substructure exhibits deterioration and spalling
- Damaged steel trusses and cross bracing

5.6.2 Potential Failure Modes

Since the St. Mary River Bridge has been replaced, discussions regarding potential failure modes will be focused on its ability to carry the siphon. Failure modes and related damage are summarized in Table 12 below.

Table 12 - Potential Failure Modes and Corresponding Damage for the St. Mary River Bridge

Potential Failure	Likelihood of Failure	Severity of Damage
Abutment & Pier	Very Low	Severe
Superstructure	Very Low	Severe
Vehicular Access Deck	Low	Minor

The likelihood of failure regarding the bridge substructure and foundation is very low. With the exception of a cataclysmic flood event, the deterioration and eventual failure of the concrete abutments and center pier will be slow and gradual. Impending failure would most likely be identified during normal, periodic inspections. Failure of the steel superstructure is also considered to be very low provided regular inspections are performed. The risk of failure is significantly reduced since the bridge has been closed to public use.

Failure of the substructure or superstructure that rendered the bridge unable to carry the siphon or causes damage to the siphon would be considered severe. The damage would result in a long-term loss of diverted water and costly repairs to restore the siphon and bridge. A collapse and rupture of the siphon barrels at the bridge would cause minor environmental damage since the discharge would be confined to the St. Mary River channel.

5.6.3 Contingency Planning

The recommended contingency planning for the St. Mary River Bridge is to maintain only restricted access. Regular bridge inspections that focus on the steel members and connections are recommended. No other proactive tasks are recommended at this time.

5.7 HALL COULEE WASTEWAY

5.7.1 Existing Conditions

The Hall Coulee Wasteway is located approximately 3,700 feet upstream of the inlet transition for the Hall Coulee Siphon (Figure 5). The wasteway, now inoperable, served as an emergency discharge and relief point in the event of a downstream failure. The wasteway had a reported capacity of 918 cfs and discharge via baffled apron drop to a natural drainage swale. Releases were controlled by three wooden-faced, radial gates. The gate operators have been removed and the gates wedged shut to reduce leakage. Earth fill has been placed within the canal adjacent to the gates to further reduce leakage. An access bridge spans the apron chute on the downstream side of the gates. Reclamation bridge inspectors closed the access bridge due to the condition of the bridge deck. Earth berms were installed on the approaches to prohibit use of the bridge until repairs are made.

The following data summarize pertinent specifications of the Hall Coulee Wasteway.

Background Data Summary

- Reported capacity of 918 cfs
- Three, 6’ by 5’ wooden-faced, radial gates
- Baffled apron energy dissipation to natural drainage
- 12’ maintenance bridge over wasteway
- Grassy spillway located 750’ downstream (Figure 5)

Operations and Issues

- Wasteway structure is not operational
- Wasteway gates not used; wedged-shut to reduce leakage
- Hoist operators have been removed
- Bridge use has been discontinued
- Deteriorated concrete structures

