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Reservoir Sedimentation: Impacts to Operations and Maintenance, and Potential Solutions

Leadville Mine Drainage Tunnel Treatment Plant Unwatering Under the Retention Pond

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This *Water Operation and Maintenance Bulletin* is published twice annually for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Bureau of Reclamation personnel and water user groups in operating and maintaining project facilities.

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***Cover photograph*:** View looking upstream of Paonia Dam showing the arrival of reservoir sediment and partial burial of the outlet works in November 2014.

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RESERVOIR SEDIMENTATION: IMPACTS TO OPERATIONS AND MAINTENANCE, AND POTENTIAL SOLUTIONS

by: Sean Kimbrel and Kent Collins, Hydraulic Engineers with the Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group, 86-68240

Abstract

As time passes, reservoirs storing water also continue to fill with sediment, causing storage loss, reducing water supply reliability, and impacting infrastructure, particularly marinas, boat ramps, outlet works, turbines, and water intakes. In addition, upstream channel aggradation and downstream channel degradation can occur. Under traditional dam building approaches, current and future generations will have to take some action to manage reservoir sedimentation after the sediment design life is reached, which could include methods that reduce inflowing sediment, passing sediment downstream, and/or recovering lost storage. Current and new Bureau of Reclamation (Reclamation) facilities must be designed, re-operated, and retrofitted for sustainable use to limit the loss of operational capability and reservoir capacity due to sedimentation.

This article focuses on: (1) the potential impacts to the operation and maintenance of dams as a result of the arrival of reservoir sediment and debris at a feature of concern, (2) planning for the management of reservoir sediment, (3) determining the relative timing of future impacts to features, and (4) the potential solutions to deal with reservoir sedimentation impacts.

Introduction

The majority of Reclamation's dams and reservoirs were designed to accommodate sedimentation over the first 100 years of operation. The "sediment design life" of a facility was determined by estimating the future volume and spatial distribution of accumulating sediment in the reservoir after 100 years, then locating the outlet works or hydropower intake sill at an elevation estimated to be the sediment level in 100 years, thereby managing reservoir sedimentation by allocating reservoir space at the onset of project development. This design approach thereby created what is known as the inactive or "dead" pool below the sill of the lowest intake in reservoirs. This design approach has worked as intended for almost all Reclamation facilities; however, Reclamation's infrastructure is aging, and the allotted space for reservoir sediment is disappearing. As of 2014, one-half of Reclamation's reservoirs were over

60 years old, nearly 20 percent were at least 80 years old, and 7 percent were already older than the sediment design life of 100 years. By the year 2024, 31 (13 percent) of Reclamation's reservoirs will be at least 100 years old, and that number will increase to 46 (19 percent) by the year 2034. As of 2015, only approximately 35 percent of Reclamation's reservoirs had been resurveyed since dam closure to monitor the volume and distribution of reservoir sediment. The increasing number of Reclamation reservoirs at or near the end of their sediment design life and the distribution of sediment in the majority of Reclamation's reservoirs being currently unknown is problematic in preparing and planning for future impacts as a result of reservoir sedimentation. Of general concern is that future sediment inflows will further decrease operational capabilities of these facilities by continually decreasing reservoir storage capacity. What will be potentially devastating, however, is the arrival of reservoir sediment and debris at outlet works and intakes not designed to pass sediment and debris, and the eventual plugging of these features, resulting in a partial to complete disruption of the beneficial use of water storage for water supply and hydropower.

Reservoir Sedimentation Impacts

An example of the potential impacts of reservoir sedimentation on the operation and maintenance of a facility can be seen at one of Reclamation's facilities, Paonia Dam and Reservoir. Located in western Colorado on Muddy Creek, a tributary to the North Fork Gunnison River, within Reclamation's Upper Colorado Region, Paonia Dam is a zoned earthfill embankment dam measuring at 199 feet in height (figure 1). Construction of the dam was completed in 1962. Paonia Dam was designed for a 50-year sediment design life rather than the 100-year sediment design life traditionally prescribed for the vast majority of Reclamation's dams. Based on the estimated sediment yield and distribution of reservoir sediment over 50 years, the intake tower elevation was set at 70 feet above the original valley floor (figure 2)

Figure 1.—Photo of Paonia Dam (from www.usbr.gov).

P551-417-2302 Paonia Dam--Paonia Project, Colorado. General view of outlet works intake structure as temporary irrigation bulkhead is being installed. Work by Bud King Construction Company, Specs. No. DC-5117. 7-11-61 Bureau of Reclamation photo by E. J. Peterson

Figure 2.—Photo of the construction of the intake tower at Paonia Dam in 1961 (photo courtesy of Philip Ipson, Western Colorado Area Office).

Based on the most recent bathymetric survey of the entire reservoir, conducted in June 2013, the estimated average annual rate of sedimentation has been 101 acre-feet per year. Nearly 25 percent of the reservoir's original capacity of 20,950 acre-feet has been lost to sediment deposition.

In 2010, the outlet works at Paonia Dam became partially blocked with sediment and debris, indicating an impending sediment deposition issue. Following the 2010 blockage, a sediment sluicing/flushing plan was implemented. Operations were changed to include drawing the reservoir down in the early spring and using high spring runoff flows to sluice and flush sediment through the outlet works before closing the gates to refill the pool for irrigation season. Meanwhile, studies to monitor and develop a long-term reservoir sustainability plan were set forth by Reclamation and the U.S. Geological Survey.

Until fall 2014, the flushing strategy was able to pass a measurable amount of sediment through the long, narrow reservoir (approximately 3 miles long and 0.2 mile wide) and downstream. However, reservoir drawdown in late October 2014 revealed the entire reservoir dead pool and 6 feet of the active pool

Figure 3.—View looking upstream of Paonia Dam showing the arrival of reservoir sediment and partial burial of the outlet works in November 2014 (photo courtesy of Philip Ipson, Western Colorado Area Office).

had filled with sediment (figure 3), and the outlet works intake trashracks became partially plugged with a mixture of submerged debris and sediment (figure 4). Due to the recent discovery of lost dead pool capacity and sediment levels above the intake sill elevation, the original study objective of developing a long-term reservoir sustainability plan to manage inflowing and deposited sediment more efficiently was altered to include short-term strategies for water delivery during the 2015 irrigation season.

At just over 50 years since dam closure, Paonia Dam operators must contend with the arrival of sediment and debris at the operational features, which jeopardizes the operation and release of late-season irrigation flows downstream. Short-term reservoir operations have been prescribed to maintain a higher reservoir pool during spring runoff to keep sediment deposition in the upstream portion of the reservoir, temporarily preventing the arrival of sediment and debris that can plug the outlet works. Meanwhile, current long-term plans are in progress to maintain reservoir storage capacity and sustainably manage the arrival of sediment and debris as a result of the loss of the dead pool.

For more information on Paonia Reservoir, see
http://acwi.gov/sos/pubs/3rdJFIC/Contents/9C-Collins.pdf

Figure 4.—Photo showing the manual removal of saturated debris and sediment at the Paonia Dam outlet works intake (photo courtesy of Philip Ipson, Western Colorado Area Office).

The arrival of coarse reservoir sediment (sands and gravels) can also abrade outlet works and hydropower features. As an example, figure 5 shows the damage to a Pelton wheel needle valve during (A) 10,000 hours of normal operation and (B) after 24 hours of operation while passing coarse sand as a result of extreme drawdown and incoming floodflows at a facility in the country of Colombia. The damage to the needle valve was extensive enough to prevent the successful closure of the valve itself, and more than a month of downtime was required to repair the valve, resulting in lost hydropower generation.

Other features, such as boat ramps and marinas, can also be impacted by the arrival of reservoir sediment. Boat ramps can be buried by the arrival of the sediment delta, and/or watercraft navigation can be cut off from the remainder of the reservoir by the sediment delta during lower water levels. A good example of this occurred at the Horseshoe Bend marina on Bighorn Lake in northern Wyoming (figure 6). Since the completion of the 525-foot-high Yellowtail Dam, which impounds Bighorn Lake, in 1967, a significant amount of sediment has accumulated in the upper portion of the reservoir primarily due to filling operations during the spring runoff period when sediment delivery to the reservoir is the highest. The Horseshoe Bend reach is much wider relative to reaches

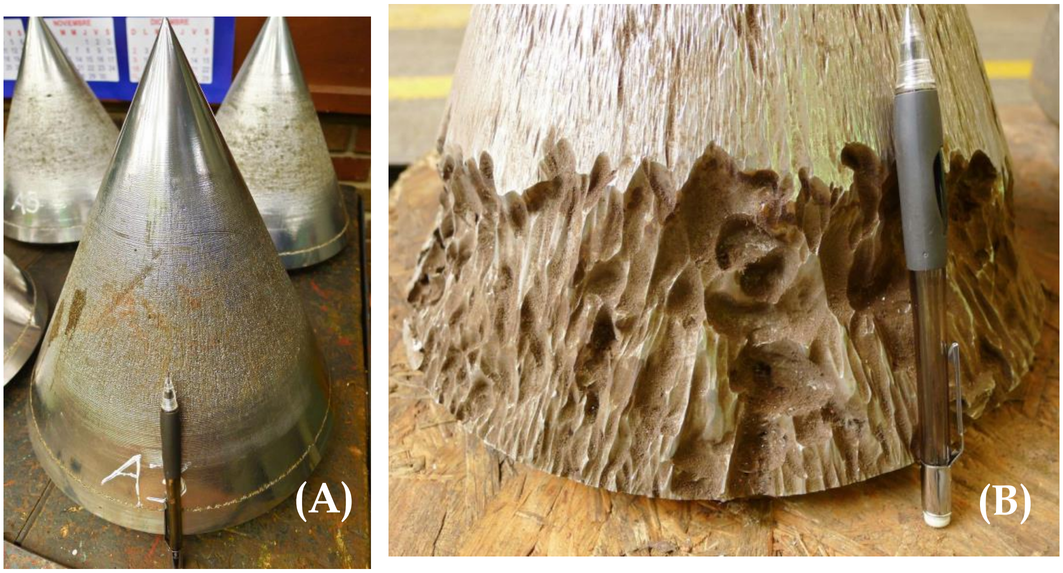

Figure 5.—Pelton wheel turbine needle after (A) 10,000 hours of normal operation and (B) 24 hours of operation with the passage of sand (photo courtesy of Greg Morris, GLM Engineering-COOP).

upstream and downstream, resulting in the deposition of a large portion of incoming sediment (Reclamation, 2010). Around the early- to mid-2000s, watercraft navigation became impaired at the Horseshoe Bend marina during lower lake levels, impacting recreation access on Bighorn Lake. Efforts to study and manage incoming reservoir sediment near the marina to maintain recreation access from the marina are ongoing.

