Stillwater No. 1 Reservoir Dam
Phase I – Feasibility Study

Yampa, Colorado

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EXECUTIVE SUMMARY

At the request of the Bear River Reservoir Company, Tetra Tech has prepared the present document that describes different methods to reduce seepage and improve water resource management capabilities in the Stillwater No. 1 Reservoir Dam. An assessment of the actual conditions of the embankment was performed by researching for existing documentation related to its construction and performance. Additionally, a geologic evaluation and geophysical survey were completed to identify the major seepage path underneath the dam.

Documents research and the geologic evaluation led to the understanding that the dam and dike embankments are founded on soils of glacial or landslide deposits. The basalt outcrops downstream of the dam and dike embankments, generally in the locations where seepage is observed. Gravel lenses in the lateral moraine adjacent to and underlying the right abutment are providing a flow path to the underlying basalt flows. From historic information, previous mitigation attempts to repair the right abutment did not succeeded as seepage is still being observed in that area.

Willowstick Technologies, LLC, performed a geophysical survey on the right abutment of the embankment to identify preferential seepage flow beneath the fill material in native soil and/or rock materials directly beneath the southwest end of the dam. From the survey results, seepage appears to be flowing through the dam between elevations 10,280 and 10,225 feet. It daylights between elevations 10,228 and 10,224 feet and then drains into a small pond located east of the embankment. The geophysical survey results correlate well with seepage observations previously made on past inspection reports. It also leads to believe that previous mitigation work failed to provide a good seal between the reservoir and the moraine formation.

Based on the assessment results, five mitigation alternatives are described to a conceptual level. The presented alternatives are based on downstream, centerline and upstream constructions methods, and depending on the selected alternative the reservoir would have to be drained or lowered to a level suitable for safe construction. Cost estimates assumptions on the presented alternatives include bedrock elevations and depth to suitable bedrock for grout curtain placement. The table below presents estimated costs for each of these options assuming bedrock at two different elevations.

Option	Estimated Cost Bedrock at 10,240 ft	Estimated Cost Bedrock at 10,220 ft
Option 1: Remove and Replace Foundation and Embankment	$1,771,000	$2,511,000
Option 2: Cut off Trench	$1,160,000	$1,406,000
Option 3: Geomembrane Liner	$1,185,000	$1,185,000
Option 4: Low Permeability Soil Blanket	$1,308,000	$1,308,000
Option 5: Upstream Trench	$ 943,000	$1,189,000

From the seepage mitigation options, the alternatives that would best provide a good seal between the moraine deposits and the reservoir are the remove and replace the foundation and embankment option, followed by the cut off trench option. These alternatives would not require drainage of the reservoir and will probably not interfere with dam operations. The next recommended option would be the geomembrane liner or the low permeability soil placed on the upstream face of the dam. Work on the next phase of the project will depend on the selected mitigation alternative.

1.0 INTRODUCTION

The Stillwater No. 1 Reservoir Dam is located in Garfield County, Colorado approximately 15-miles from the town of Yampa. The dam is situated on the Bear River which is a tributary of the Yampa River. The dam was constructed in 1939 to provide irrigation water supply for the owners located downstream along the Bear and Yampa Rivers. The dam is classified as an intermediate size with a height of 75 feet and a maximum capacity of 7,500 acre-feet. There are also some flood control and recreation benefits.

The Stillwater No. 1 Reservoir Dam has a long history of seepage from the left abutment and downstream toe. The reservoir has rarely been filled, and reportedly, the spillway has been used several times since construction was completed in 1940. The seepage is measured through several Parshall flumes located to intercept much of the visible surface seepage. The seepage appears to be increasing over time. The Bear River Reservoir Company (Company) has initiated a program to investigate methods to reduce seepage and improve water resource management capabilities.

Considering the site conditions and the large area where seepage is occurring, a phased approach to enable an efficient solution to the problem was proposed. The first Phase of the project consists of a feasibility study involving a water balance (performed by Owner) to evaluate the measured seepage with reservoir stage, a geologic mapping and an assessment of the conditions existing before construction of the dam and impact of the embankment to the site. Additionally, a geophysical survey to help identifying and locating the major seepage paths, engineering analysis of the embankment and foundation, and the development of mitigation alternatives are included in Phase I of the project.

Once the alternative selection has been made,Phase II will consist of a field investigation to characterize the conditions of the soils underneath the footprint of the embankment, a preliminary design of the selected alternative, consultation with the Company and State Engineer's Office (SEO), permit applications, final design, and approval of the design.

Phase III of the project will consist of construction phase services, which will be defined upon completion of Phase II.

2.0 PROJECT BACKGROUND

2.1 Site Location

The Stillwater No. 1 Reservoir Dam is located about 15 miles southwest of Yampa, Routt County, Colorado. The dam and reservoir are located in Section 26, Township 1 North, Range 87 West, on the Bear River, a tributary of the Yampa River.The dam is at elevation 10,290 feet. The location of the project is shown on Figure 2.1.

2.2 Project Features

The Stillwater No.1 Reservoir Dam was designed and constructed in the late 1930s for the Yampa Reservoir Public Irrigation District (District) and is now owned by the Bear River Reservoir Company (Company). The dam is a zoned earth embankment with riprap slope protection on both the upstream and downstream slopes. The embankment has a length of about 1,500 feet, a crest width of 15 feet, and a maximum height of about 75 feet. The exterior slopes are 2.5:1.0 upstream and 2.0:1.0 downstream and there are two foundation cutoff trenches. A 500-foot-long dike extends from the dam abutment on the right side of the valley. The embankment has an unusual downstream curve that was incorporated in the project during construction. The modification was reportedly made to found the dam on suitable materials.