Notes

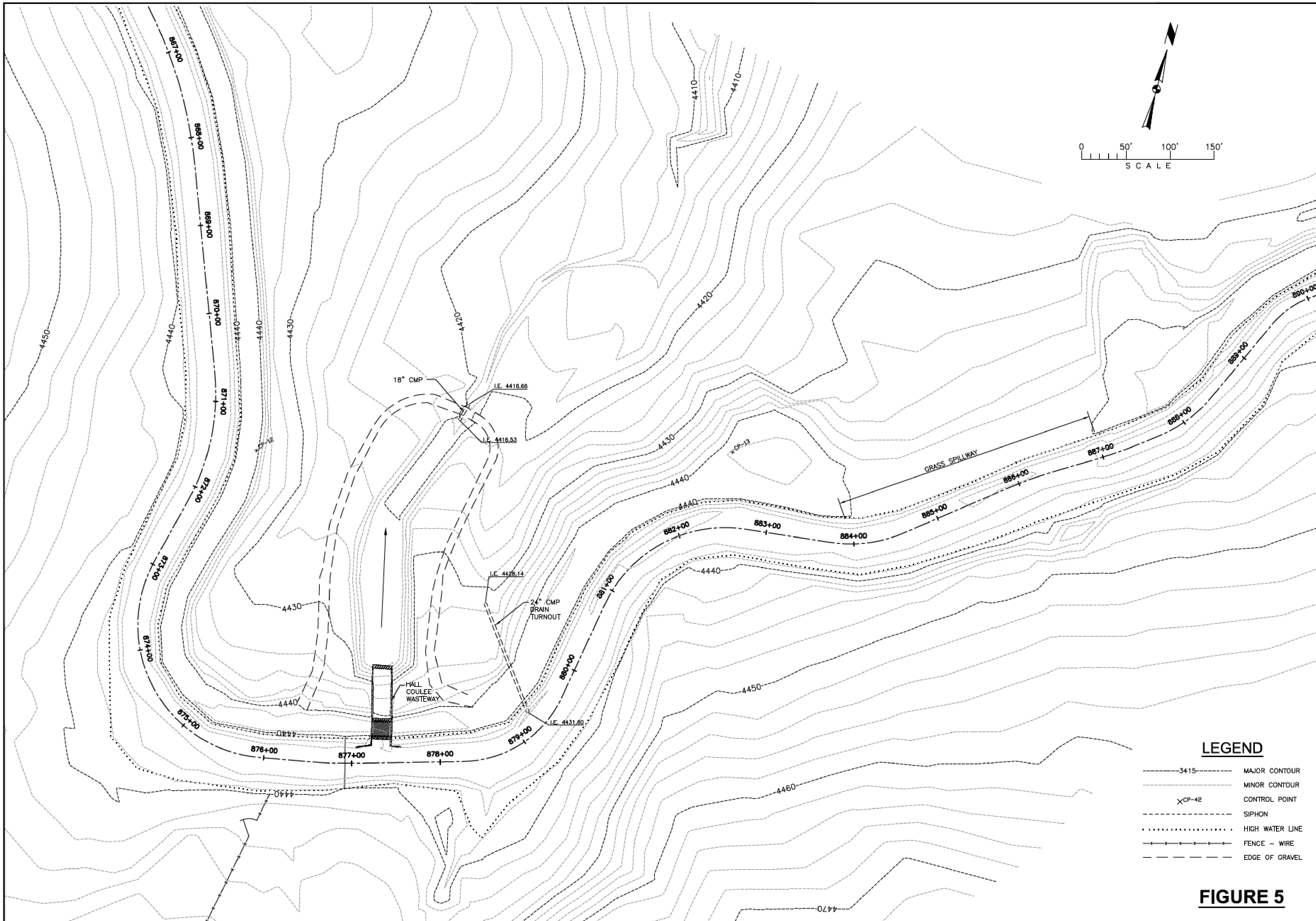


FIGURE 5

ERLING A. JUEL 10740PE
MONTANA REGISTERED PROFESSIONAL ENGINEER

THOMAS, DEAN & HOSKINS, INC.
ENGINEERING CONSULTANTS
GREAT FALLS–BOZEMAN–KALISPELL–HELENA
SPOKANE
LEWISTON
MONTANA
WASHINGTON
IDAHO

TD&H

REVISIONS		
BY	DATE	DESCR
BY	DATE	DESCR
BY	DATE	DESCR

DRAWN BY:	WAB
DESIGNED BY:	EAJ
QUALITY CHECK:	
DATE:	11.21.08
JOB NO.	04-167
FIELDBOOK	

DNRC - WATER RESOURCES DIVISION
ST. MARY DIVERSION FACILITIES

EXISTING HALL COULEE WASTEWAY

CAD NO. 04167-8F6.DWG
SHEET 1 OF 1

Notes

Estimated Replacement Costs

Depending on the desired discharge capacity, the estimated replacement cost varies from $0.7 to $0.8 million (TD&H, 2006).

5.7.2 Potential Failure Modes

Failure of the inoperable wasteway is similar to a canal breach, which would result in a loss of diverted flow. The likelihood of this occurring is very low. A failure would be relatively minor since the wasteway and drainage were initially designed to handle over 900 cfs. The St. Mary Canal typically is less than 700 cfs in this reach. The potential failure modes and resulting severity of damage are summarized in Table 13 below.

Table 13 - Potential Failure Modes and Corresponding Damage for the Inoperable Hall Coulee Wasteway

Potential Failure	Likelihood of Failure	Severity of Damage
Wasteway Gates	Very Low	Minor
Concrete Collapse	Very Low	Minor
Piping/Erosion	Very Low	Minor

5.7.3 Contingency Planning

The recommended contingency planning for this structure is to continue periodic inspections. Monitoring and observing the nature and quantity of seepage draining away from the nonfunctioning wasteway could provide an early indication if deteriorating conditions begin to occur. No other emergency planning activities are recommended at this time.

5.8 HALL COULEE SIPHON

5.8.1 Existing Conditions

The Hall Coulee Siphon (Figure 6) was constructed in two phases with similar construction to the St. Mary River Siphon. (Photos 30 & 31). The Hall Coulee Siphon is relatively stable compared to the St. Mary River Siphon, but has experienced some minor problems with sliding, leakage and closure of expansion/contraction joints (Photo 32).

Photo 30. Looking downstream at concrete inlet transition structure for the Hall Coulee Siphon crossing (10/13/04).

Photo 31. Looking upstream toward inlet of Hall Coulee Siphon (10/13/04).