The impacts to the operation and maintenance of these particular features demonstrate the need to manage reservoir sedimentation on a proactive basis – before the arrival of reservoir sediment creates a crisis in delivering water and power.

Communities upstream of reservoirs can also impacted by increased flood risk as a result of reservoir sedimentation. A good example of this case is in reaches upstream of Black Canyon Diversion Dam, which impounds Black Canyon Reservoir in the Payette River drainage, approximately 30 miles northwest of Boise, Idaho. Black Canyon Diversion Dam was constructed in 1924 for authorized uses of irrigation and power. Black Canyon Diversion Dam was constructed between 1922 and 1924 as part of the Payette Division of the Boise Project (Reclamation, 2004). A small community of Montour was located upstream of Black Canyon Reservoir along the Payette River (figure 7).

After completion of the Black Canyon Dam, sediment carried by the Payette River began filling the upper end of Black Canyon Reservoir. In time, this sediment deposition caused water to back up into the Montour area. As the water backup into Montour grew worse, several solutions were considered. In 1976,

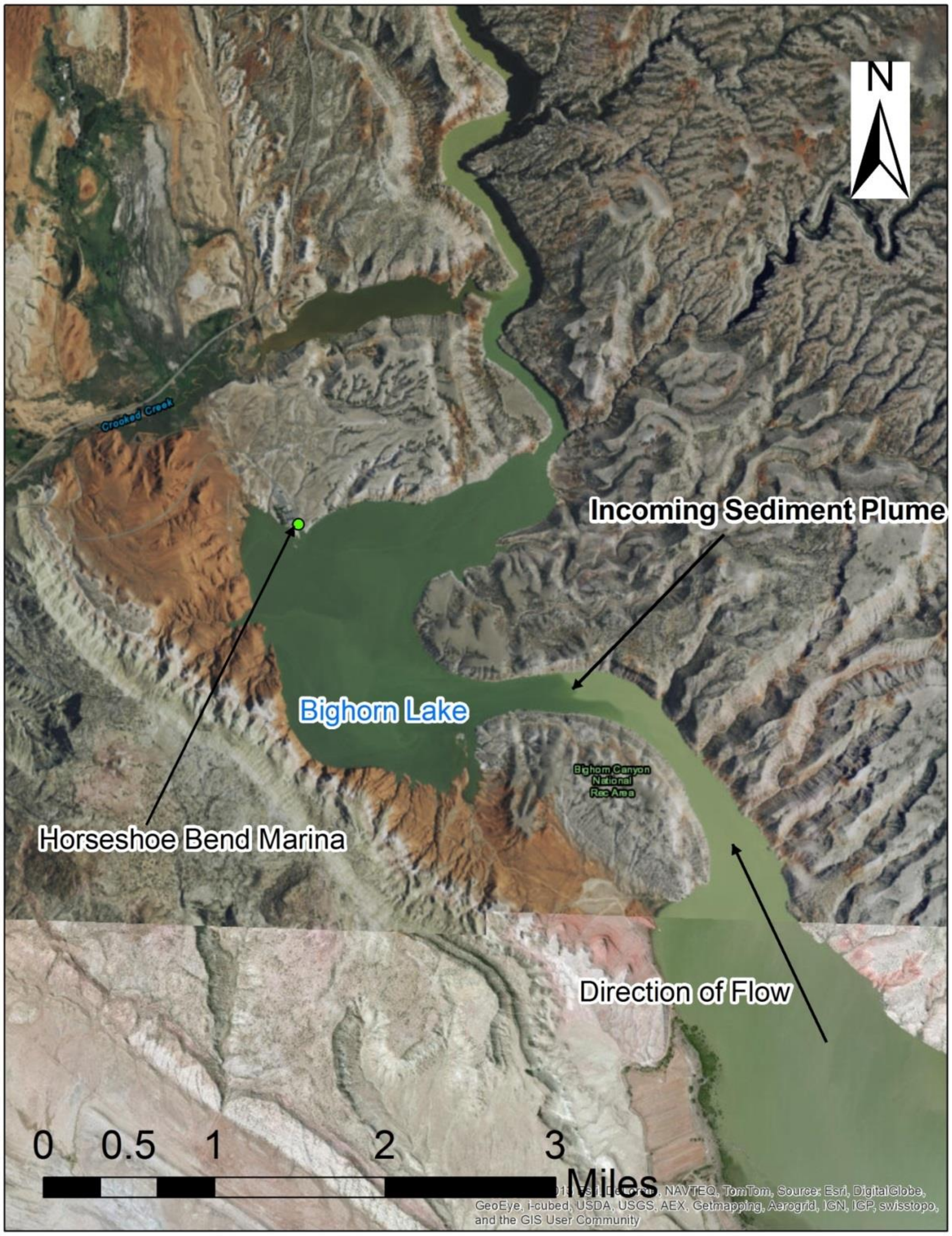

Figure 6.—Location map of the Horseshoe Bend marina and the upper portion of Bighorn Lake.

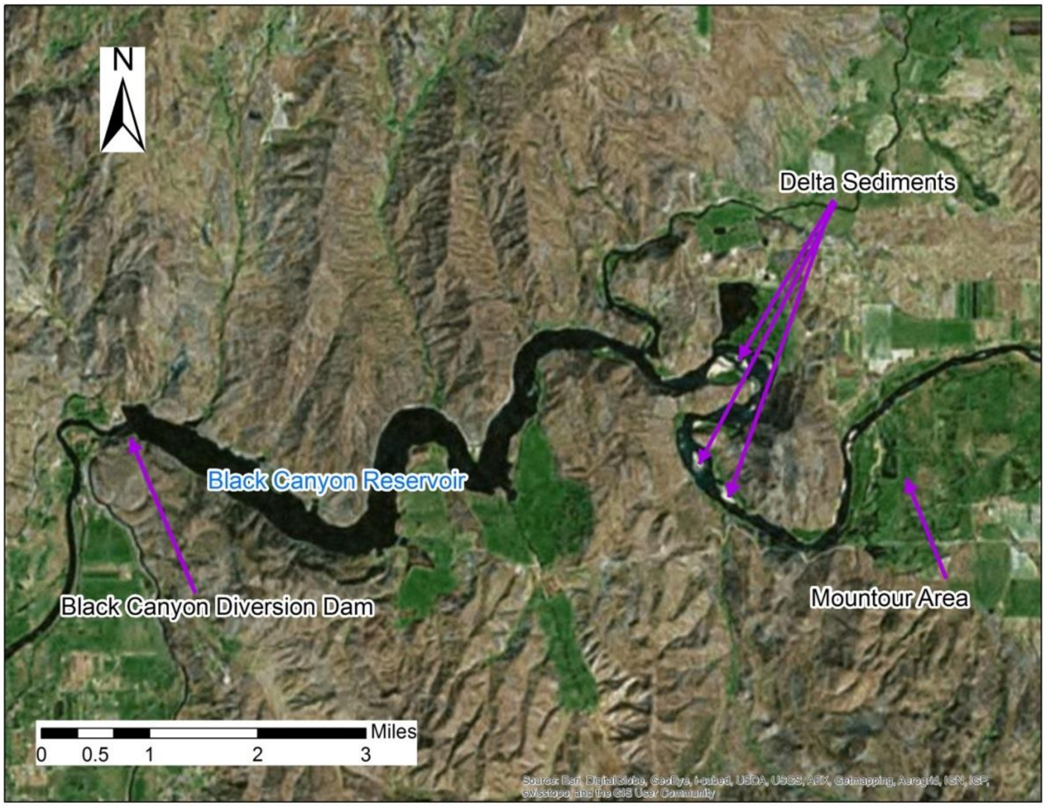

Figure 7.—Location map of Black Canyon Reservoir and the former community of Montour.

Reclamation purchased lands within the 100-year flood plain under the Montour Flood Project. Realizing its value for wildlife and public use, Montour Valley was designated by Reclamation as the Montour Wildlife Management Area. In 1983, the Idaho Department of Fish and Game and Reclamation entered into a cooperative agreement to manage the area (Reclamation, 2004).

The above potential reservoir sedimentation impacts support the need for future planning to manage reservoir sediment at Reclamation's facilities, which is further detailed in the next section.

Planning for the Management of Reservoir Sedimentation

In the field of natural resources management in the United States, managers, engineers, and scientists have paid more attention lately to reservoir sedimentation. An example is this recent resolution proposed by the Subcommittee on Sedimentation (SOS) to the Advisory Committee on Water Information, who represents the interests of water information users and professionals in advising the Federal Government on Federal water information programs and their effectiveness in meeting the Nation's water information needs (www.acwi.gov):

> "Continued sedimentation threatens the project benefits for many of the Nation's reservoirs. The SOS encourages all Federal agencies to develop long-term reservoir sediment-management plans for the reservoirs that they own or manage by 2030. These management plans should include either the implementation of sustainable sediment-management practices or eventual retirement of the reservoir. Sustainable reservoir sediment-management practices are practices that enable continued reservoir function by reducing reservoir sedimentation and/or removing sediment through mechanisms that are functionally, environmentally, and economically feasible. The costs for implementing either sustainable sediment management practices or retirement plans are likely to be substantial, and sustainable methods to pay for these activities should also be identified.
>
> Federal agencies are encouraged to start developing sustainable reservoir sediment-management plans now for one or two reservoirs per year on a pilot basis. From this experience, interagency technical guidelines will be developed for preparing sustainable reservoir-sedimentation plans."