The outlet works is located on the left side of the dam, in the original Yampa River channel. It has two hydraulically-operated 30-inch control gates at the upstream end of the 63-inch by 42-inch concrete outlet conduit. The spillway, an open channel with partial concrete lining, is located on the right abutment of the dike. The spillway crest is a concrete core wall with an elevation of 10,290 feet.

The foundation is composed of landslide and glacial moraine deposits that overly basalt flows and Mancos Formation sandstones and shales. The basalt outcrops in the left abutment and on the right side of the river channel. The basalt also outcrops downstream of the dam and dike on the right one-third of the valley.

2.3 Historic Performance

The dam has experienced seepage from the left abutment (bedrock) and from basalt outcrops below the right abutment for its recorded history. Several Pars hall flumes have been installed at locations downstream of the dam to measure the seepage flows. Records indicate that the seepage quantities can total nearly 10 cfs, and are related to reservoir stage. Below a reservoir stage near the mid-point of the dam’s hydraulic height, the seepage quantity reduces significantly.

Inspections of the dam and seep areas reveal that the water is emerging from fractures in the basalt flows, both in the left abutment area and in the area below the right abutment above the glacial pond. Left abutment seepage appears related to direct flow of water through the fractured basalt outcrops. Groundwater is suspected of contributing to the left abutment seep measurements. It appears that the right side dam and dike embankments are founded on soils of glacial deposits. Gravel lenses in the lateral glacial morainal deposits may provide a flow path to the fractured basalt flows underlying the right abutment. Flow measuring flumes have been installed on both the right and left sides of the river channel, adjacent to the outlet conduit. OneParshall flume has also been installed at locations on the right side of the valley for measuring the seepage. Data has been taken from these flumes for several years. At the highest part of the dam, where basalt outcrops at the foundation and left abutment, seepage of nearly 2cfs has been recorded. Below the right abutment, above a glacial pond, seepage was observed from several basalt outcrops, resulting in estimated flows of nearly 8 cfs.

An attempt was made to control the seepage under the right abutment of the dam in 1983. A slurry trench was installed near the transition between the lateral moraine and the right abutment. The trench was approximately 120 feet long and 25 feet deep. During excavation of the trench two gravel lenses were encountered. The slurry trench installation does not appear to have limited seepage in that area and dam inspections completed over the last 20 years have revealed a series of sinkholes in the face of the dam near where the slurry trench was installed.

It does not appear that the safety of the dam is impacted by the seepage at this time, but a conversation with John Blair of State Engineer's Office (SEO), indicates that seepage flow quantity may be increasing. Review of documents do not indicate increase in seepage flow, but it may be occurring considering the dam age and the seepage mechanism. The Company would like to reduce seepage flow to better manage water resources.