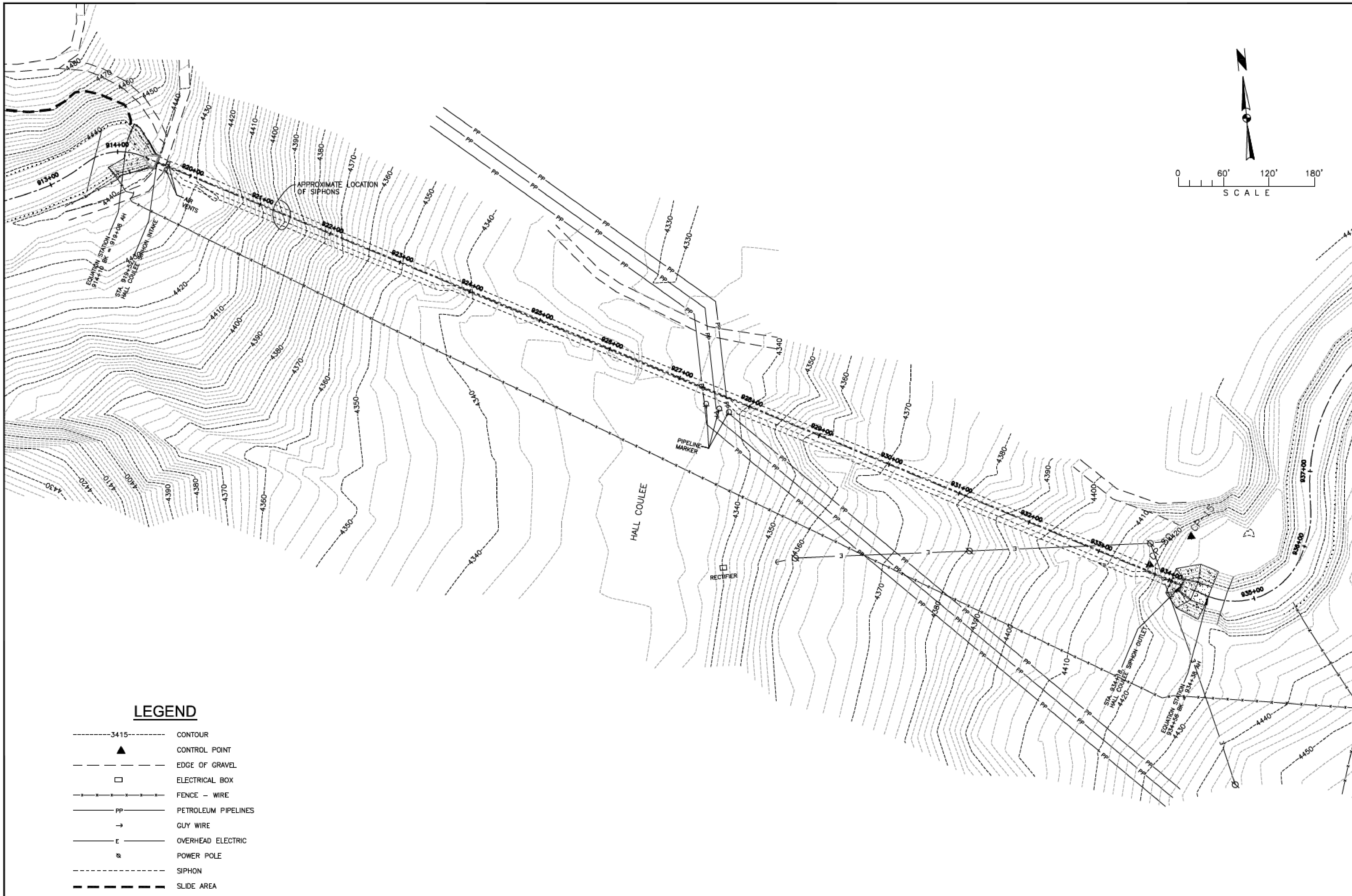


FIGURE 6

MONTANA ERLING A. JUEL 10740PE REGISTERED PROFESSIONAL ENGINEER

REVISIONS

BY	DATE	DESCR
BY	DATE	DESCR
BY	DATE	DESCR

TD&H

THOMAS, DEAN & HOSKINS, INC.
ENGINEERING CONSULTANTS
GREAT FALLS–BOZEMAN–KALISPELL–HELENA MONTANA
SPOKANE WASHINGTON
LEWISTON IDAHO

DRAWN BY:	WAB
DESIGNED BY:	EAJ
QUALITY CHECK:	
DATE:	11,20,08
JOB NO.	04-167
FIELDBOOK	

DNRC - WATER RESOURCES DIVISION
ST. MARY CANAL REHABILITATION

EXISTING HALL COULEE SIPHON CROSSING

CAD NO. 04167-BF7.DWG
SHEET 1 OF 1

Notes

Photo 32. Looking downstream along the Hall Coulee Siphon at leaking expansion/contraction joint (06/24/04),

Background Data

The pertinent specifications of the Hall Coulee Siphon crossing are summarized below.

- Siphon plan length – 1466’, including transitions – 1548’
- Overall hydraulic drop – 14.01’
- 2 riveted, mild steel barrels each with 425 cfs design capacity
- Diameter – 78”
- Nominal wall thickness ¼”
- Approximate static head 85’ (37 psi)
- Left barrel buried (1912 to 1915), right barrel above ground (1925-1926)
- Concrete transition structures with grouted riprap aprons
- Crosses over several petroleum product pipelines at the valley bottom
- Impressed current cathodic protection

Operations and Issues

The operation of this siphon is passive with no active controls. The siphon is dewatered during the off-season, which involves dewatering the entire upstream canal. If the blowoffs on the St. Mary River Siphon are not opened, then Spider Lake would drain towards the Hall Coulee Siphon.

The operational and maintenance issues are summarized below.

- No mechanism to isolate flow to one barrel.
- Concrete deterioration on transition structures
- Dewatered during off-season
- Leaks at some locations, mainly at expansion/contraction joints
- Both slopes moving—however, minor compared to river siphon
- Corrosion, wall thickness as thin as 0.19” measured in 2004
- Hazardous condition at inlet due to limited safety features

Estimated Replacement Cost

Depending on the design capacity, configuration and alignment, the estimated replacement cost varies from $12 to $16 million (TD&H, 2006).

5.8.2 Potential Failure Modes

Similar to the St. Mary River Siphon, the Hall Coulee Siphon possesses a wide range of potential failure modes and related levels of damage. The Hall Coulee Siphon has experienced failures related to ground movements although not to the degree of the St. Mary River Siphon. The potential failure modes and corresponding levels of damage are summarized in Table 14 below.

Table 14 - Potential Failure Modes and Corresponding Damage for the Hall Coulee Siphon

Potential Failure	Likelihood of Failure	Severity of Damage
Concrete Transitions	Moderate	Catastrophic
Siphon Leaks	Moderate	Minor
Slope Movements	Moderate	Moderate
Progressive Slope Failure	Moderate	Catastrophic
Siphon Supports	Very Low	Moderate
Corrosion/Cathodic Protection	Very Low	Minor

The risk of failure due to corrosion or collapse of the concrete support piers is assumed to be very low. The slow process of both failure modes would likely be identified during regular inspections.

Ground movement and subsequent siphon movement can cause the same variety of failures as the St. Mary River Siphon, ranging from minor to catastrophic. Catastrophic failure at Hall Coulee would be less of an environmental issue but could cause a similar economic disaster as discussed in Section 5.5.2.

5.8.3 Contingency Planning

It is too early in the geotechnical monitoring program at the Hall Coulee Siphon to identify groundwater trends; however, observations suggest that siphon movement is directly related to groundwater issues in the trench excavation and backfill zones of the buried portions of the siphon. The source of groundwater is canal seepage and siphon leakage. Eliminating siphon leakage and canal seepage within the vicinity of the siphon crossing will improve stability and reduce movement. Similar to the St. Mary River Siphon crossing, the following improvements would reduce the detrimental effects of leakage and seepage:

- Identify and repair leaks in the pipe, at riveted joints and at expansion/contraction joints
- Inspect and seal the interface at the steel pipe to concrete transitions
- Line the approach and trailing canal within 400 feet of the transitions
- Install an effective drainage system alongside the buried siphon sections
- Regrade the terrain to direct surface runoff away from the siphon

Since the Hall Coulee Siphon is similar to the St. Mary River Siphon, most of the contingency planning discussions and emergency response activities are applicable and are briefly reiterated below:

- A catastrophic midslope failure would result in a multi-season loss of diversions and cost millions of dollars to repair. Repairing or rebuilding the structure to the old design and alignment is a concern.
- At the earliest possible time, the new design should be developed and available in the event of a catastrophic failure.