A sediment management plan must address social, environmental, technical, economic, and legal challenges. With guidance adapted from the Utah Division of Water Resources (2010) and Garcia (2008), the following broad and general steps are necessary to develop a reservoir sustainability plan. Note that not all steps are mandatory, and some steps can occur concurrently (from Reclamation, 2015):

a. Determine the magnitude of the sediment problem
b. Define preliminary sediment management options
c. Define stakeholders and constraints
d. Assess feasibility and economic viability of options
e. Develop and implement a sediment management plan
f. Monitor and revise plan if necessary

In the context of developing reservoir sediment management plans for an inventory of reservoirs with the limitation of time and resources, prioritization is required to effectively manage reservoir sedimentation at facilities that are the most likely to see adverse impacts soonest.

Preliminary technical guidance has been developed by staff at Reclamation's Technical Service Center staff in order to effectively plan and prioritize the development and implementation of reservoir sediment management plans for a large inventory of reservoirs owned by Reclamation (see Reclamation, 2015). More detailed guidance is in the works by Reclamation staff to further assist in the development and implementation of reservoir sediment management plans.

Determining the Potential Impact of Features

Performing Step a. from Reclamation (2015), direct measurement of sediment accumulation is key in determining the potential impact of reservoir sedimentation on facilities at a given reservoir.

With sediment accumulation measurements, one useful way to determine the relative impact of the arrival of sediment at infrastructure near a dam is comparing factors of hydrologic size (reservoir storage capacity / mean annual runoff), Kw, and reservoir capacity to sediment inflow (reservoir storage capacity / mean annual sediment yield), Kt, of a particular facility to other facilities in an inventory. figure 8 presents an empirical diagram of the aforementioned factors, derived from Basson and Rooseboom (1997), which provides a means to understand ways to manage reservoir sedimentation. The larger the hydrologic size (Kw) of the reservoir, the more important carryover storage into multiple years for reliable water delivery becomes for the facility. Data needs for this empirical method are:

1. Total reservoir capacity
2. Mean annual sediment yield
3. Mean annual runoff

In general, the farther a particular reservoir is toward the bottom left quadrant of figure 8, the sooner that reservoir's sediment will impact infrastructure located near the dam. For example, in Reclamation's inventory of dams, Black Canyon, Guernsey, Paonia, and Lake Sumner are reservoirs near the bottom and left of the diagram. Currently, all these facilities pass measurable amounts of sediment through their respective outlet works facilities. The former Lake McMillan was nearly filled with sediment and replaced with the larger Brantley Dam, inundating the structure. An important feature of figure 8 is that, as time passes and reservoirs fill with sediment (decrease in storage), their plotting position moves toward the bottom left quadrant of the diagram.

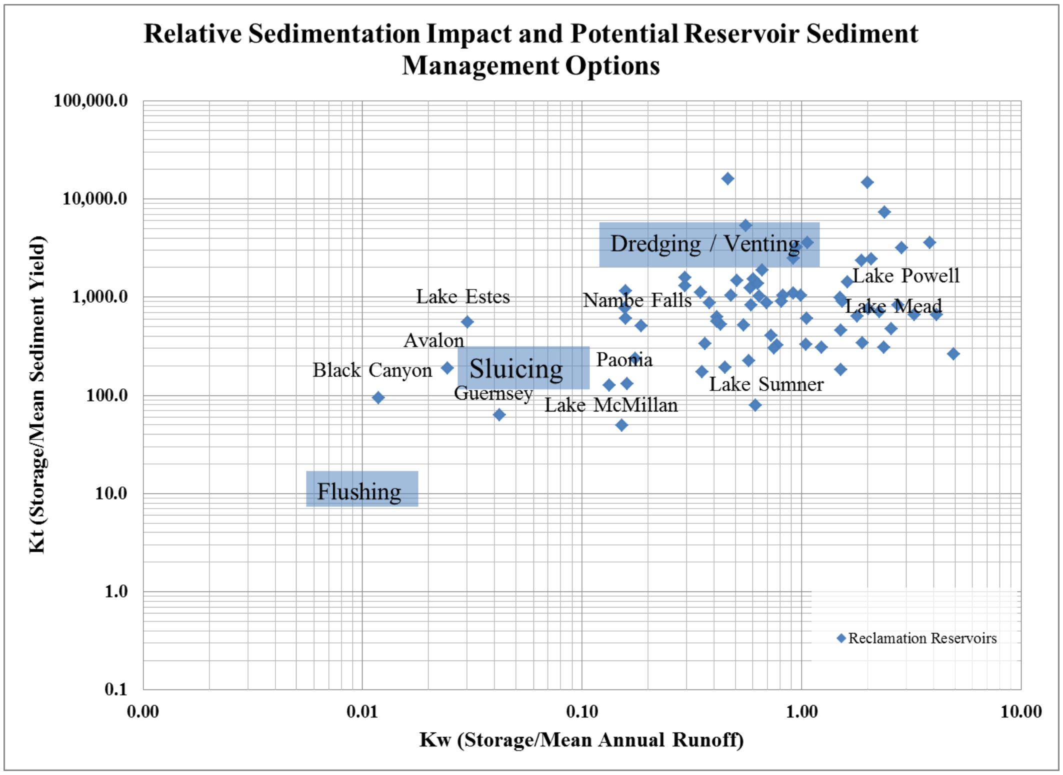

Figure 8.—Diagram adapted from Basson and Rooseboom (1997) for determining relative reservoir sedimentation impact and preliminary reservoir sediment management options at Reclamation's reservoirs.

Potential Solutions for Dealing with Reservoir Sedimentation

Figure 8 also presents three potential sediment management options: flushing, sluicing, and dredging/venting. The ranges of these preliminary options are taken from Basson and Rooseboom (1997) and are based on empirical data from Chinese and South African reservoirs. At the bottom-left of the plot, flushing is defined as drawing down the water level to re-entrain previously deposited sediment and to remove these sediment from the reservoir through bottom outlets. In the middle, sluicing is defined as an operation technique in which the reservoir water level is lowered prior to a flood or flood season and sediment-laden inflows are allowed to pass through the reservoir before the sediment particles can settle, thereby reducing the sediment trap efficiency of the reservoir, and maintaining reservoir storage capacity. The dredging option is defined as requiring a mechanical means to maintain or possibly regain storage after inflowing sediment is stored in a reservoir, with the exception that the "venting" of turbid density currents is a possible sediment management option for reservoirs in this category. The majority of Reclamation's reservoirs in the National RESservoir SEDimentation Database, RESSED (Gray et al., 2010) fall into the "dredging/ venting" category.

Summary and Future Activities

The arrival of reservoir sediment at operational features within Reclamation's facilities is an inevitable problem that must be addressed, preferably on a proactive basis. Monitoring of the distribution of sediment in a reservoir is key in determining and estimating the timing of the problem. Potential solutions to deal with reservoir sedimentation that can maintain storage capacity and prevent operational impacts are known. These potential solutions can be implemented in an economical and sustainable manner compared to the costs of decommissioning a facility as a result of reservoir sedimentation and finding an alternative source of a reliable water supply.

The following activities are currently in progress by Reclamation staff in the field of managing reservoir sedimentation at Reclamation facilities:

- Coordinate and perform pilot studies at Reclamation facilities to test the competency of the preliminary reservoir sustainability guidelines.

- Refine and develop additional reservoir sedimentation distribution tools to estimate the spatial and temporal impacts of reservoir sedimentation on important features.

- Research and develop potential options to manage incoming sediment and debris at racked outlet works and hydropower intakes.

- Improve the amount and availability of Reclamation reservoir sedimentation data into an interagency reservoir sedimentation database for reservoir sediment management prioritization and planning.

References

Basson, G.R. and A. Rooseboom. (1997). Dealing with Reservoir Sedimentation. Water Research Commission Report No. TT 91/97, Pretoria, xxxiii+395 p.

Bureau of Reclamation (Reclamation). (2004). Resource Management Plan. Black Canyon Reservoir and Montour Wildlife Management Area. U.S. Department of the Interior, Bureau of Reclamation, Snake River Area Office, Boise, Idaho.

_____. (2010). Bighorn Lake Sediment Management Study. U.S. Department of the Interior, Bureau of Reclamation, and the U.S. Army Corps of Engineers, Omaha District.

_____. (2015). Formulating Guidelines for Reservoir Sustainability. Submitted for the Reclamation Science and Technology Program, U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

García, M.H. (2008). Sedimentation Engineering, Manual 110, Chapter 12, American Society of Civil Engineers, Reston, Virginia.

Gray, J.R., J.M. Bernard, D.W. Stewart, E.J. McFaul, K.W. Laurent, G.E. Schwarz, J.T. Stinson, M.R. Jonas, T. Randle, and J.W. Webb. (2010). "Development of a National, Dynamic Reservoir Sedimentation Database." Proceedings of the 9th Federal Interagency Sedimentation Conference, June 27 – July 1, Las Vegas, Nevada. 12 p.

Utah Division of Water Resources (2010). Managing Sediment in Utah's Reservoirs: Utah State Water Plan.

LEADVILLE MINE DRAINAGE TUNNEL TREATMENT PLANT UNWATERING UNDER THE RETENTION POND

by: Lee Sears, Materials Engineer, Bureau of Reclamation, Technical Service Center, Materials Engineering and Research Laboratory, 86-68180

Introduction

The Leadville Mine Drainage Tunnel (LMDT) Treatment Plant's retention pond was most recently inspected in June 2015. Observations made during this inspection included:

- The liner in the southern portion of the pond was observed to be floating at the time of the inspection (area highlighted in red on figure 1). Floating could be detected by a trampoline effect when these areas were walked over. These areas were slightly convex (raised) and would bounce when one of the team stood or jumped on them.

- Water is collecting in the southeast corner of the pond from the wells (figure 1) that are pumping groundwater from under the pond.

- The gravel is discolored in the bottom of the pond, especially near the southeast corner (area highlighted in green on figure 1). This discoloration is likely due to sediment in the LMDT water.