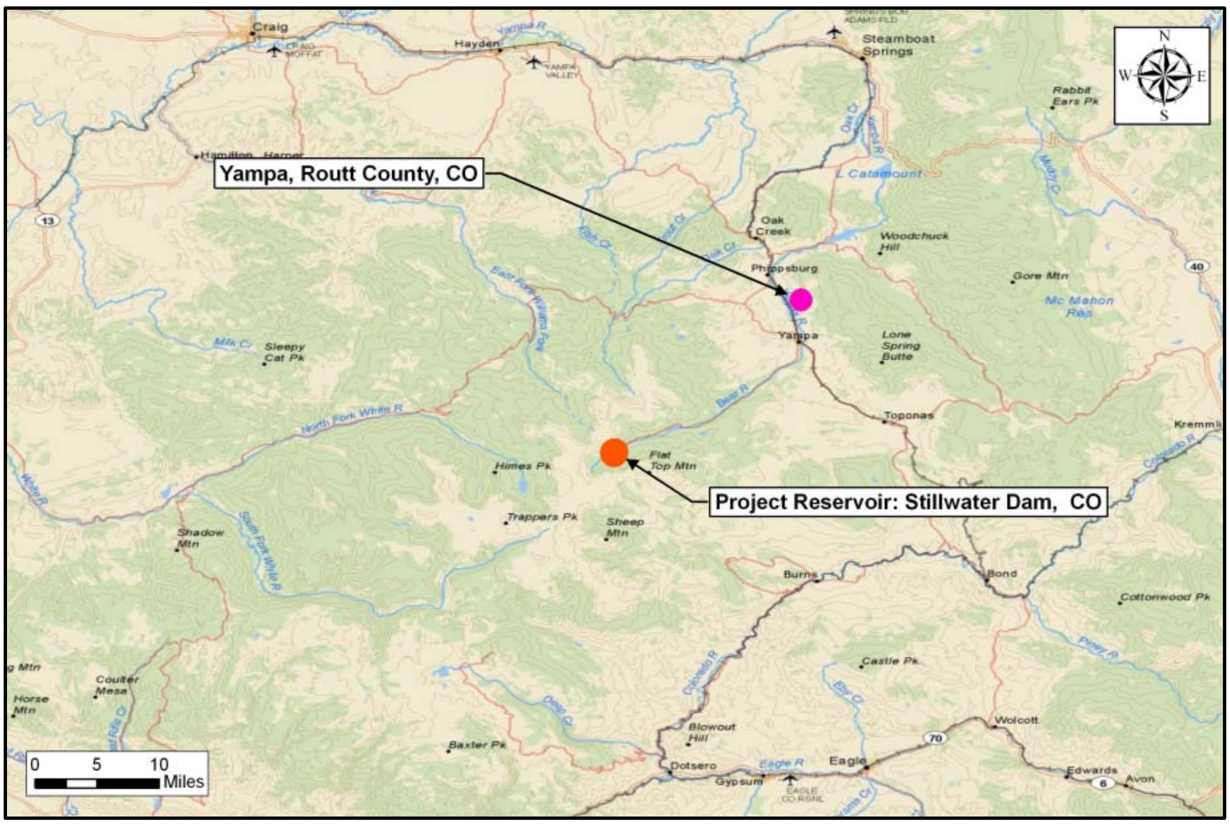

Figure 2.1 Project Location

3.0 CONDITION ASSESSMENT AND GEOLOGIC MAPPING

Tetra Tech personnel researched for existing documents and performed a geologic evaluation of the site. Additionally, a geophysical survey of the dam was completed by Willowstick to assist identifying and locating the major seepage pathways underneath the dam.

3.1 Existing Documents

Tetra Tech personnel visited the Colorado Division of Water Resources, Dam Safety Division to review the records on file for Stillwater Dam No. 1 on August 18, 2011. The personnel also visited the Division 6 office on August 24, 2011. On September 22, 2011 a telephone conversation was held with John Yurich of Oak Creek, for his understandings of the facility. The available records were reviewed and are summarized below:

3.1.1 Construction Specifications and Contract

- Pre-construction specification documents from 1939 with no as-built documentation.

3.1.2 Emergency Action Plan

- Contained no information relevant to the current investigation.

3.1.3 Inspection Reports: Annual Dam Inspection Reports available from 1986 to present and intermittently from 1942.

- 5-3-83 – Storage restricted to 19 feet below the crest of the dam due to seepage.
- 7-10-10 - Sinkholes on the right abutment and sounds of large volumes of water moving through the dam were reported. WL=33.1ft below crest, Gauge Reading=35.9ft
- The sinkholes are located near an old access road on the right abutment.
- Seepage noted in most reports starting in 1948.

3.1.4 Emergency Action Plan

- Contained no information relevant to the current investigation.

3.1.5 Project notes dated: 6/21/89

- "Construction records indicate that the percolation tests near where the reservoir leaks into the upstream slope would take water faster than it could be filled. In addition, the dam was apparently built downstream of and above the original moraine. They were never able to locate the discharge from the tests."
- "Left abutment seepage – During construction water was coming in from the hillside and the outlet leaked prior to filling. Since the seep flow does not generally fluctuate with reservoir level, this may be groundwater."

3.1.6 "Phase I Inspection Report National Dam Safety Program Stillwater No. 1 Reservoir Garfield County, Colorado", by Hydro-Triad, Ltd., May 1980.

- Brief description of the geology, composition of the dam, and construction history based on previous records. It also describes the conditions and problems encountered in the dam at the time of the inspection in November 1979.

3.1.7 "Stillwater No. 1 Dam Repair Feasibility Bear River Reservoir Company", by B&RW Construction Co. Inc., October 1999

- Report based on dam inspections, construction notes and drawing reviews. It concludes that the dam sits on top a fractured lava formation that outcrops to the surface or have thin layers of covering material that allows for water flow downstream to the soil below the dam.
- This report proposes the following options for repairing the dam: Sealing the entire face of the dam; sealing the known areas of leakage; collection of seepage for releasing it to the river and get credit for that; sealing the known areas and seepage collection; other methods (curtain wall through dam, trenching the dam and abutments).

3.1.8 "Stillwater No. 1 Reservoir Dam Rehabilitation" Plan, by Western Engineering, September 1983

- Single drawing of the reservoir and a detail of the slurry trench procedure. The accompanying report was not found.

3.1.9 Survey data from August 1994 through October 2007

- Data from 12 survey monuments located along the crest of the dam. Readings available were taken once a year.
- The survey monuments were installed in 1993.

3.1.10 Seepage and Reservoir stage

- Quantified seepage data from a wooden flume for the period of June 1991 through September 2001. Additional seepage data from three Parshall flumes at three locations for the period of May 2002 through September 2010. Figure 3.1 shows the seepage rate at these three locations versus the reservoir stage.