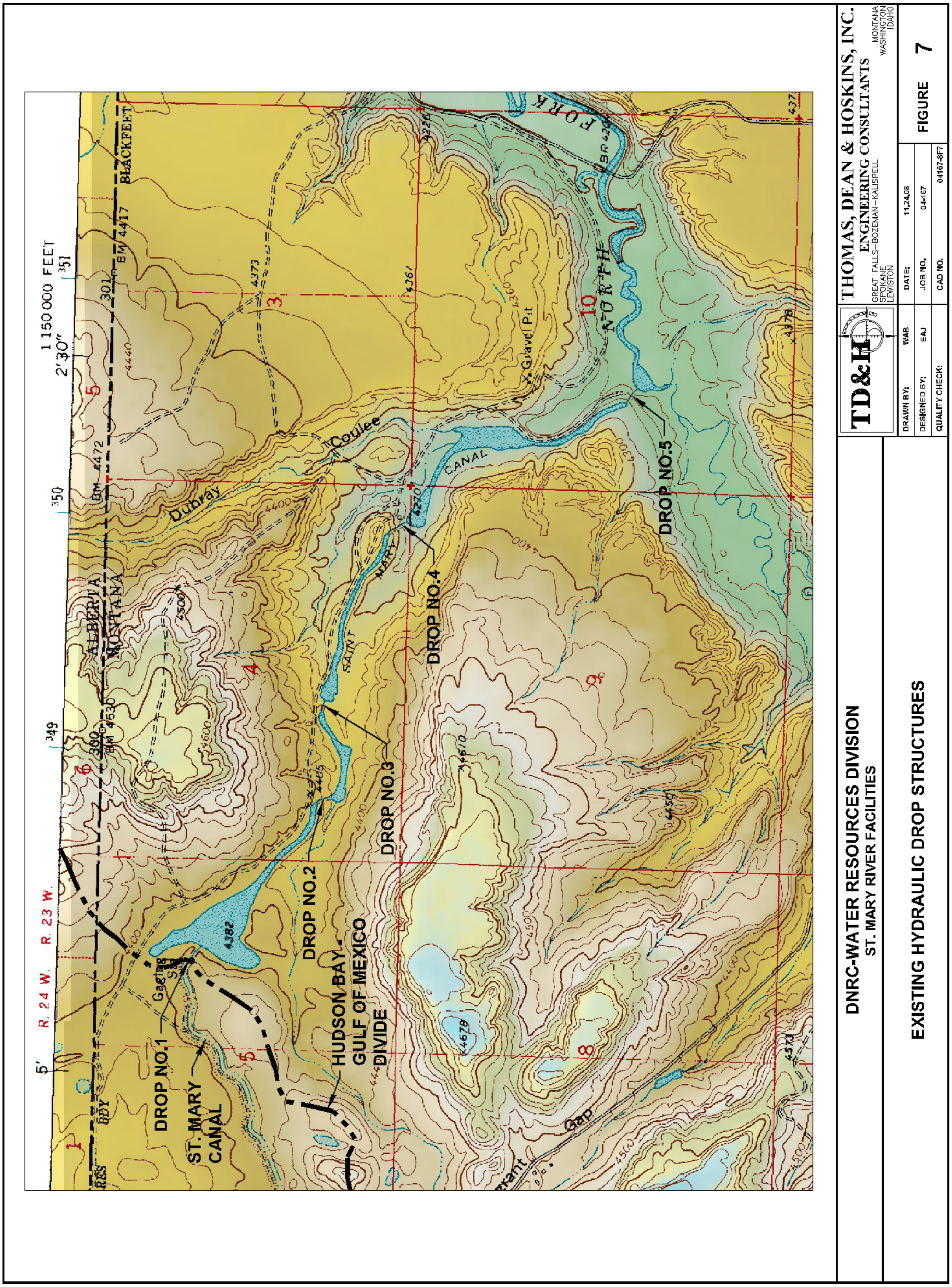
- Stop log guides installed and pre-made stoplogs constructed for both transitions to allow repairs without a total system shutdown.
- Regular and thorough inspections to document and monitor deterioration.
- Establish reference points on the exposed sections of both barrels to monitor movements.

5.9 HYDRAULIC DROPS

5.9.1 Existing Conditions

The St. Mary Canal discharges to the North Fork Milk River after passing over the Hudson Bay - Gulf of Mexico Divide (Figure 7). Energy dissipation is achieved through five reinforced concrete drop structures that have a combined drop of approximately 218 feet. Photos 33 and 34 show drops 1 and 2 operating.

Photo 33. Looking downstream at Drop No. 1 chute and stilling basin (06/24/04),


DROP NO.1
DROP NO.2
DROP NO.3
DROP NO.4
DROP NO.5
ST. MARY CANAL
HUDSON BAY-GULF OF MEXICO DIVIDE
SAINT MARY CANAL
NORTH FORK
Dubray Coulee
Gravel Pit
ALBERTA
MONTANA
BLACKFEET
R. 24 W.
R. 23 W.
1 150 000 FEET
THOMAS, DEAN & HOSKINS, INC.
ENGINEERING CONSULTANTS
GREAT FALLS–BOZEMAN–KALISPELL
SPOKANE
LEWISTON
MONTANA
WASHINGTON
IDAHO
TD&H
DRAWN BY: WAB
DESIGNED BY: EAJ
QUALITY CHECK:
DATE: 11.24.08
JOB NO. 04-167
CAD NO. 04167-8F7
FIGURE 7
DNRC-WATER RESOURCES DIVISION
ST. MARY RIVER FACILITIES
EXISTING HYDRAULIC DROP STRUCTURES

Notes

Photo 34. Looking upstream towards Drop No. 2 (05/16/06),

Various concrete repairs have been made to the drop structures over the years. These repairs have ranged from grouting cracks to replacing entire sections of a structure due to concrete deterioration and failure. Recent failures and repairs include: Entire chute and side wall replacement of Drop No. 2 in 2002; chute floor replacement of Drop No. 3 in the 2004/2005 off-season (Photo 35); and a major rebuilding of the plunge pool basin and wing walls on drops No. 2 and 3, and a section of the chute floor on Drop No. 2 in the 2008/2009 off-season.