- The geocell near the pond bottom around the treatment plant sump is pulled above the detention pond surface and exposed more than it should be. Ice forming on the surface of the pond water is likely adhering to the geocell and preferentially lifting it as the water is pumped into the treatment plant. No evidence of gravel sliding down the side slopes toward the pond invert was observed during the site visit.

- Some of the gravel in the geocells is in poor condition. One possibility is that existing gravel in the geocell is deteriorating due to a chemical reaction with the LMDT water, and another possibility is that sediment in the pond is precipitating or agglomerating onto the gravel.

- There are several sections on the bottom of the pond where algae growth is apparent.

Figure 1.—Aerial view of the LMDT retention pond.

Recommendations

Based on information available at the time of this report, we recommend installing a deeper pumping and backup well around the retention pond to lower the groundwater under the pond (Alternative 1).

More information is required to determine the efficacy of installing a collection trench (Alternative 2) or slurry cutoff wall (Alternative 3) relative to Alternative 1. A three-dimensional groundwater model should be developed to assess the complex interplay of the various groundwater sources and sink for this site and to assist in the development of an efficient, effective solution for the long-term control of groundwater below the pond. The following recommendations are for collecting and developing the final design information:

- Perform a full-scale aquifer test at the site to develop the hydrogeologic parameters required to design a well and pump system.

- Obtain pumping information (rate, duration, and water levels before and after pumping intervals) for the Molly Brown Trailer Park well.

- Record groundwater levels in the monitoring wells onsite weekly.

- Install additional monitoring wells along River Road, between the trailer park and the pond, and throughout the trailer park (particularly within 100 feet of the water well). The groundwater level information provided by the additional monitoring wells would be invaluable in developing an understanding of the flow regime for the area.

In addition to collecting information for mitigation design, we also recommend that the discharge line and manholes be inspected to check for leaks; any leaks found should be repaired. Prompt completion of repairs will increase confidence in the observation well data. If the pond liner is replaced in the future, a collection trench should be installed around the inside perimeter of the pond to facilitate dewatering. Another long-term maintenance option to lower the groundwater near the pond is to plant a row of trees along the fence line between the pond and the trailer park road. Species such as the lodgepole pine or Douglas fir could grow at that elevation, and they have rooting behaviors that could extend to the groundwater table.[1, 2]

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[1] Horton, K.W. 1958. Rooting Habits of Lodgepole Pine. Forest Research Division Technical Note No. 67. Canada Department of Northern Affairs and National Resources, Forestry Branch. Available at : http://www.cfs.nrcan.gc.ca/bookstore_pdfs/30546.pdf (accessed on September 18, 2015).

[2] Anderson, Michelle D. 2003. Pinus contorta var. latifolia *in*: Fire Effects Information System, (Online). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Available at: http://www.feis-crs.org/feis (accessed on March 23, 2016).

Background

The LMDT is an underground excavation constructed by the U.S. Bureau of Mines during World War II and the Korean War to drain groundwater from metal mines located near Leadville in Lake County, Colorado. The Bureau of Reclamation (Reclamation) acquired the LMDT in 1959 for water rights associated with the tunnel with the intent of using the drainage water as a potential water source for the Fryingpan-Arkansas Project. Due to more senior water rights, no water rights were obtained by Reclamation.

LMDT drainage water contains metals in excess of water quality standards. In order to bring the discharge water into compliance, Reclamation designed and constructed a water treatment plant. This plant was completed in 1992 and included a water retention pond where LMDT water could be diverted during outages at the treatment plant.

The retention pond originally included an exposed geomembrane liner on the invert and side slopes and had a design service life of 20 years. A condition assessment for the treatment plant and retention pond was completed in 2010 by United Research Services (URS). URS found several tears in the geomembrane lining that were likely caused by wildlife in the area as well as debris being thrown into the pond. Additionally, testing of the geomembrane liner material showed a significant increase in brittleness and a significant decrease in thickness and break strength.

A new geomembrane liner was installed in 2012. This new liner includes a leak detection system and a gravel cover to mitigate mechanical damage from debris falling into the pond and ultraviolet damage from the sun. LMDT treatment plant personnel have noticed bulging in the bottom of the pond during each spring as snowmelt raises the groundwater table and floats the geomembrane liner.

June 2015 Inspection

Two wells located on the south bank of the pond pump groundwater from beneath the pond and discharge into the pond. The depth-to-water of detention pond dewatering wells (DPDWW) 1 and 2 was recorded over a period of one or two pumping cycles, including the recharge period between pumping. The observation and pumping wells were sounded, and the well stickup was measured with a steel tape; these values are summarized in table 3.

Based on the pumping water level measurements, the pumping and recharge flow rates for each well were calculated and are summarized in tables 1 and 2. The observed pump flow rate for DPDWW1 was 26 gallons per minute (gpm); for DPDWW2, it was 46 gpm. Details on the calculations performed to obtain the flow rates are included in the following section.

Table 1.—Pump/recharge data from DPDWW1

Pump or recharge phase	Time (seconds)	Depth-to-water (feet)	Elevation of water level (feet)	Flow rate (cubic feet per second)	Flow rate (gallons per minute)
Pump - start	0	16.1	9947.9	0.0E+00	0.0
Pump - end	25	17.3	9946.7	5.7E-02	25.8
Recharge	40	16.95	9947.0	-2.8E-02	-12.5
Recharge	50	16.85	9947.1	-1.2E-02	-5.4
Recharge	55	16.8	9947.2	-1.2E-02	-5.4
Recharge	63	16.75	9947.2	-7.5E-03	-3.4
Recharge	70	16.7	9947.3	-8.5E-03	-3.8
Recharge	79	16.65	9947.3	-6.6E-03	-3.0
Recharge	88	16.6	9947.4	-6.6E-03	-3.0
Recharge	100	16.55	9947.4	-5.0E-03	-2.2
Recharge	110	16.5	9947.5	-6.0E-03	-2.7
Recharge	122	16.45	9947.5	-5.0E-03	-2.2
Recharge	135	16.4	9947.6	-4.6E-03	-2.1
Recharge	153	16.35	9947.6	-3.3E-03	-1.5
Recharge	171	16.3	9947.7	-3.3E-03	-1.5
Recharge	193	16.25	9947.7	-2.7E-03	-1.2
Recharge	220	16.2	9947.8	-2.2E-03	-1.0
Recharge	253	16.15	9947.8	-1.8E-03	-0.8
Recharge	261	16.1	9947.9	-7.5E-03	-3.4
Pump - start	0	16.1	9947.9	0.0E+00	0.0
Pump - end	26	17.35	9946.6	5.7E-02	25.8

Table 2.—Pump/recharge data from DPDWW2

Pump or recharge phase	Time (seconds)	Depth-to-water (feet)	Elevation of water level (feet)	Flow rate (cubic feet per second)	Flow rate (gallons per minute)
Pump - start	0	15.9	9947.22	0	0
Pump - end	19	17.5	9945.62	1.0E-01	45.19
Recharge	120	17.25	9945.87	-3.0E-03	-1.33
Recharge	240	17.1	9946.02	-1.5E-03	-0.67
Recharge	480	16.75	9946.37	-1.7E-03	-0.78
Recharge	780	16.4	9946.72	-1.4E-03	-0.63
Recharge	960	16.1	9947.02	-2.0E-03	-0.89
Recharge	1080	15.95	9947.17	-1.5E-03	-0.67
Recharge	1140	15.9	9947.22	-1.0E-03	-0.45
Pump – start	0	15.9	9947.22	0.0E+00	0.00
Pump - end	18	17.5	9945.62	-1.7E-03	47.70

Table 3.—Observed well/casing dimensions

Well	Casing height (inches)	Depth of well sounding (feet)
DPDWW1	21.0	[1]19.33
DPDWW2	6.0	[1]19.00
DPMW1	37.2	[2]16.83
DPMW2	25.2	[3]25.00

[1] Depth to the bottom inside casing or refusal as applicable.
[2] The furthest depth the tape measure could go – possibly encountered a blockage in the well or infilling.
[3] Extent of measuring tape.

Area Hydrogeology

There are two aquifer systems at the site: the bedrock and an unconfined surficial aquifer. The surficial aquifer generally follows topography but is influenced by the geometry of the bedrock.[3] Figure 2 shows a conceptual presentation of the potential groundwater flow in the vicinity of the detention pond. Three systems are shown on figure 2; one is the unconfined aquifer flow, which is inferred on the figure based on topography. The second system shown is an empirical cone of depression induced from the Molly Brown Trailer Park water well located southwest of the pond. The third system is the groundwater equipotential gradient calculated from the three monitoring wells and the groundwater levels provided by the area office. The flow lines generated for each system are depicted independently; additional analyses and modeling would be required to establish the interaction effects from each system.

Figures 3 and 4 show the calculated groundwater maps for the pond site before and after the installation of the existing pumps. The groundwater flow at the pond site appears to be flowing southeast, against the topographical slope and away from the river valley to the north. This is the opposite direction from what was anticipated. Based on the equipotential lines, it is apparent on figures 3 and 4 that there is either a groundwater source northwest of the site or a sink southeast of the site.

Figure 5 shows the site plan; the discharge pipe for the treatment plant runs along the northeast side of the pond and could be a source of water from leakage. Cross

[3] Leadville Mine Drainage Tunnel Risk Assessment. 2008. Bureau of Reclamation, Denver, Colorado. November 2008.