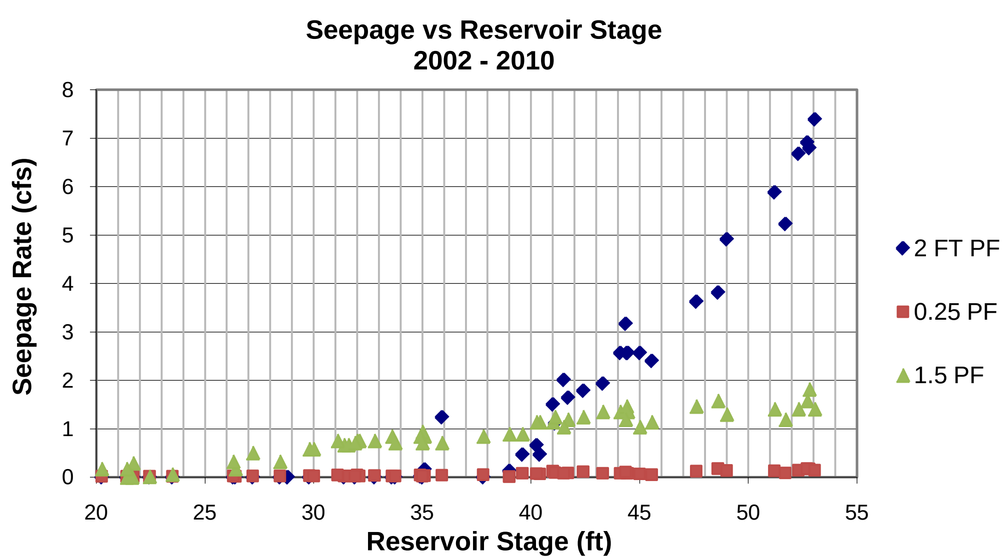

Figure 3.1 Seepage Rate vs. Reservoir Stage

The 2-ft Parshall flume is located about 350 feet east of the toe of the dam. The 0.25-ft and 1.5-ft flumes are located to the south and north of the Bear River, near the left abutment.

3.2 Geologic Evaluation

The site was mapped by an engineering geologist using existing, published information and site mapping. The mapping included the conditions existing before construction of the dam and the impact that the dam embankment has made to the site. It is understood that grout holes were drilled during construction and at a later time. We did not plan on drilling borings during this phase of the work.

The reservoir is located in a steeply sided glacial valley surrounded by mesas. There are two types of bedrock in the valley; sedimentary rocks comprising the Mancos Shale which are overlain by the tertiary basalt flows.

The basalt flows are evident in the cliffs surrounding the Stillwater Reservoir. The volcanic plateaus rise 1,000 to 2,000 feet above the valley floor. The bedded character of the volcanic series is obvious in the exposed cliffs above the Stillwater Reservoir. Outcrops of the basalt flows were observed in the areas around the Stillwater Dam and their locations are shown on Figure 3.2. The flows consist mainly of dark grey, fine-grained basaltic and diabasaltic lava flows. Average thicknesses of the flows ranges from 15 to 30 feet although some flows are as thick as 60 feet. Basalt outcrops are present near the left abutment of the dam and south of the right abutment. Where possible, strike and dip measurements were taken on the jointing present in the basalt outcrops. These measurements are summarized in Table 3.1below.Site photos of the geologic evaluation are presented in Appendix A.

Table 3.1 Basalt strike and dip measurements

Location	Strike	Dip
1	295	89S
2	305	90
3	297	86S
4	298	88S
5	259	88S
6	264	84S
7	260	87S
8	250	90
9	286	90
10	260	85S
11	258	90
12	280	87S
13	287	86S

The joint spacing at each of the locations averaged 1.5 to 3.0 feet. Orthogonal jointing was observed at locations 1 through 6. The outcrops at locations 7 through 13 were highly weathered and mostly covered with vegetation making detailed observations difficult.

During the site visit it was not possible to correlate the basalt outcrops on the left abutment to those near the right abutment. It is likely that the different basalt flows present in the area have different joint spacing and orientations based on the different conditions during their deposition.