<u>Background Data</u>

The pertinent specifications of the five hydraulic drops are summarized below:

- Drop lengths: No. 1 – 203'; No. 2 – 237'; No. 3 – 202'; No. 4 – 225'; No. 5 – 275'.
- Vertical Drop: No. 1 – 31.32'; No. 2 – 25.8'; No. 3 – 25.1'; No. 4 – 61.31'; No. 5 – 60.89'. Combined vertical drop - 204 (drop structures), 218' (total)
- Drops are concrete chutes with plunge pools/stilling basins
- 850 cfs design capacity
- Sloping sidewalls
- Vertical terminal drops
- Safety cable and floats at Drop No. 1 only

Photo 35. Repairs being made to chute floor of Drop No. 3 during off-season (10/13/04).

Operations and Issues

Operation of the hydraulic drops is passive. The majority of each stilling basin drains away during the off-season; however, the plunge pool and stilling basin at the base of each hydraulic drop remain inundated and must be pumped dry in order to visually inspect the plunge pool floors.

The operational and maintenance issues are summarized below.

- Severe concrete deterioration
- Chute jumping potential
- Adequate safety features are lacking

Estimated Replacement Cost

Depending on type and design capacity, the estimated replacement cost for all five drops varies from \$4.2 to \$5.4 million (TD&H, 2006). Reconstruction of interconnecting canals is estimated to cost between \$2.9 and \$3.7 million..

5.9.2 Potential Failure Modes

Failures associated with the hydraulic drops include and/or result from the following:

- Erosion related to flows exceeding the hydraulic capacity or inadequate design
- Erosion related to chute jumping due to deterioration of the hydraulic flow regime
- Progressive failure due to concrete deterioration and structural collapse
- Progressive failure due to cavitation
- Progressive failure due to stagnation pressures and hydraulic jacking
- Foundation erosion and piping

Erosion Due to Inadequate Capacity

The hydraulic flow regime of the drops is regulated except during storm water inflows. These inflows are usually small compared to the diversion discharge. Flows that exceed the canal capacity would most likely breach the downslope embankment, preferably at a dedicated grassy spillway. The reported chute design capacity is 850 cfs, which exceeds the current canal capacity of 700 cfs. Therefore erosion-related failure from exceeding the hydraulic capacity of the drops is very low.

Erosion could result from chute jumping, which occurs when concrete deterioration affects the flow regime. Photos 36 and 37 illustrate the flow regimes over both a new smooth concrete surface and an older, deteriorated surface.

Photos 38 and 39 also show deteriorating flow regimes and potential chute jumping. This is evident from the staining on the chute sidewalls. Loss of containment associated with chute jumping, combined with the steep terrain and erodible soils, could result in progressive backside erosion and sidewall collapse.

Photo 36. Looking downstream at Drop No. 2 during diversion. Note dramatic change in flow regime. Also see Photo 37 (05/16/06)

Photo 37. Drop No. 2 in the off-season. Note clean flow lines over new concrete surfaces replaced in 2002 and increased flow depth over rougher, older concrete surfaces (10/13/04).

Photo 38. Downstream view of Drop No. 4. Note irregular flow regime and potential chute jumping as evident from the concrete staining (10/13/04).

Photo 39. Downstream view of Drop No. 5. Note irregular flow regime and potential chute jumping as evident from the concrete staining (09/27/07).

Structural Failure

Surface roughness and offsets at joints or displacement cracks can create net negative pressure differentials that can cause uplift. This phenomenon can also drive water through the cracks and into the underlying soils leading to foundation erosion and failure. Also, fragmentation and picking can occur, decimating a concrete surface which in turn increases the roughness and the propensity for additional fragmentation and lifting. Concrete deterioration is accelerated when exposed to freeze-thaw cycles. Photos 40 through 47 show various structural failures at the drop structures.

Photo 40. Close-up of concrete deterioration of Drop No. 4 chute floor (11/10/04).

Photo 41. View of chute floor directly above plunge pool headwall of Drop No. 2. Note the degree of concrete ablation (09/27/07).

Photo 42. View of slab offset in chute floor of Drop No. 2. (09/27/07).

Photo 43. Close-up of concrete deterioration of Drop No. 4 chute floor (11/10/04).

Photo 44. Looking downstream at lower end of chute floor for Drop No. 5. Note condition and surface roughness of concrete (09/27/07).

Degradation of the foundation soils can occur from erosion and piping caused by the intrusion of chute seepage. This is magnified by stagnation pressures and hydraulic slab jacking. Use of water stops, keyed concrete joints, and well-constructed subsurface drainage can negate these impacts. Drains can fail over time due to plugging, corrosion of metal drains, and settlement of poorly consolidated soils. Potential failure modes and related damages are summarized in Table 15 below.

Table 15 - Potential Failure Modes and Corresponding Damage for the Hydraulic Drop Structures

Potential Failure	Likelihood of Failure	Severity of Damage
Piping/Erosion	Moderate to High	Catastrophic
Chute Floor	Moderate to High	Catastrophic
Wingwall or Structure Collapse	Moderate	Moderate
Slope Failure	Very Low	Catastrophic
Stilling Basin	Very Low	Minor
Drain Failure	Low	Moderate

Photo 45. View of plunge pool headwall of Drop No. 1. Note condition of concrete and exposed reinforcement steel (09/27/07).

Photo 46. View of plunge pool headwall of Drop No. 2. Note condition of concrete and exposed rebar (09/27/07).

Photo 47. Heavily damaged/eroded wing and training walls on Drop No. 5 11/10/04).

5.9.3 Contingency Planning

The concrete surfaces of the hydraulic drops are difficult to inspect and monitor during the diversion season; however, changes in the characteristics of the flow regime could indicate degradation of these submerged concrete surfaces. Frequent observations during the diversion season help identify deteriorating conditions.