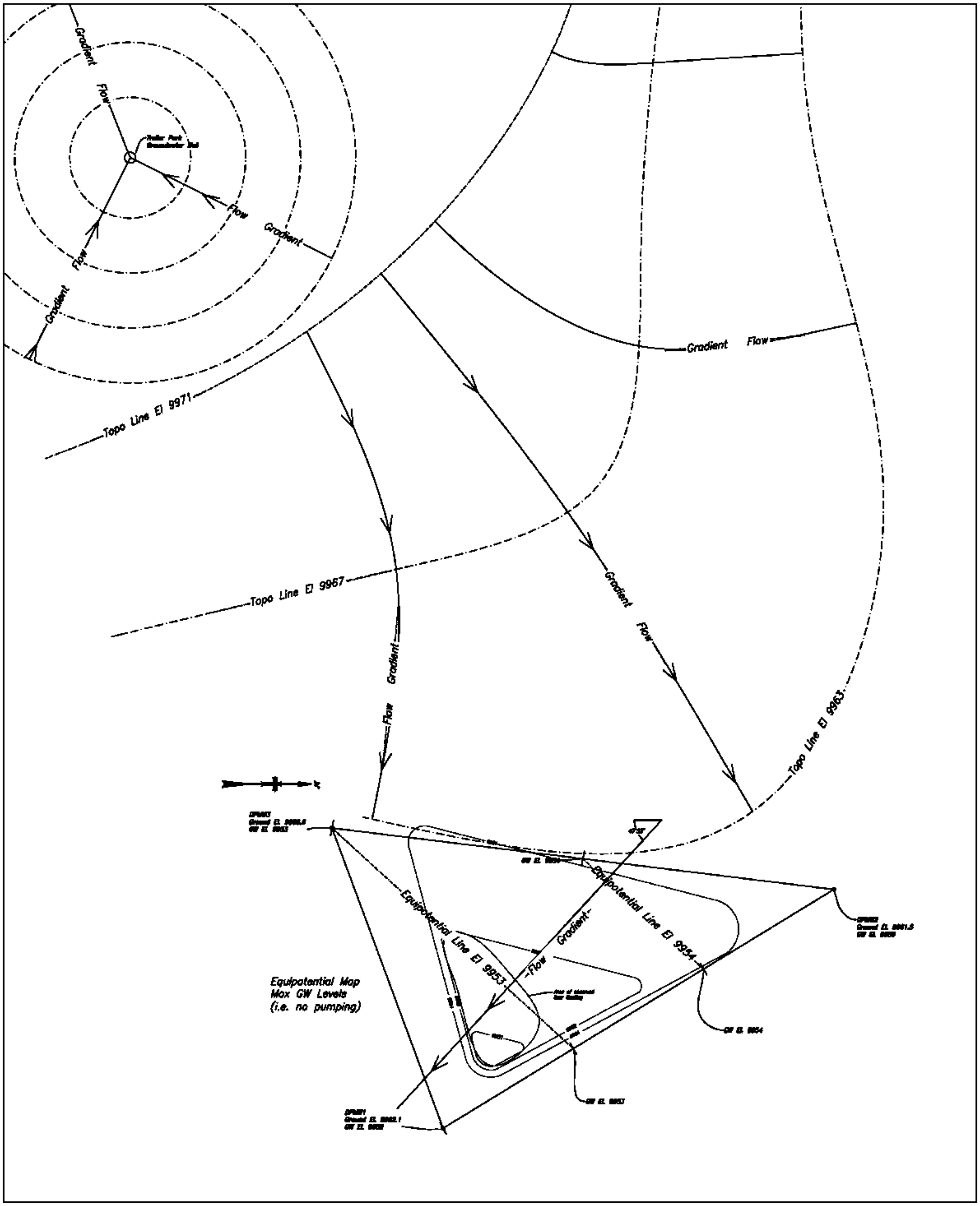

Figure 2.—Conceptual map of regional groundwater in pond vicinity.

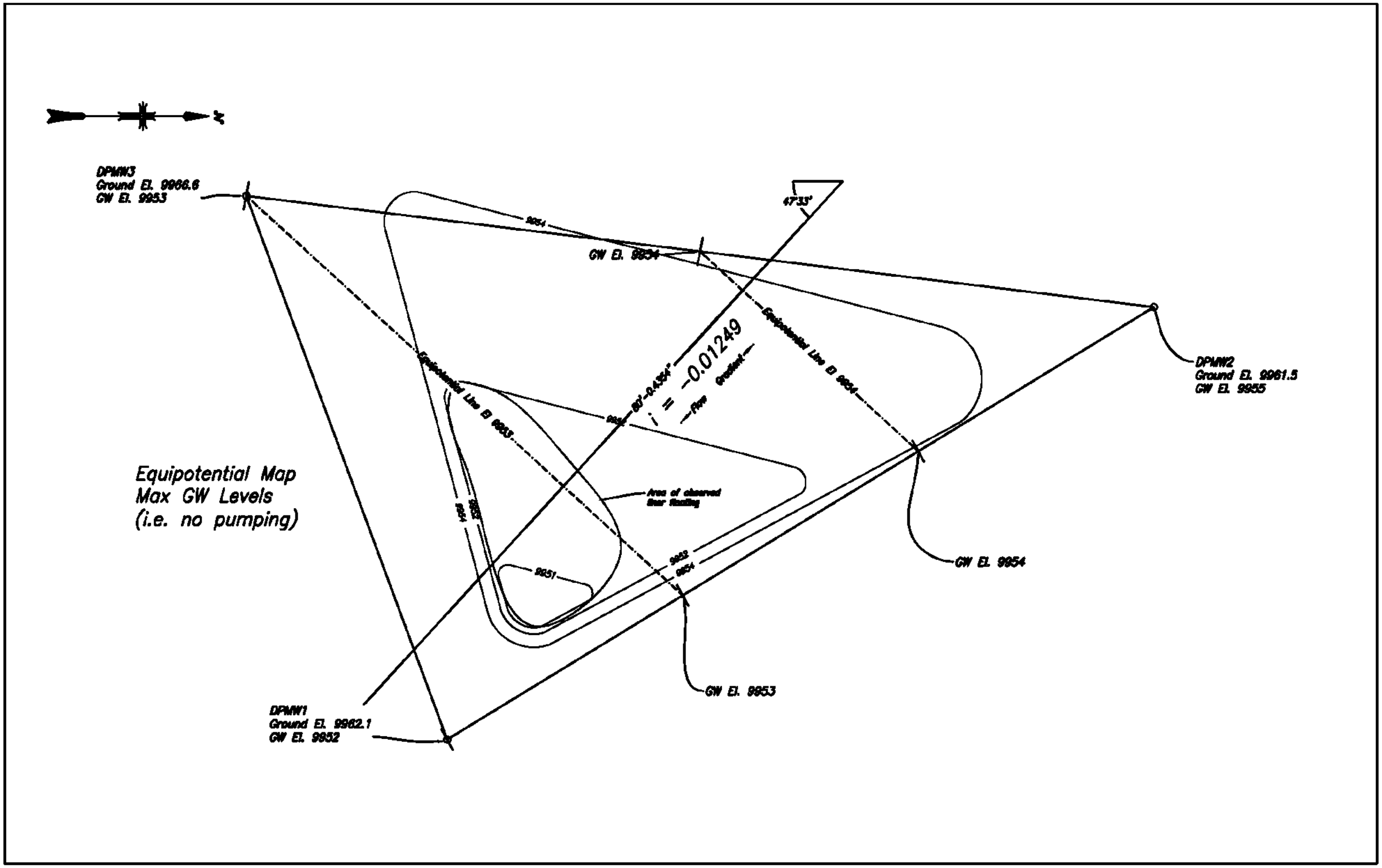

Figure 3.—Equipotential map of LMDT pond – before pumping.

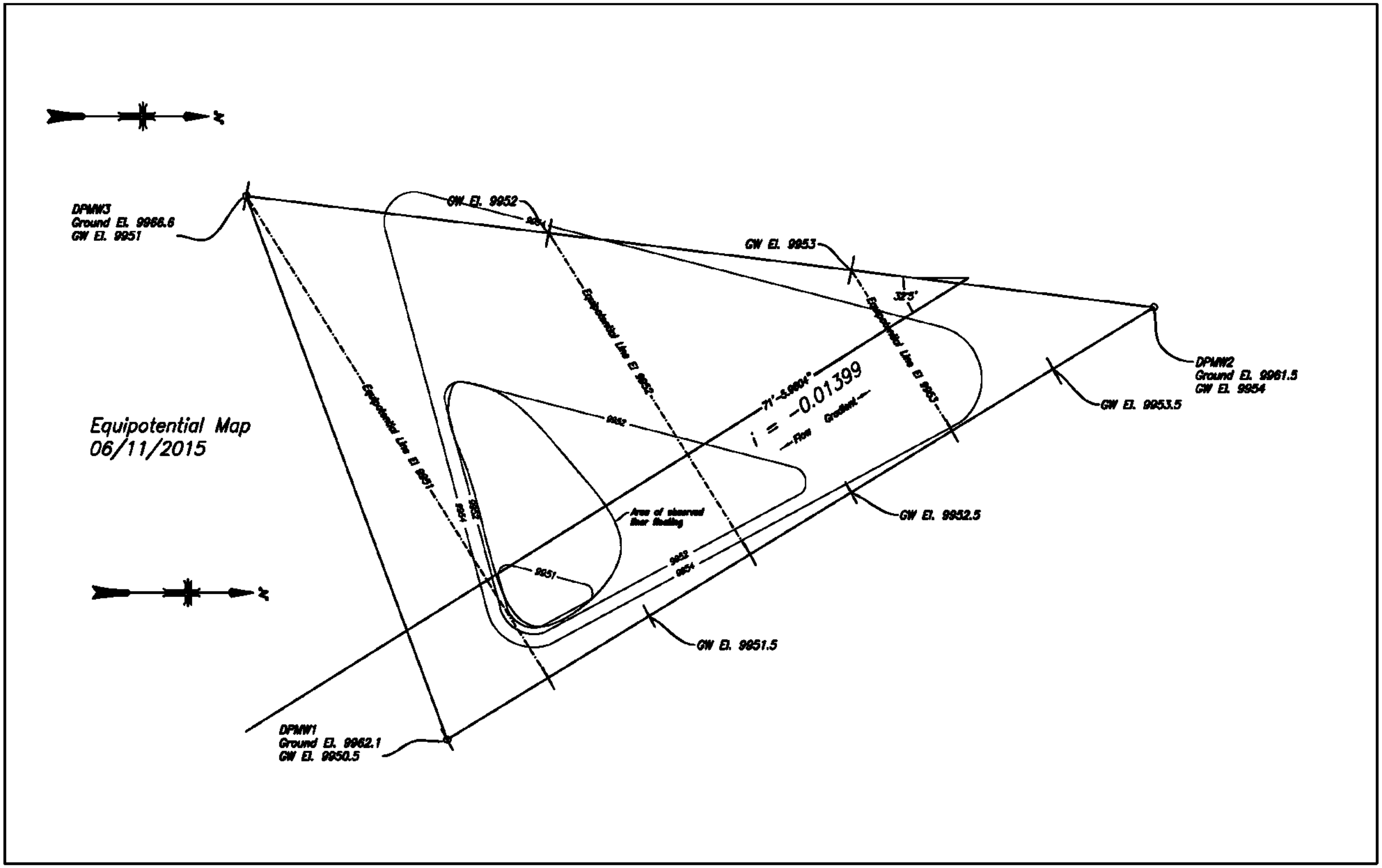

Figure 4.—Equipotential map of LMDT pond – June 11, 2015.