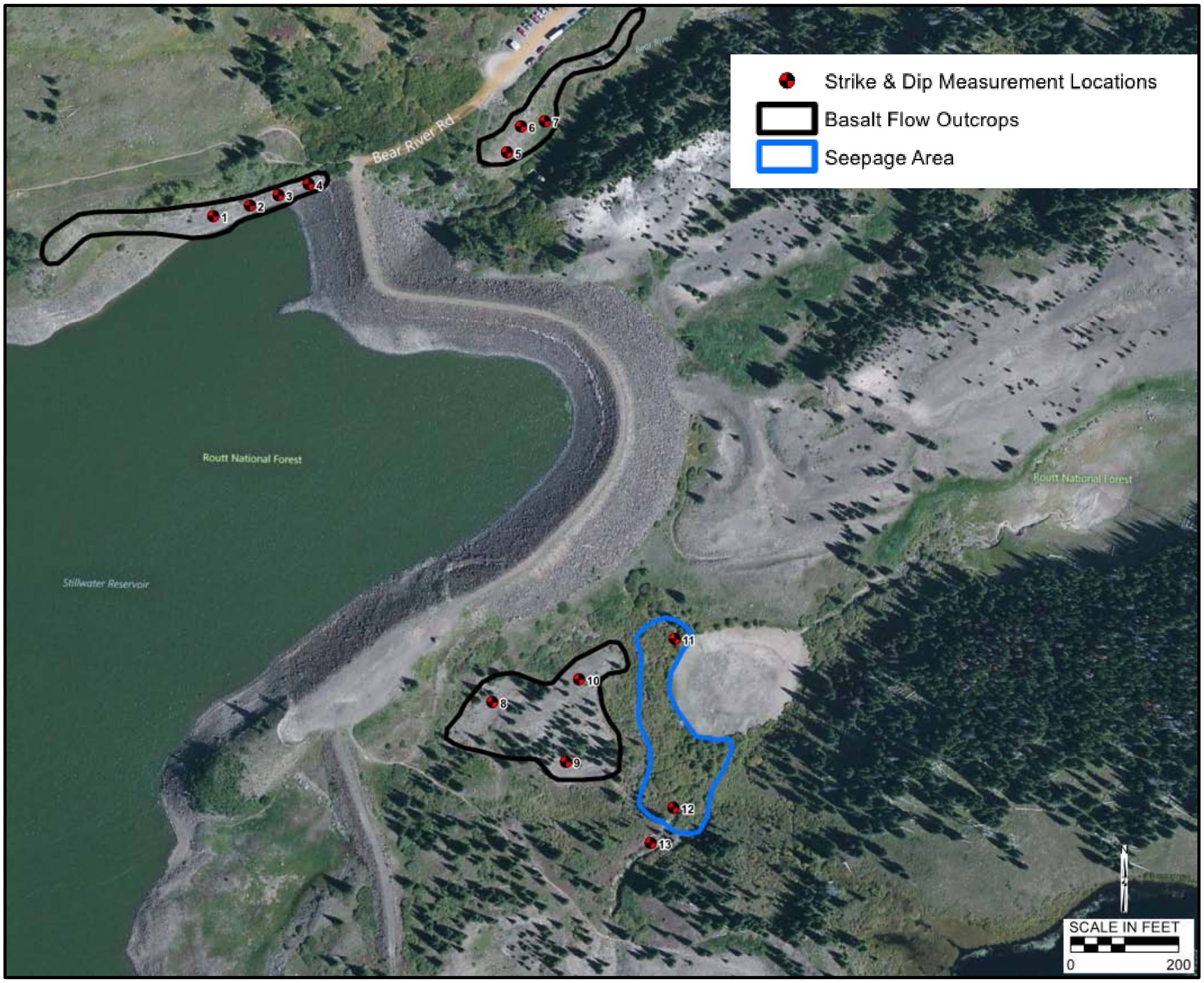

Figure 3.2 Geologic Evaluation Map

Given the distribution of seeps above the outlet structure on the left abutment and in the open area below the right abutment, it seems likely that water is flowing through the joint system in one or more of the basalt flows in the area.Glacial outwash deposits, like those observed along the right abutment, typically contain alternating layers of fine and coarse materials. Gravels encountered during the 1983 slurry trench excavation in the right abutment seem to provide a likely flow path through the moraine down to the underlying basalt flows. The highly weathered nature of the some outcrops indicates that flow paths through the basalt flows may be significant.

The seepage data collected from the 1.5-ft and 0.25-ftParshallflumes below the left abutment show the seepage rates increasing slightly as the reservoir stage increases, showing a correlation to increasing head pressures (Figure 3.1). The seepage rate through the right abutment increases drastically above the reservoir stage of approximately 37 feet (elevation 10,261 feet). This steep rise in seepage flows possibly indicates the location of an exposed highly conductive gravel layer in the upstream face of the lateral moraine in the right abutment. The lateral and terminal moraine materials adjacent to the dam have surfaces that are hummocky and irregular, and are dotted with numerous depressions, most of which are occupied by ponds or marshes. A seepage fedpond is located just to east of the right abutment at an elevation of 10,220 feet. The tills downstream of the dam are composed of fragments of basalt embedded in a matrix of unstratified sand and clay. The boulders in general are not large, with not many exceeding threefeet in diameter. Several areas downstream from the dam appear to have been reshaped during the dam construction activities based on the distribution and varying ages of vegetation in the area.

The Mancos Shale is a comprised of approximately 2,000 feet of dark grey to black carbonaceous shale with thinly bedded sandy shale and sandstone layers. Outcrops of the Mancos shale were not observed during the Stillwater No. 1 dam inspection. Geologic maps from the area indicate that the closest outcrop of the Mancos Shale to the Stillwater Reservoir is located approximately 0.5-mile downstream along the Bear River.

3.3 Willowstick Investigation

Willowstick Technologies, LLC, performed geophysical surveys to assist in identifying and locating the major seepage pathways. The Willowstick method is based on the principle that water seeping through the subsurface substantially increases the conductivity of earthen materials. Electrodes were placed strategically on both sides of the study area of the dam, so electric current flowing through them concentrates in the more conductive zones where water seeps relatively freely through and/or beneath the earthen embankment. Concentration and distribution of the electric current is then interpreted and modeled to identify how and where seepage occurs. Although this technology does not identify the volume of water or the direction of the flow, it can be used in conjunction with other data to better understand the seepage conditions.

Seepage in two areas was evaluated using the Willowstick method: Survey Area #1 (right abutment) and Survey Area #2 (Right Rim). Figure 3.3 shows the extent of these two study areas.