Annual inspections are performed on each drop chute immediately following dewatering. This maximizes the use of favorable weather conditions to implement comprehensive inspections or repairs if necessary. Midseason shut-downs provide additional opportunities to perform inspections. Inspection of the plunge pool floor, wing walls and stilling basins are complicated by off-season inundation. In general, submerged concrete tends to be less exposed to freeze-thaw cycles and therefore more protected from their detrimental effects. However, it is imperative to inspect these portions of the drop structures. Their condition and age warrant inspections every 2 to 3 years.

Due to high flow velocities, chute floors and chute sidewall failures would require replacement with a reinforced concrete section matching existing lines and dimensions. A temporary, non-erodible, alternative, surface may be utilized, but would most likely require significant flow reductions to maintain safety. A system shut-down and an expedited replacement of the failed section may be the preferred solution, similar to what was done on Drop No. 2 in 2002.

Catastrophic failure of a drop structure would likely result in loss of the remaining diversion season. Restoration of the failed drop would require rehabilitation of the existing structure or a replacement structure. The goal would be to restore the failed drop prior to the next diversion season. The following tasks are recommended to expedite the necessary repairs:

- Completed designs consistent with the new grade and alignment
- Cultural resource and environmental studies completed on the approved impacted corridor; and
- Procure the Right-of-Way to install an adjacent, replacement structure.

The plunge pools represent an area of high energy dissipation and the potential for erosion. Failure of the plunge pools and related components could be permanently repaired with similar cast-in-place concrete construction, or temporarily repaired with erosion-resistant materials such as large riprap or gabion structures. Use of these materials could restore diversions until permanent repairs are made in the off-season.

5.10 CANAL PRISMS, CROSS DRAINS, AND TURNOUTS

5.10.1 Existing Conditions

CANAL

The St. Mary Canal was constructed between 1907 and 1915 with an original design capacity of 850 cfs. The 26-mile canal portions are earthen, unlined, one-bank, contour design (Photo 48). The current capacity is about 650 cfs primarily due to slope instabilities and landslides.

Photo 48. Canal, looking upstream toward Big Cut Slide. Note winding, contour-following nature of the canal alignment. (05/16/07).

Reclamation maintains a Landslide Register for all landslide and embankment instabilities that either currently impact or could impact their projects. As of November 2008, 16 landslides are listed for the St. Mary Facilities. Primary factors contributing to the slope instabilities include low shear strengths, elevated soil moisture contents and hydrostatic/artesian forces, surcharge loads, slope geometry and toe erosion. Large precipitation events cause the majority of the landslides and stabilities on the canal backslopes. The original typical canal section consisted of 1½:1 (H:V) backslope and 2:1 fill slope angles, which are too aggressive for the marginal soil strengths and the effects of saturation on them. The steep angles were likely dictated to minimize the excavation performed by horse-drawn fresnos during original construction.

CROSS DRAINS

There are currently seven underdrains conveying cross drainage under the canal. All other drainages flow directly into the canal as inflows from surface runoff. Grassed spillway overflow sections were constructed at several locations to accommodate excess canal discharges and inflows from runoff. The existing underdrains and proposed replacements are listed in Table 16 below.

Table 16 - Existing and Proposed Underdrains Along the St. Mary Canal

Station/Locations	Existing Underdrain Structure	Proposed Replacement
331+55	Twin 66" Φ RCP Pipes	In-Kind
791+34	180 LF - 4.5' x 5.0' Conc. Box	Twin 72" Φ RCP
978+46	143 LF – 24" Φ RCP Pipe	48" Φ RCP
1051+68	140 LF – 30" Φ RCP Pipe	48" Φ RCP
1094+05	168 LF – 30" Φ RCP Pipe	48" Φ RCP
1132+33	143 LF – 30" Φ RCP Pipe	42" Φ RCP
1195+82	157 LF – 30" Φ RCP Pipe	42" Φ RCP

TURNOUTS

The St. Mary Canal turnout structures are used to facilitate drainage for dewatering and maintenance. There are currently eight turnouts on the canal (USBR, 2003). Reclamation maintenance crews have expressed a need for more drain turnouts to facilitate their maintenance activities. One new turnout was installed during the fall of 2009 upstream of the Kennedy Creek wasteway to eliminate the need for the wasteway to be left in the open position through the winter.

Background Data

The following data summarizes pertinent specifications of the St. Mary Canal

- Canal Length – 26 miles (Overall project length – 29 miles)
- Passive operation – Gravity
- Design Capacity – 850 cfs
- Current Capacity – 650 cfs
- 26' flat bottom trapezoidal prism
- 2:1 (H:V) embankment fill slopes
- 1½:1 backslopes
- Invert slope of 0.00010 feet per foot (0.53 feet per mile)
- Constructed of native materials
- 7 Underdrains (Table 16)
- 8 Turnouts (9 as of fall 2009)

Estimated Replacement Costs

Depending on final capacity, the estimated cost to rehabilitate the 26-mile earthen canal varies from $59.9 to $70.8 million (TD&H, 2006). Depending on the width of the rehabilitated canal, the estimated cost to replace the underdrains alone varies from $1.1 to $1.3 million.

5.10.2 Potential Failure Modes

Potential failure modes involving the canal, underdrains, or turnouts would result in bank erosion and loss of containment. A failure of the backslope would reduce the flow area, which could result in over-topping, erosion, and breaching. Pipe failure of either the underdrain or turnout conduit could be progressive and result in a loss of the fill embankment.

The potential damage resulting from the discussed failure modes could be catastrophic depending on the terrain and location of the failure. Failures on steep slopes or near ecologically sensitive streams may result in severe environmental damage. Property damage is also possible. Depending on the extent of damage, loss of diversion and repair time could last up to several weeks. Failure modes and damage severity associated with the canal, underdrains, or turnouts are summarized in Table 17 below.