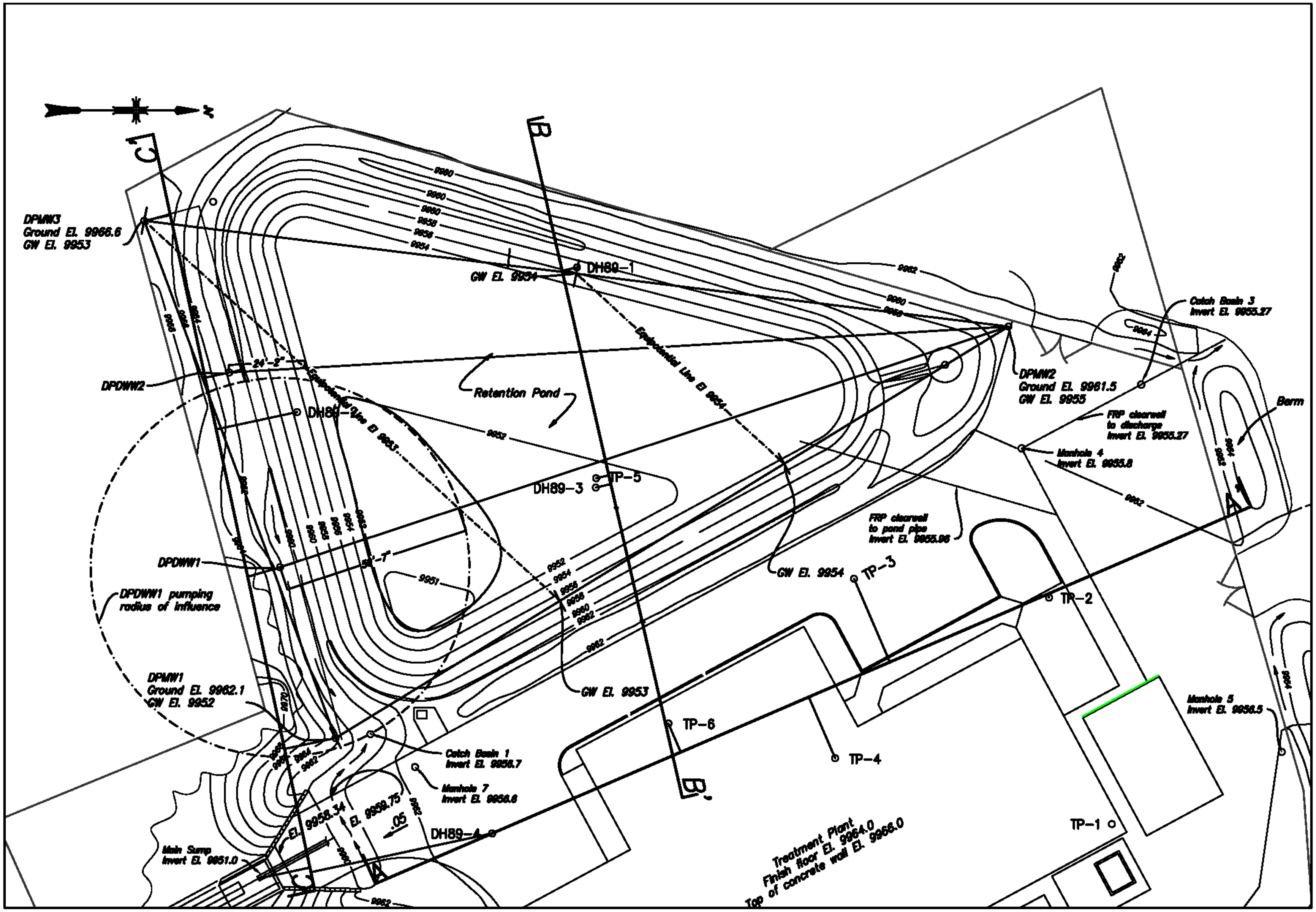

Figure 5.—LMDT site plan view.

sections developed for the area by the U.S. Geological Survey (USGS)[4, 5] indicate sloping sandstone, quartzite, and granite bedrock in the area as well as a set of faults, which could be a source of upwelling groundwater. The tunnel acts as a sink for groundwater regionally and could be doing the same at the pond site. Finally, the local stratigraphy shows a lean clay confining layer that dips to the west which could be forcing the groundwater to flow toward the south by restricting flow from continuing to the east. Figures 5 and 6 show a plan view and geologic cross sections for the site.

Flow Rate Calculations

The pumping wells onsite were observed to be operating intermittently. According to Janelle Ortiz, the pumps operate in response to a float: when the water level in the casing reaches a certain level, the pumps turn on. When the water level was lowered to a certain level by pumping, the pumps turned off. For this report, one pump cycle is defined as the time from the pump switching on until the time that the pump switches on again. So one pump cycle includes a short period when water is being discharged from the well and then a longer period when the water level in the casing rises from groundwater recharge while the pump is off.

The pumping wells were constructed with 16-inch nominal outer diameter Schedule 40 polyvinyl chloride pipe[6] with a 2-inch nominal diameter Schedule 80 polyvinyl chloride discharge pipe.[7] An electronic water meter was used to determine the depth from the top of the casing to the water level immediately prior to pumping and then again immediately after pumping stopped. The water level in the casing was measured at regular intervals for the duration of the recharge period until the pump turned on again. The depth to water measurements and the times for each recording are summarized in tables 1 and 2.

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[4] Tweto, Ogden. 1974. Geologic map and sections of the Holy Cross quadrangle, Eagle, Lake, Pitkin, and Summit Counties, Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-830, scale 1:24,000.

[5] Turk, Taylor. 1979. Appraisal of Ground Water in the Vicinity of the Leadville Drainage Tunnel, Lake County, Colorado. Open-File Report 79-1538, U.S. Geological Survey.

[6] Per a daily inspection report from the construction records at the time of well installation; provided by Janelle Ortiz.

[7] Estimated diameter and material, based on observed pipe.

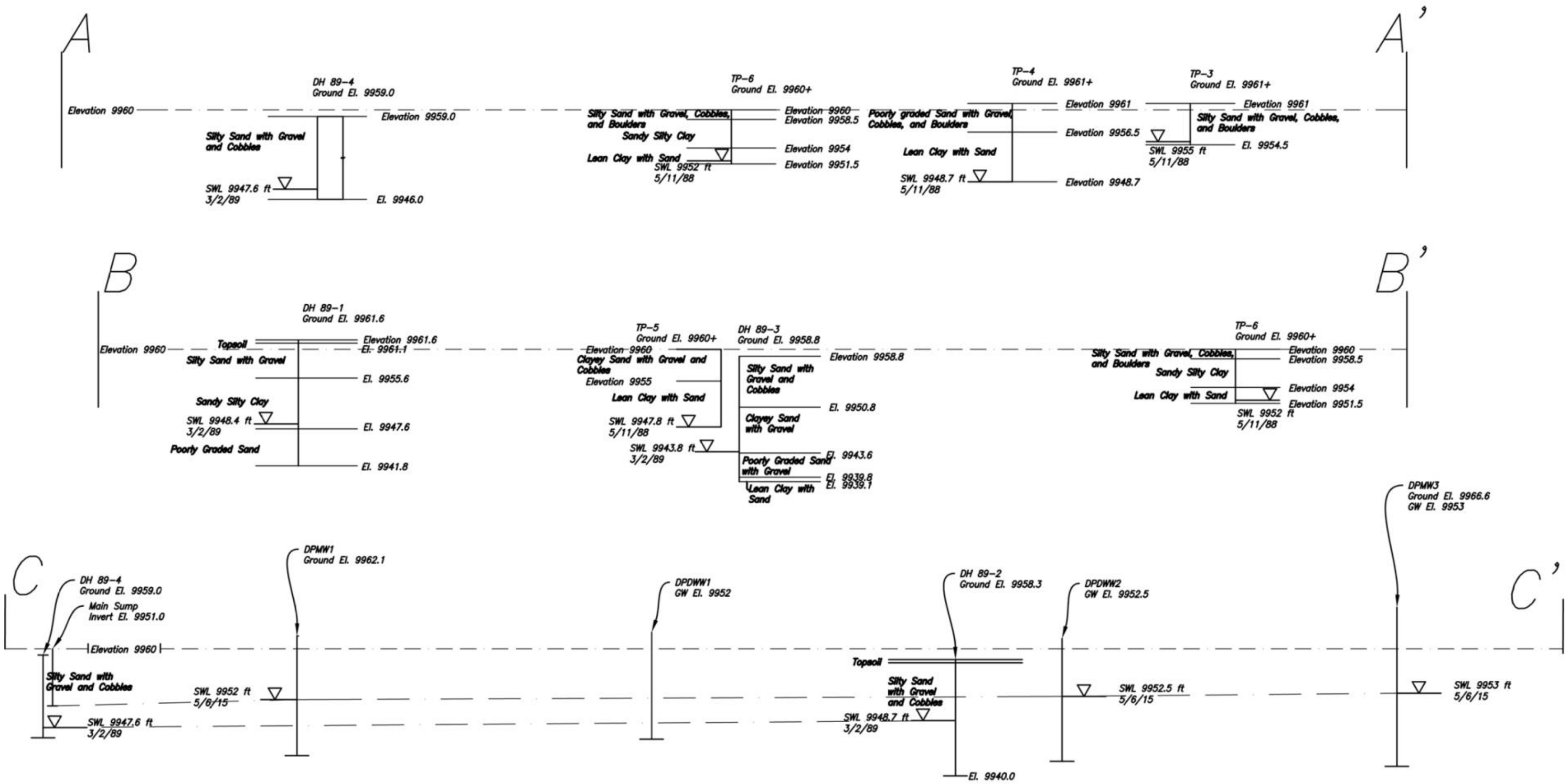

Figure 6.—LMDT site cross sections – DRAFT.