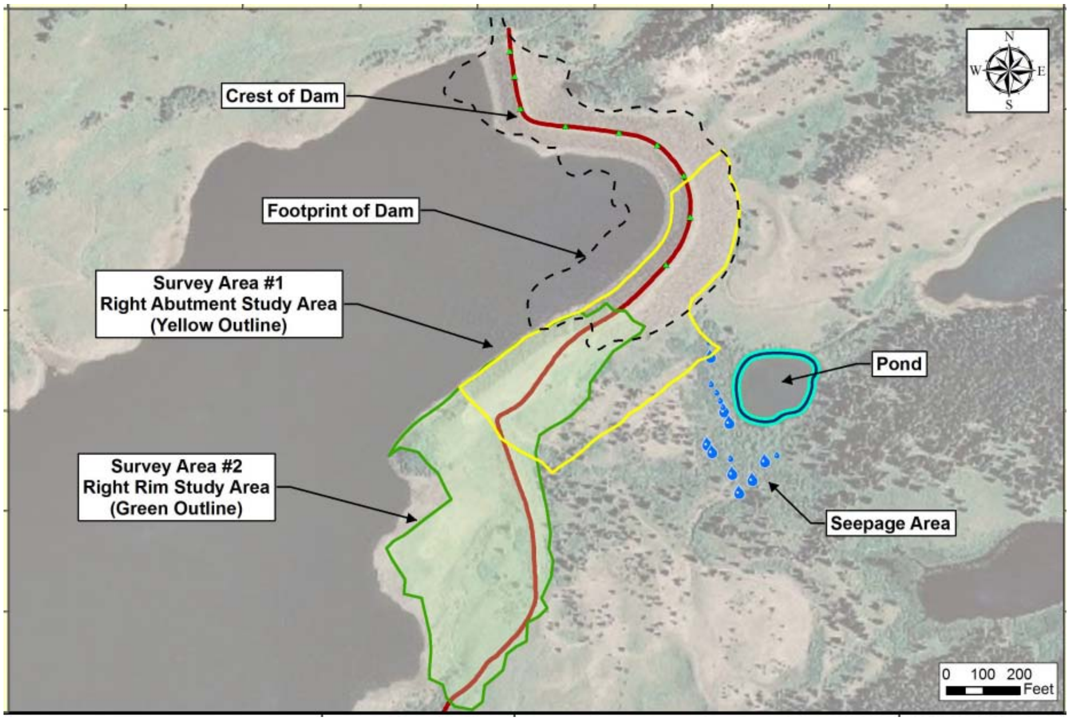

Figure 3.3 Survey study areas

Results of the Willowstick investigation identify the preferential seepage flow beneath the fill material in native soil and/or rock materials directly beneath the southwest end of the dam. Seepage flows through the dam between elevations 10,225 feet and 10,280 feet and then daylights downstream between elevations 10,228 and 10,224 feet. The water drains into a small pond located east of the embankment. The width of seepage is roughly between 250 and 300 feet. Figure 3.4 shows the results of the investigation.

Another possible seep was located on the north end of Survey Area #1, but due to the position of the electrodes at the moment of the survey, the extent of the seepage could not be confirmed. Additional survey would have to be performed north of Survey Area #1 to identify the preferential seepage flow in this area. No additional seepage flow paths were identified through Survey Areas #1 and #2 during this investigation.

A more detailed description of the process and results of this investigation are presented in the Willowstick report in Appendix B.

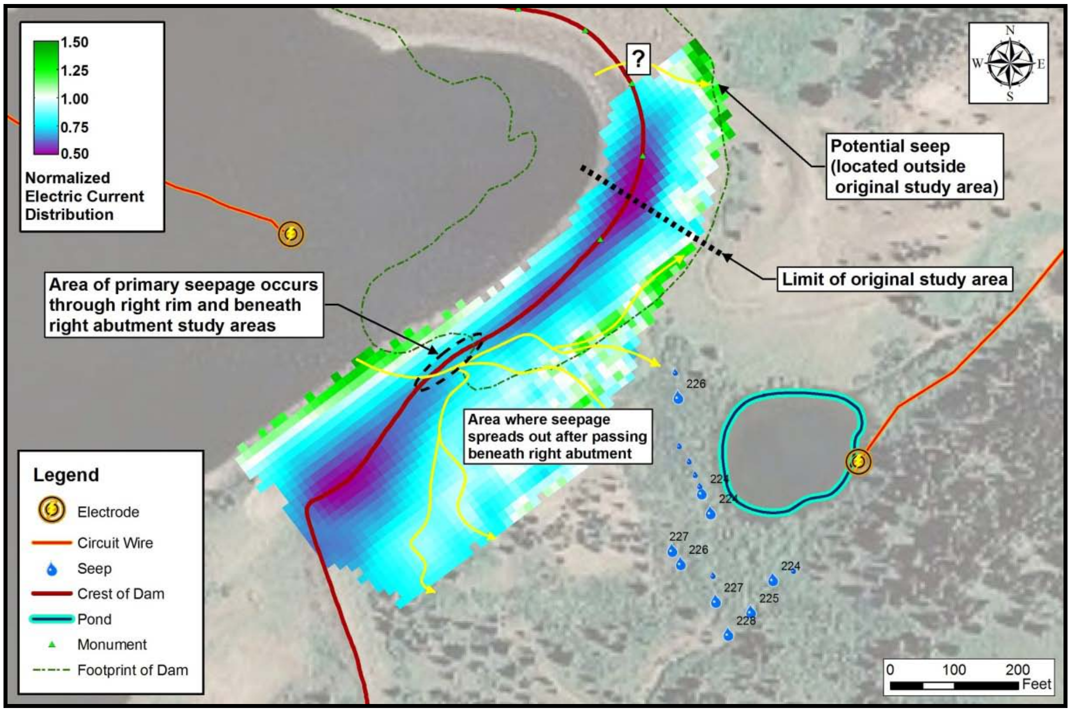

Figure 3.4 Willowstick investigation results.

3.4 Seepage Assessment

The Willowstick investigation results on the right abutment of the embankment correlates well with seepage locations observed in previous inspections reports (1982), the slurry trench work shown in the Western Engineering Plan (1983), and another investigation report performed in 1986 by Mr. Greg Hammer. On the later mentioned investigation report, Mr. Hammer noted seepage flowing on the right abutment of the dam near the top of the natural hill, which led him to believe that the slurry trench work failed to provide a good cut-off between the reservoir and the morainal gravels. Additionally, an inspection report performed in 1999 shows the location of two sinkholes on the upstream side of the right abutment by the old haul road. It is probable that these sinkholes are the result of seepage through the moraine deposits and bedrock. The seepage elevations identified by Willowstick coincide well with those identified by comparing the reservoir stage to the flows at the 2.0-ft Parshall flume located below the pond, east of the right abutment.

All these findings on the right abutment of the embankment could prove that seepage on this area flows through the moraine deposits and bedrock. Smaller amounts of seepage on the left abutment of the embankment and downstream toe appear to be the result of reservoir water flowing through bedrock.