Table 17 - Potential Failure Modes and Corresponding Damage for Canal Prisms, Underdrains, and Turnouts

Potential Failure	Likelihood of Failure	Severity of Damage
Backslope Failure	Moderate to High	Minor to Catastrophic
Embankment Failure	Moderate to High	Moderate to Catastrophic
Piping/Erosion	Low to Moderate	Moderate
Conduit Collapse	Very Low to Moderate	Moderate
Plugging	Very Low	Minor

5.10.3 Contingency Planning

The recommended contingency planning for these components is to continue regular and thorough inspections. This involves monitoring areas of known instability and areas that exhibit downslope seepage. For conduits, monitoring for evidence of piping failure and seepage may provide early warning signs of an impending failure. Early detection means corrective measures can be taken before a failure occurs. Also, canal gauging stations with alarms and telemetry should be deployed as a means of remote monitoring for canal failure or other loss of containment.

Notes

6.0 FACILITY BACKGROUND

Water diverted from the St. Mary River to the Milk River Basin via the St. Mary Diversion and Conveyance Facilities is essential to the economy of Montana's Hi-line Region and to the State of Montana. The 95-year-old St. Mary Facilities are in dire need of rehabilitation or replacement to avert failure and avoid economic and environmental catastrophes. The "North Central Montana Regional Feasibility Report" (USBR, 2004) screened numerous alternatives to reduce water shortages in the Milk River Basin and concluded that rehabilitating the St. Mary River Diversion and Conveyance Facilities was the most viable option – the only one that would produce net positive economic benefits. In 2006, two additional routes and means to convey U.S.-apportioned water from the St. Mary River to the Milk River drainage were evaluated as alternatives to rehabilitating the St. Mary Facilities. Rehabilitating the existing facilities was again determined to be the most cost-effective solution to deliver water to the Milk River Basin (TD&H, 2006).

Rehabilitating the St. Mary Facilities will include realigning or reconstructing nearly 26 miles of earthen canal and replacing several major hydraulic structures. The overall project, including inverted siphons and drop structures is approximately 29 miles long. The significant components are shown on Figure 8. Major structures in need of replacement include the diversion facilities, three large diameter siphon structures that cross active streams and topographical low areas, and five energy-dissipating, hydraulic drops. Numerous other structures including bridges, wildlife crossings, checks and wasteways, underdrains, turnouts, and inlet structures would also be replaced as part of the project rehabilitation. The new canal may also include an all-weather service road, canal armoring, and miscellaneous riprap. In many reaches, landslide stabilization will be required.

In 2006, the overall St. Mary River Diversion and Conveyance Facilities rehabilitation cost was estimated to vary from $120 to $140 million depending on the diversion capacity (TD&H, 2006). The St. Mary Facilities rehabilitation was authorized in the Water Resources Development Act (WRDA) of 2007 at a total cost of $153 million. As of December 2009, funding for the remaining support studies, engineering design, and construction has yet to be appropriated under the authorization. The schedule for federal appropriations, the time necessary to complete the rehabilitation, and the practical, remaining life of the St. Mary Facilities all represent unknowns.

The St. Mary River and Conveyance Facilities have exceeded their design life. The frequency and magnitude of extraordinary maintenance and emergency repairs to maintain operation of the facilities has escalated since the 1990's. This has created a sense of urgency to rehabilitate the facilities, and led to formation of the SMRWG. The goal of the SMRWG is to find a "workable solution" to rehabilitate the St. Mary Facilities before a catastrophic failure occurs.

With increasing age of the St. Mary Facilities, comes increasing frequency and risk of failure. Potential failures range from relatively minor to catastrophic. The latter could result in environmental damage to the Blackfeet Indian Reservation, the St. Mary River, the North Fork Milk River, and an economic catastrophe for North Central Montana from a prolonged loss of St. Mary River water.

About This Reference Guide

The Montana DNRC and the SMRWG called for this Guide to initiate a proactive approach to avoid St Mary Facilities failure, minimize the risk of environmental and economic harm, and stabilize O&M costs. The objectives of this study include the following:

- Characterize the existing conditions of individual components
- Identify potential failure modes for the individual components
- Characterize the levels of economic and environmental impacts arising from identified failure modes
- Provide recommendations that would avoid or reduce the risk of failure
- Provide recommendations to lessen the impact of failure
- Expedite repairs in the event of a failure to minimize downtime
- Stabilize rising O&M costs

Rehabilitation design and construction appear to be years away; therefore, it is important to characterize the nature and likelihood of potential failure modes of each component of the St. Mary Facilities. This is useful information for developing and implementing a Failure Contingency and Emergency Response Plan. It can also be used to plan and prioritize maintenance activities within the annual O&M funding constraints.