For each change in the water level, the volume of water was calculated using the formula for a cylinder and the equivalent area of the water in the casing, which is the difference between the internal diameter of the casing and the outer diameter of the discharge pipe:

$$Equivalent\ Area\ (A_{eq}) = \pi\left(\frac{14.94}{2}\right)^2 - \pi\left(\frac{2.0}{2}\right)^2 = 1.196\ ft^2$$

$$Volume\ of\ water(V_w) = h * A_{eq}$$

where: A_{eq} = Equivalent area of water in casing (ft^2)
V_w = Volume of water pumped into or out of casing (ft^3)
h = Change in height of water level (ft)

The flow rate for each interval was calculated by dividing the volume by the time interval over which the volume changed:

$$Flow\ rate = \frac{V_w}{t_1 - t_2}$$

For example, the flow rate for the first pumping phase of well 1:

$$Flow\ rate = (17.3 - 16.1) * \frac{(1.196)}{(25 - 0)} = 0.0574\ \frac{ft^3}{sec}$$

$$Flow\ rate = 0.0574\ cfs * \frac{448.831 gpm}{cfs} = 25.7\ gpm$$

For the recharge intervals, the flow rate represents the rate of groundwater moving back into the casing from the surrounding aquifer. Negative flow rates indicate flow into the pipe from the aquifer. Positive flow rates indicate flow out of the pipe through pumping discharge.

Site Parameters

One of the liner displacement mitigation options considered included using pumps to lower the groundwater in the vicinity of the lowest point of the pond liner. In order to develop the recommendations for the pump and dewatering well, it was necessary to develop the site stratigraphy, hydrogeologic parameters for the soil horizons, and establish the groundwater levels across the site.

Site stratigraphy was assumed based on the USGS map of the area[8] and the history of site development for the treatment plant. The site was assumed to be benched by excavating approximately 20 feet from the original ground surface to create a level building pad. Based on the USGS map and interpolated from the cross section, the site stratigraphy consisted of approximately 43 feet of glacial drift (Qd) underlain by approximately 73 feet of Malta Gravel (Qm), underlain by inclined sandstone (€p), interbedded granite (su), and quartzite bedrock (€s).

Another cross section done by the USGS in 1979[9] shows the site to be comprised of approximately 10 feet of glacial moraine (Qd) underlain by approximately 30 feet of terrace gravel (Qm), underlain at depth by coarse sandstone (Pw). The authors of the 1979 report identify the units differently than the 1974 USGS map they referenced, but the descriptions are similar. Therefore, the units are considered to be equivalent. For the pump calculations, the 1974 unit thicknesses were used. More detailed investigation will be necessary to determine the site-specific stratigraphy.

The hydrogeologic properties of interest for the pumping alternative (Alternative 1) are transmissivity (T) and storativity (S). The Qd and Qm geologic units were assumed to be similar with respect to hydrogeologic behavior. The hydrogeologic properties for Qd were assumed based on the USGS description, the U.S. Department of Agriculture (USDA) soil mapping description and properties,[10] the gradations of a nearby test pit, and the analysis of the pumping cycles observed for pumping well 1. The Qd was assumed to have T = 2,860 square feet per day (ft^2/d) and S = 0.23.

An aquifer test reported in the 1979 USGS report indicates the following hydrogeologic values for the unconfined alluvial aquifer: T = 2,300 ft^2/d, S = 0.30, and hydraulic conductivity of 50 feet per day. These values are reasonably close to the values estimated from the USDA soil maps.

The groundwater levels across the site were determined based on the observed levels at the time of the site visit (June 11, 2015) and on the water levels measured and provided by the area office staff. The water levels from the site visit and the day prior were used to develop the equipotential groundwater lines for the site; it is apparent that the gradient for the site is flowing southeast, toward the tunnel and away from the river. The water levels in DPMW2 are consistently higher than those in DPMW3 and 1, indicating that there is either a sink to the southeast or a groundwater source to the northwest of the observation wells. By comparing the equipotential maps from prior to pumping (steady state, also

[8] Tweto, Ogden. 1974. Geologic map and sections of the Holy Cross quadrangle, Eagle, Lake, Pitkin, and Summit Counties, Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-830, scale 1:24,000.

[9] Turk, Taylor. 1979. Appraisal of Ground Water in the Vicinity of the Leadville Drainage Tunnel, Lake County, Colorado, Open-File Report 79-1538, U.S. Geological Survey.

[10] http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx, U.S. Department of Agriculture, Natural Resources Conservation Service.

happens to be the maximum observed groundwater levels (May 16, 2015) to after when the pumps were installed, its apparent that the groundwater levels in the vicinity of the observation wells are lower, and the groundwater flow is directed south. However, given the complexity of the groundwater regime at this site, there could be a number of factors influencing the observed change; most likely, it is a combination of the factors presented in the “Area Hydrogeology” section.

Figure 5 was used to develop the pumping alternative. The equipotential lines are shown, indicating the groundwater level for the maximum observed observation well values. The difference between the equipotential line closest to the area of liner observed to be floating and the elevation of 1 foot below the pond liner is the amount of drawdown required to prevent the liner from floating. Sixty feet was chosen for the required drawdown radius to cover the majority of the floating liner area. The pumping rate to produce 3 feet of drawdown 60 feet away from the well was determined to be 240 gpm, using the USDA values of $T = 2{,}860\ ft^2/d$ and $S = 0.23$. Using the USGS values of $T = 2{,}300\ ft^2/d$, $S = 0.30$, a pumping rate of 225 gpm is required to produce 3 feet of drawdown 60 feet away from the well. The quantity estimate for the pumping alternative was conservatively developed with the 240-gpm pumping rate.

Unwatering Alternatives

Alternative 1

Description: Installing a primary pumping well and backup well to lower the groundwater under the pond. The well for Alternative 1 would be installed to a depth of 40 feet below ground surface, in the location that pumping well 1 occupies currently. The existing well casing would be removed, and the hole would be reamed out to a larger diameter. It would be 16 inches in diameter, screened over the lower 35 feet. Alternative 1 would also include the installation of a backup well, constructed similarly, and located northeast of pumping well 1 between the pumping plant and the pond. Figure 7 shows the basic well construction details.

Both wells would include a variable frequency pump capable of producing 240 gpm against 40 feet of head. The total design head would be based on the discharge location and configuration.

Pros: Would allow the groundwater in the immediate vicinity of the pond to be lowered sufficiently to prevent the pond liner from floating.

Cons: Would produce significantly more water (approximately 237 gpm more according to preliminary estimates of hydrogeological parameters) than is currently being produced with the intermittent pumping system in place. If the additional pumped water must be treated prior to being discharged, that could impact the treatment plant’s operation and capacity.

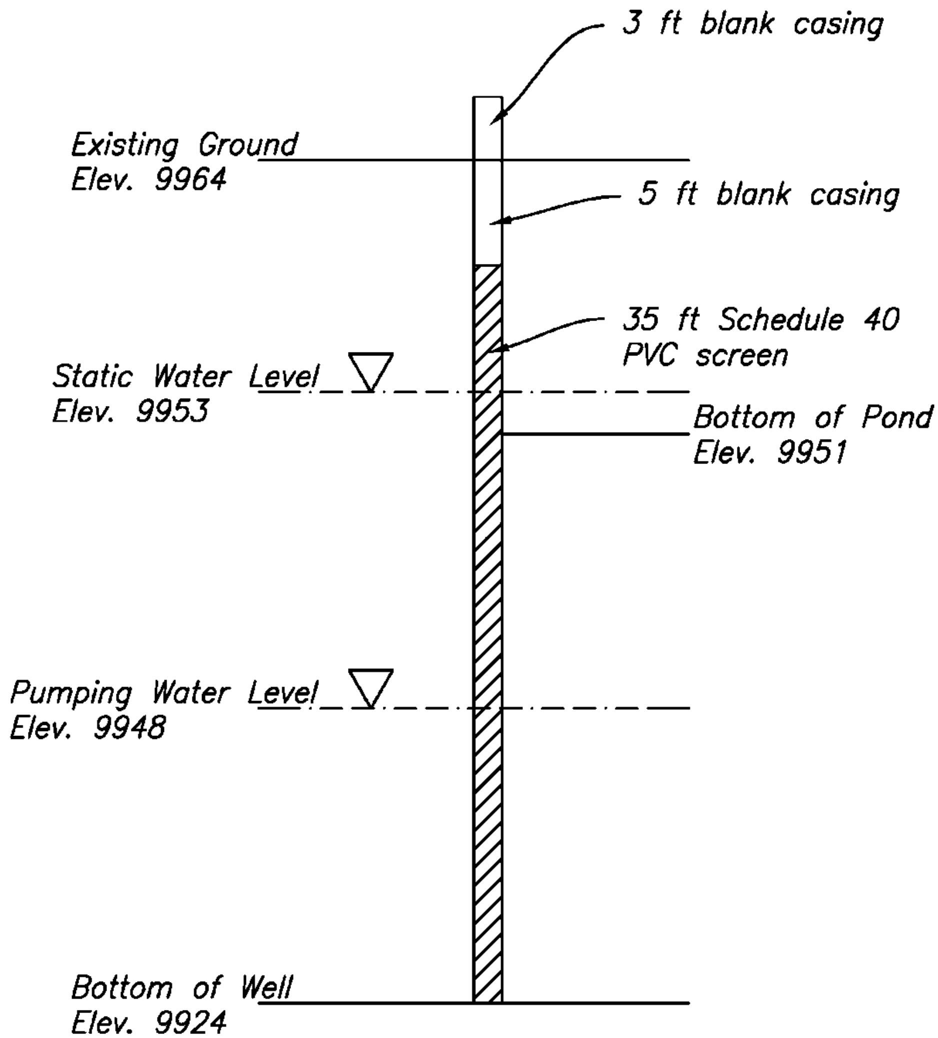

Figure 7.—Well construction details.