Drawing 1compiles theWillowstick investigation results, the slurry trench work, areas of observed seepage and sinkholes locations.

4.0 MITIGATION ALTERNATIVES

The Stillwater No. 1 Reservoir Damhas historically experienced seepage at three locations: downstream toe, left and right abutments, which are measured through several Parshall flumes, located to intercept much of the visible surface seepage. Measured seepage on the downstream toe and left abutment of the embankment are less than 0.4cfs and 2.0cfs, respectively; whereas, seepage measured on the right abutment varies from zero to nearly 8.0cfs. The present report focuses only on mitigation alternatives for seepage on the right abutment.

Based on the Willowstick geophysical results, field observations, and documents research, the area of primary seepage on the right abutment is located about 70 to 75 feet deep on the southwest end of the dam, beneath the fill material in native soil. Based on the geophysical model, the width of seepage is between 250 and 300 feet. Although a second seep area is possibly located north of the original survey area, it does not seem to be the preferential seepage flow path.

The seep located southeast of the dam and below the southwest end of the right abutment is identified as the area of primary seepage that drains into a small pond located east of the dam. As a result of these findings, the following mitigation alternatives are presented and described to conceptual levels:

- Option 1: Remove and replace foundation and embankment;
- Option 2: Cut off trench;
- Option 3: Geomembrane liner;
- Option 4: Low permeability soil blanket; and
- Option 5: Upstream trench.

The seepage on the left abutment of the embankment may partially be groundwater. This abutment could be grouted to reduce seepage, particularly if groutingis selected for the right abutment seepage mitigation.This has not been considered in the mitigation methods presented above.

The selected alternatives are based on downstream (1), centerline (2) or upstream (3, 4and 5) constructions methods. If the preferred alternative uses downstream or centerline construction methods, the water elevation in the reservoir would have to lowered to a level that permits safe construction. If theoption chosen uses upstream construction methods, the reservoir would have to be drained.

Remediation width areas of 400 feet (downstream and centerline methods) and 350 feet (upstream) extending from the southwest end of the dam to the right abutment were considered. These potential areas of mitigation will have to be confirmed with results from the field investigation.

The mentioned alternatives assume that seepage flows in the upper reaches of the basalt bedrock or within the glacial till materials on the right abutment of the dam. However, information about the stratigraphy of this area is very limited to nonexistent and bedrock elevations at 10,240 and 10,220 feet were assumed. Low permeability bedrock is assumed to be 20 feet below the top of bedrock. These assumptions will have to be corroborated with the results of the field investigation proposed for the next phase of the project.

4.1 Option 1: Remove and Replace foundation and embankment

This option uses the downstream construction method, so drainage of theentire reservoir is not anticipated.The option requires the removal and replacement of the existing dam and part ofthe downstream moraine deposits located within the footprint of the embankment and southwest of the right abutment. The new downstream part of the dam would be placed on top of a grout curtain at an approximate elevation of 10,240 feet, the estimated bedrock surface based on field observations. The proposed grout curtain would need to be anchored to suitable bedrock or impermeable material. The total length of the area considered for remediation is about 400 feet.

The existing soil on the upstream side of the embankment will be maintained, removing part of the moraine deposit and grading the downstream side to a slope of 1.5H:1V. The new portion of the embankment would consist of a soil fill core, a filter layer, and a protective shell composed of the removed moraine material. The downstream side of the dam will have a final slope of 2.5H:1V. A gravity drain channelthat will direct surficial water to the northeast side of the dam area would be placed at the toe of the embankment.Drawing 2 shows this option in more detail.

4.2 Option 2: Cut off Trench

The cut off trench alternative uses the centerline construction method and does not contemplate drainage of the reservoir or interruption of dam operations. This option requires the installation of a grout curtain from the top of bedrock, located at an approximate elevation of 10,240 feet, to suitable bedrock or impermeable material. A cement-bentonite slurry wall would be placed from the crest of the existing embankment to the top of the grout curtain. This option has the potential to be developed in two seasons: the slurry wall during the first season, and the grout curtain during the second season. The reservoir will be filled at the end of the first season, and if seepage is not observed, grouting may not be necessary. Otherwise, the grout curtain would be needed. The approximate length of the area to be mitigated using this option is 400 feet.Drawing 2 shows more details of this option.

4.3 Option 3: GeomembraneLiner

This option uses the upstream construction method; and would involve draining the reservoir to a certain elevation that would allow construction. The current upstream slope protection would need to be removed, filled with suitable soil and regraded to a 3H:1V slope to facilitate placement of the geomembrane liner.

Once the upstream side of the embankment is regraded, the geomembrane liner (60mil HDPE) would be placed between asoil bedding layer that will later be covered by rip rap material. The estimated length of the area to be covered by the geomembrane layer is 350 feet. More details of this option are presented in Drawing 3.

4.4 Option 4: Low Permeability Soil Blanket

This option would require the drainage of the reservoir to an elevation that would allow the proposed work. As described in the previous option, it involves the removal of the existing rip rap layer on the upstream side of the embankment, soil fill placement, and regrading of the upstream face of the dam to a 2.5H:1V slope.

A filter layer would be placed on top of the regraded slope, covered with the low permeability soil, soil bedding, and rip rap material. The estimated length of the remediation work using this option is 350 feet. Drawing 3presents the details of this option.