St. Mary Diversion Facilities

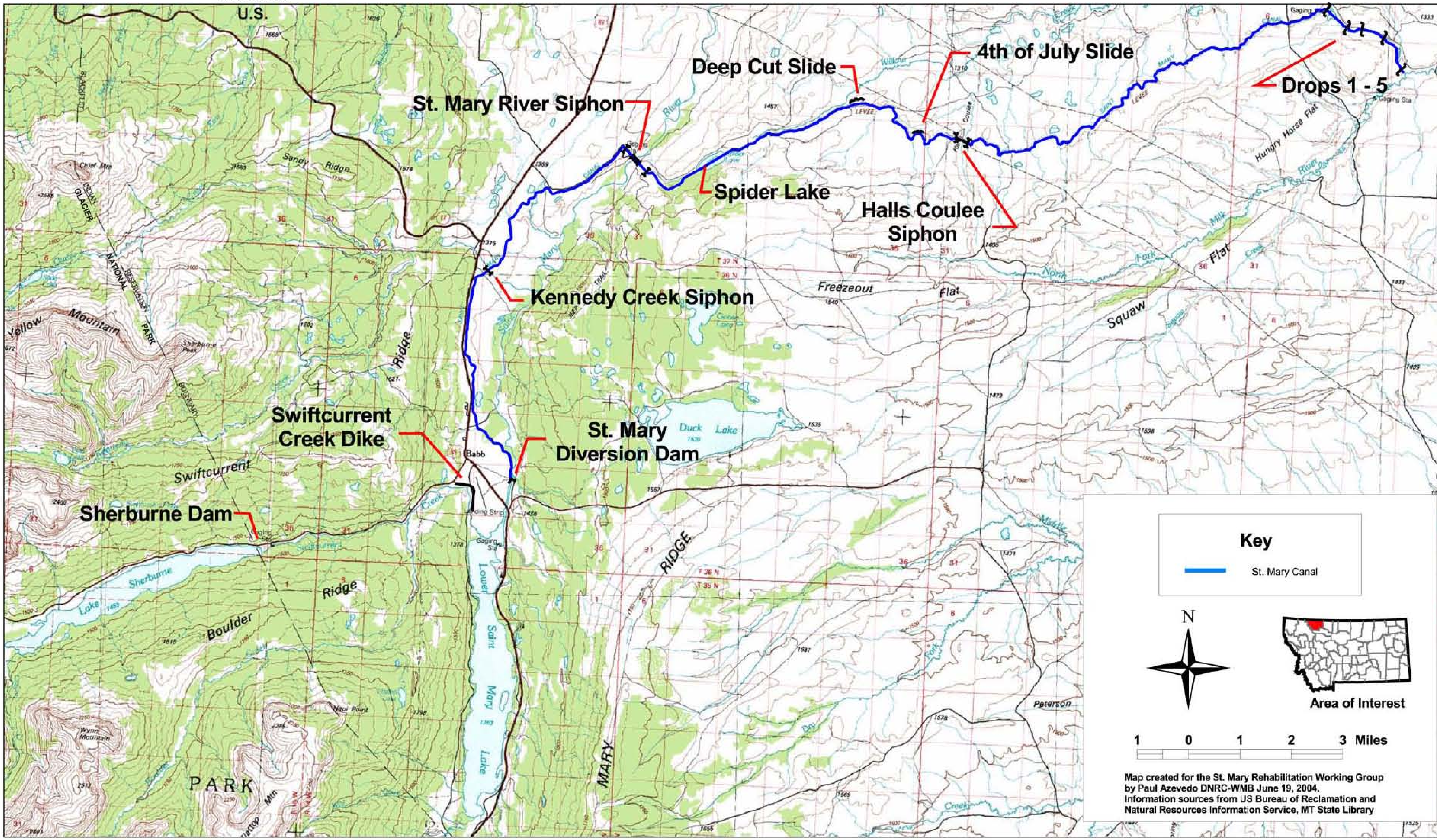


Figure 8

Notes

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Mr. John Sanders, P.E.
Montana Department of Natural Resources
P.O. Box 201601
Helena, MT 59620-1601

Subject: St. Mary Diversion and Conveyance Facilities Failure and Operation & Maintenance (O&M) Reference Guide, Milk River Project

Dear Mr. Sanders:

This letter is in response to your e-mail message to Kelly Titensor and Mike LaFrentz on December 11, 2009, in which you asked for their review of the "St. Mary Diversion and Conveyance Facilities Failure and O&M Reference Guide". I acknowledge that considerable effort was put forth to prepare this document and I appreciate being afforded the opportunity to comment. The document includes worthwhile discussion; however, the Bureau of Reclamation does have some concerns, which I will try to articulate.

Reclamation's responsibilities for the O&M (including emergency repairs) of the St. Mary facilities are established through existing project authorizations and are further defined by provisions within our project repayment and O&M contracts with the Milk River Project water users. Consistent with those contractual obligations, any major maintenance and/or repair action undertaken by Reclamation would have to be discussed in advance with the project water users. Additionally, we typically budget our proposed activities three years out. In short, the "St. Mary Diversion and Conveyance Facilities Failure and O&M Reference Guide" does not align well with our business processes.

The "St. Mary Diversion and Conveyance Facilities Failure and O&M Reference Guide " also discusses how future maintenance activities can align themselves with system-wide rehabilitation, including potential realignment of the St. Mary Canal. Rehabilitation of the St. Mary facilities is currently authorized through the U. S. Army Corps of Engineers (USACE), but to date funds have yet to be been appropriated for this purpose. Without either USACE appropriations or alternative congressional authorization, implementation of the recommended contingency measures would have to be accomplished through Reclamation's O&M program. Accordingly, expenditures for such activities would necessarily be considered operation and maintenance expense (74 percent of which is funded by the Milk River Project water users), at a time when Reclamation continually hears from the water users that O&M costs are already excessive.

Reclamation believes that contingency planning can be both a practical and proactive approach to resolving some of the aging infrastructure issues associated with the St. Mary system. Although we are not in a position to endorse your document for the reasons stated above, we do acknowledge that the document can provide some value in helping to plan and prioritize major out-year maintenance activities for the St. Mary system. Accordingly, we will take it into consideration as we formulate our future maintenance plans in collaboration with our Milk River Project water users.

In closing, I want to thank you again for the opportunity to review your document and I appreciate your continued efforts as we work towards a common solution to the aging infrastructure issues associated with our St. Mary facilities.

If you have questions or concerns, please contact me at 406-247-7307 or by e-mail rlong@usbr.gov.

Sincerely,

RL Long

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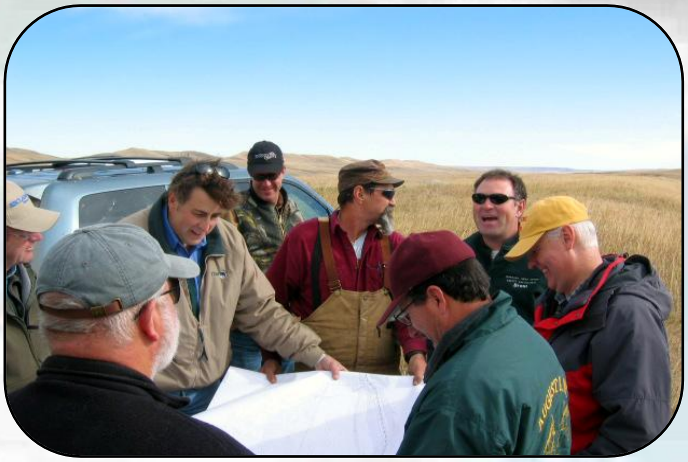

Members of Catastrophic Failure Planning Team study draft map/design sheet showing potential realignment of a portion of the St. Mary Canal during the Engineering Walkthru in Sept 2007

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