Alternative 2

Description: Install a collection trench along the west side of the pond, possibly in the road between the facility and the trailer park. Based on the preliminary groundwater information, it appears that intercepting the source flows coming from the west would be more efficient with respect to controlling the groundwater levels under the pond than pumping downgradient of the pond. The invert of the drain would need to be at or below the bottom of the pond (elevation 9951 feet) to be effective and would discharge along the northwest side of River Road. This alternative would require the installation of approximately 400 feet of drainpipe and would require the excavation of a trench up to 15 feet deep. Figure 8 shows a conceptual plan view and typical section.

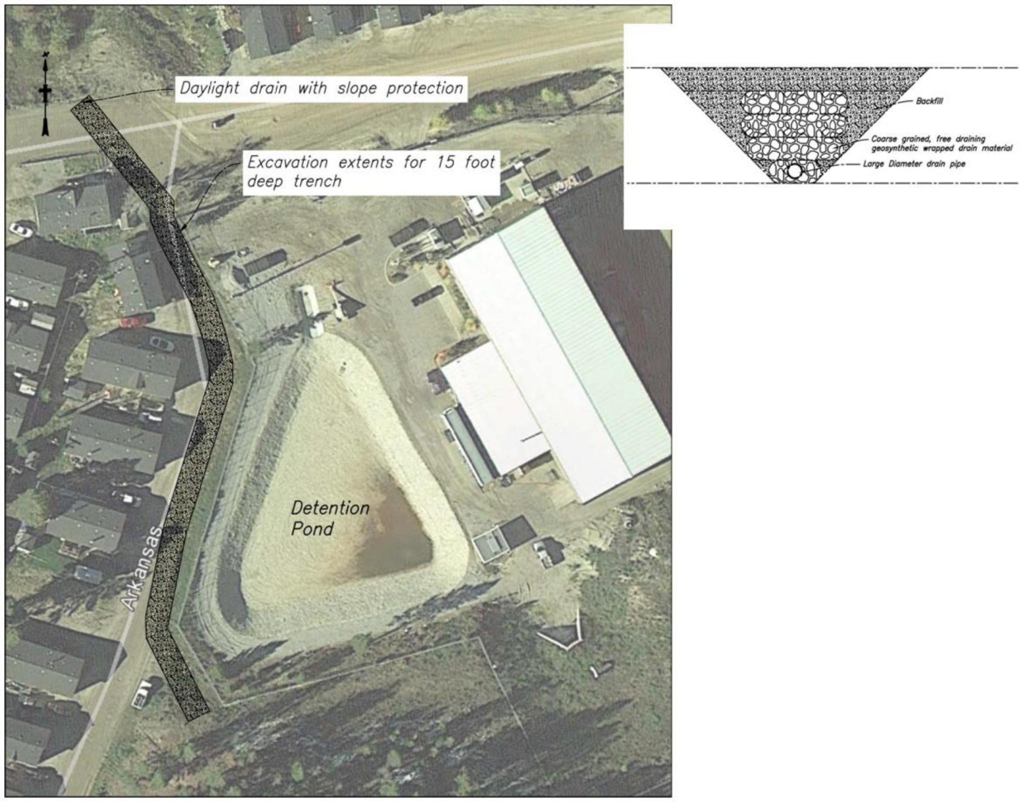

Figure 8.—Alternative 2 concept – plan and typical section.

Pros: Could reduce the groundwater levels enough to prevent the liner from floating without producing additional water requiring treatment. This option would also not require active monitoring of the groundwater levels and pumping rates.

Cons: Alternative 2 was not evaluated in this study due to the installation costs and because it could present challenges with respect to property rights and construction access. This option may not intercept the groundwater sufficiently to prevent the pond liner from floating. More data and analyses would be required to determine the efficacy of this option.

Alternative 3

Description: Install a slurry cutoff wall along the northwest side of the pond, between the pond and the trailer park. The wall would be approximately 450 feet long and installed with a trench slurry method along the road between the pond and the trailer park. The wall would most likely need to extend at least 80 feet below ground level to key into the bedrock for complete cut off. A shallower wall may provide sufficient lowering of the groundwater levels to prevent the pond liner from floating but would require additional information and analyses. Figure 9 shows a conceptual plan view and typical section.

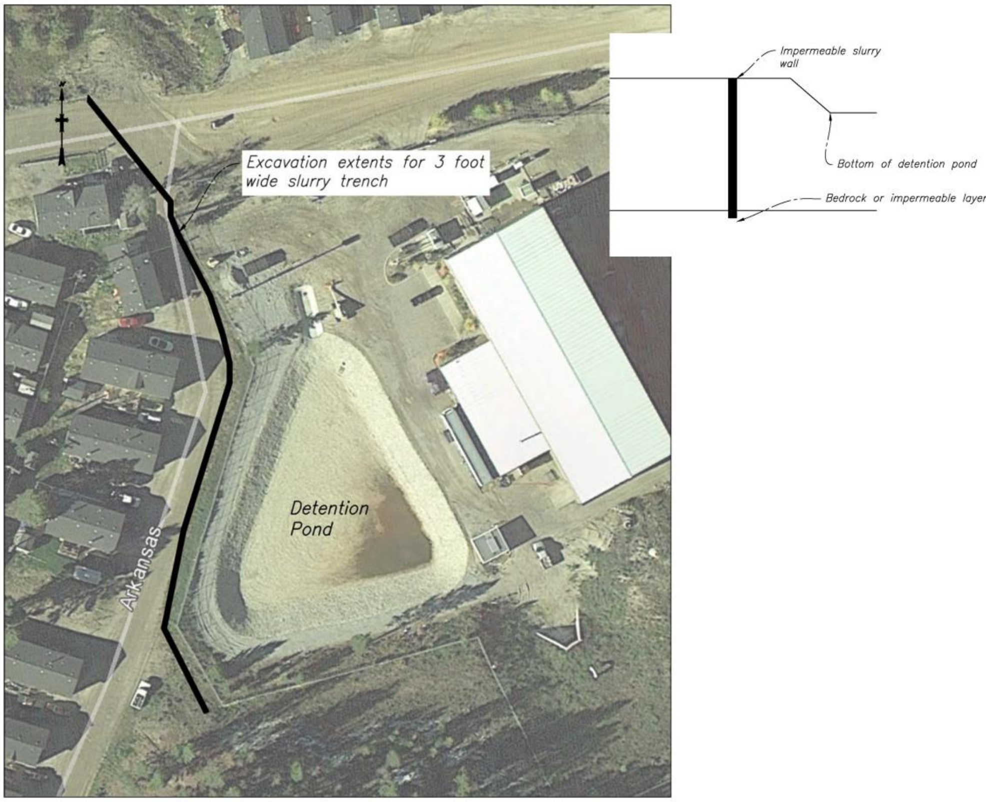

Figure 9.—Alternative 3 concept – plan and typical section.

Pros: This option could provide a passive exclusion barrier to prevent groundwater from collecting below the pond, which could reduce the groundwater enough to prevent the liner from floating without producing additional water requiring treatment. This option also would not require active monitoring of the groundwater levels and pumping rates.

Cons: Alternative 3 was not evaluated in this study due to the cost of construction and because it could present challenges with respect to property rights and construction access. This alternative could induce ponding of the groundwater on the west side of the wall and also may not intercept the groundwater sufficiently to prevent the pond liner from floating. More data and analyses would be required to determine the efficacy of this option.

Conclusions

A summary of the conclusions are as follows:

- Based on the available information, Alternative 1 is the best option for lowering the groundwater around the retention pond and preventing the liner from floating in the future.

- More information is required to determine the efficacy of installing a collection trench (Alternative 2) or slurry cutoff wall (Alternative 3) relative to Alternative 1.

- The groundwater in the vicinity of the pond is being recharged from the northwest rather than from the south as previously expected. The possible sources for groundwater recharge include:

    - A surficial aquifer, with flow coming from the trailer park area

    - Leaking water from the treatment plant discharge (pipe or manholes)

- Area hydrogeology data indicate that there is either a groundwater source northwest of the site or a sink southeast of the site.

- Based on site stratigraphy, hydrogeologic parameters for the soil horizons, and the groundwater levels across the site, a pumping rate of 240 gpm will be needed to produce 3 feet of drawdown 60 feet away from the well.

- A full-scale aquifer test should be performed at the site to develop the hydrogeologic parameters required to design a well and pump system.

- Pumping information (rate, duration, and water levels before and after pumping intervals) for the Molly Brown Trailer Park well should be obtained and provided prior to final design work.

- Groundwater levels in the monitoring wells onsite should be recorded weekly and reported on a monthly basis.

- Additional monitoring wells could be installed along River Road, between the trailer park and the pond, and throughout the trailer park (particularly within 100 feet of the water well). The groundwater level information provided by the additional monitoring wells would be invaluable in developing an understanding of the flow regime for the area.

- The discharge line and manholes should be inspected to check for leaks; any leaks found should be repaired.

- Another consideration to lower the groundwater near the pond is to plant a row of trees or shrubs along the fence line between the pond and the trailer park road. Species such as the lodgepole pine or Douglas fir could grow at that elevation.

If the pond liner is replaced in the future, a collection trench should be installed around the inside perimeter of the pond at that time to facilitate dewatering.

If you have any questions or need further assistance, please call or email Lee Sears (lsears@usbr.gov) at (303) 445-2392 or Bethany Jackson (bnjackson@usbr.gov) at (303) 445-2387.

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