An alternative to the low permeability soil blanket option is the soil cement blanket option, but is not considereddue to the need of non-cohesive silty sands in the area, and the costs of mixing and placing soil cement.

4.5 Option 5: Upstream Trench

It is possible that the slurry trench completed in 1985 was not long or wide enough to seal seepage on the right abutment or through the moraine layer.Based on the conditions of the current slurry trench installed on the southwest side of the right abutment, an extension of the trench or the installation of a new trench may be feasible.

The Willowstick investigation results show the area of seepage on the upstream side of the embankment extends about 50 feet southwest of the right abutment with an approximate elevation between 10,280 and 10,225 feet. From historic information, the dimensions of the existing slurry trench are 110 feet long, 25 feet wide and 25 feet deep. This option incorporates the same concept with extended coverage.Depth of the proposed trench will depend on the depths of suitable bedrock or impermeable material identified in the field with a drilling program. This option is not preferred because of the poor performance of the existing trench.

4.6 Cost Estimates

Quantity and cost estimates for the construction of the aforementioned option are presented below. The quantity estimates were prepared using CAD software. The indicated quantities are based on digitized topography from the Western Engineering (1983) drawing and do not include excavation bulking and compaction shrinking changes.

A cost sensitivity analysis was prepared assuming bedrock depths at elevations 10,240 feet and 10,220 feet; and suitable bedrock elevations of 10,220 and 10,200 feet, respectively. Depending on the results of bedrock depth analyses and approach selected, cost estimates for Options 1, 2 and 5 will have to be re-evaluated.

The unit costs applied to each quantity are based on past experience from other projects. The unit cost applied to each quantity shown in the cost estimate spreadsheets represent the best estimate of present day costs.

Mobilization and demobilization costs of 10 percent of the overall construction cost were added to each option. Additionally, a contingency of 30 percent of the total cost was included on each estimate. This is an owner’s contingency and represents the level of design detail with feasibility level design engineering. Construction quality assurance (CQA) technician, laboratory support and as-built documentation are not considered on these estimates.

Table 4.1 presents a summary of the total construction costs for each of the considered options. These cost estimates are conceptual-level estimates for alternative evaluation and selection.Additional investigation and analysis are needed to prepare an accurate cost estimate.

Appendix C shows a detailed description of line items quantities and prices, including assumptions used in the estimation process. Estimated remediation areas for each option are presented in Drawing 4.

Table 4.1 Options Cost Estimate

Option	Estimated Cost Bedrock at 10,240 ft	Estimated Cost Bedrock at 10,220 ft
Option 1: Remove and Replace Foundation and Embankment	$1,771,000	$2,511,000
Option 2: Cut off Trench	$1,160,000	$1,406,000
Option 3: Geomembrane Liner	$1,185,000	$1,185,000
Option 4: Low Permeability Soil Blanket	$1,308,000	$1,308,000
Option 5: Upstream Trench	$ 943,000	$1,189,000

5.0 CONCLUSIONS AND RECOMMENDATIONS

The Stillwater No. 1 Reservoir Dam, located to the southwest of Yampa, in Colorado, has been experiencing seepage from the left abutment and from the right side of the valley through its history. Seepage flows measured at different locations downstream of the dam are related to reservoir stage and seem to be increasing over time.

Tetra Tech was retained by the Bear River Reservoir Company to investigate methods to reduce seepage and improve water resource management capabilities. A thorough assessment of the actual conditions of the dam was performed by researching for existing documentation related to its construction and performance. Additionally, a geologic evaluation and geophysical survey were completed to identify the major seepage path underneath the dam.

From historic information and the geologic evaluation, it appears that the dam and dike embankments are founded on soils of glacial or landslide deposits. The basalt outcrops downstream of the dam and dike embankments, generally in the locations where seepage is observed. Gravel lenses in the lateral moraine adjacent to and underlying the right abutment are providing a flow path to the underlying basalt flows. Previous mitigation attempts to repair the right abutment did not succeeded as seepage is still being observed in that area.

The geophysical survey evaluation performed on the right abutment by Willowstick Technologies, LLC, identified preferential seepage flow beneath the fill material in native soil and/or rock materials directly beneath the southwest end of the dam. Seepage appears to be flowing through the dam between elevations 10,280 and 10,225 feet. It daylights between elevations 10,228 and 10,224 feet and then drains into a small pond located east of the embankment. The geophysical survey results correlate well with seepage observations previously made on past inspection reports. It also leads to believe that previous mitigation work failed to provide a good seal between the reservoir and the moraine formation.

Based on the assessment results, five mitigation alternatives are described to a conceptual level. The presented alternatives are based on downstream, centerline and upstream constructions methods, and depending on the selected alternative the reservoir would have to be drained or lowered to a level suitable for safe construction. Cost estimates assumptions on the presented alternatives include bedrock elevations and depth to suitable bedrock for grout curtain placement.

From the seepage mitigation options, the alternatives that would best provide a good seal between the moraine deposits and the reservoir are the remove and replace foundation and embankment option, followed by the cut off trench option. Thesealternatives would not require drainage of the reservoir and will probably not interfere with dam operations.The next recommended option would be the geomembrane liner or the low permeability soil placed on the upstream face of the dam. Work on the second phase of the project will depend on the selected mitigation alternative.

6.0 REFERENCES

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APPENDIX A
SITE PHOTOS

APPENDIX B
WILLOWSTICK GEOPHYSICAL INVESTIGATION OF STILLWATER DAM

APPENDIX C
MITIGATION ALTERNATIVES COST ESTIMATE

DRAWINGS