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Water Resource Advisors for the West

Memorandum

Date:	April 6, 2016	AG Job No.: P16-116
To:	Sira Sartori, Seth Turner, PRRIP Executive Directors Office	
From:	Mike Applegate	
Subject:	**Potential for using slurry walls for gravel pit liners in Nebraska**	

Purpose

This memo is a reconnaissance level discussion on the potential for using slurry walls to line gravel pits for water management in Nebraska. It was prepared at the request of the Executive Director's staff for the Platte River Recovery and Implementation Program. (PRRIP). It is intended to be used as an initial guideline for studying the feasibility of using this approach to create water storage to manage flows on the Platte River. The cost of water storage is a major budgetary concern for meeting PRRIP goals. There are numerous existing gravel pits along the Platte River corridor that could potentially provide a source of supply for the PRRIP. There are also unmined properties located strategically that could provide additional storage. The technical feasibility and the economics of this approach warrant further study.

Background and History

Slurry wall technology has been in existence for many years. The first slurry trench cutoff wall was constructed in 1948 in Long Beach, California. A slurry wall is an impermeable barrier to the flow of a liquid through an aquifer. Design and construction techniques have evolved significantly to the point that they are considered a simple solution to provide low permeability barriers to fluid flows. A slurry wall is essentially maintenance free and can achieve low permeabilities down to 10^{-7} cm/sec or lower if properly designed and constructed.

Gravel pit lining started in Colorado in 1989 with Senate Bill 120. This legislation required unlined gravel pits to augment evaporative losses because a recent Supreme Court ruling had determined that these losses were injuring senior water rights. The cost of augmenting water losses provided an economic incentive to gravel mining operators to reduce their overhead costs. At the same point in time, many metropolitan cities in the Colorado Front Range had been impacted by a 404 permit veto of the Two Forks Reservoir project proposed by Denver Water. This left a large gap in needed water storage for future demands. Many mining operators quickly learned that lining gravel pits not only eliminated their augmentation obligations, but provided a secondary source of revenue. Many gravel pits along the South Platte River in the metropolitan Denver area have been lined specifically for purposes of providing raw water storage. Slurry walls and clay core liners have both been used successfully.

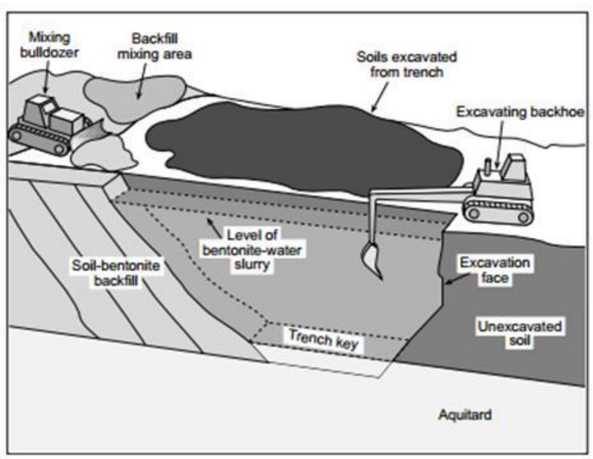

Figure 1 - Slurry Wall Schematic

A slurry wall for the purposes of lining a water reservoir can be described as a vertical perimeter mud wall excavated into a groundwater aquifer that penetrates and keys into bedrock. It blocks the flow of groundwater either into or out of a gravel pit reservoir that is constructed in the alluvial aquifer (see Figure 1). This provides dominion and control over stored water in the gravel pit. The key factor for lining a gravel pit is to have a solid underlying bedrock formation. Bedrock is the bottom liner that eliminates concerns about uplift pressures from groundwater.

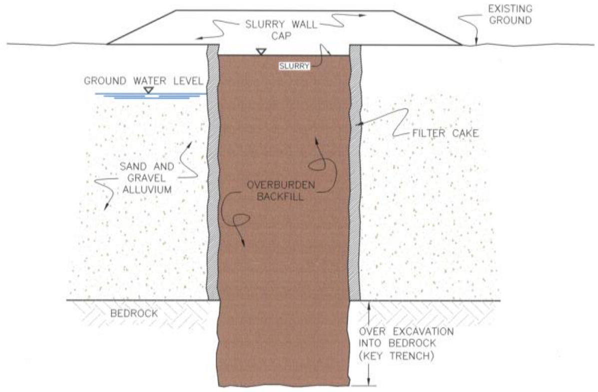

Figure 2 - Slurry Wall Cross Section

Slurry walls comprise two lines of impermeable barrier. The first barrier is known as a filter cake and is formed on the sides of the trench wall as the mud pressure of the bentonite mixture forces clay fines into the surrounding sandy alluvial aquifer. It quickly forms a plug (see Figure 2). The second stage comes from backfilling the slurry trench with a bentonite overburden mixture that was originally excavated by the trackhoe and mixed adjacent to the pit with a swamp dozer (a bull dozer with extra wide tracks to keep it from getting stuck). This second stage displaces the slurry mixture and pushes it along with the trackhoe as it constructs the slurry trench. The two in combination can provide a low permeability barrier to prevent seepage into or out of a gravel pit reservoir.

<u>Design and Permitting</u>

Data

Data collection for reservoir design starts with a good topographical survey of the property, complete with control points suitable for tying in construction coordinates. If an existing gravel pit is being rehabilitated, a bathymetric survey of the reservoir that is inundated will be necessary to determine the condition of existing slopes into the water. The location and capacity of existing power lines for pump station operations will be needed. The delineation of jurisdictional wetlands would be needed to either avoid them in the design or obtain permits if the slurry wall needs to cross them. The location of potential fill and release structures such as irrigation ditches, laterals or drains need to be identified for evaluation. Floodplain information, particularly if the pit is adjacent to the Platte River or a significant tributary needs to be gathered. Much of this information might already be in the files of the PRRIP or could be collected by its staff.

Groundwater impacts from lined gravel pit reservoirs are usually limited to what is called mounding and shadowing effects on groundwater flow. These impacts can be estimated using simple groundwater modeling approaches. Installing a slurry wall around a gravel pit reservoir in an alluvial aquifer is essentially the same as dropping a brick into the alluvium. The up gradient side of a gravel pit reservoir will see a mounding effect and elevated groundwater levels. The down gradient side will likely see a shadowing effect and a drop in groundwater levels. The amount of impact is dependent on the size and orientation of the reservoir in the aquifer and the permeability of the alluvium. If the impacts need mitigation, simple approaches like installing a French drain around the outside perimeter of the slurry wall are usually adequate.

Design Criteria

Geotechnical information that is necessary would include normal characterization of the soils: Atterberg limits, gradation, classification, shear strength properties. Boreholes should be placed along the centerline of the proposed slurry wall to characterize the underlying strata. The underlying bedrock needs to be characterized both in location (depth), engineering properties, and estimated thickness. The bedrock formation provides the impermeable liner for the reservoir floor. The slurry wall must penetrate the weathered portion of the bedrock and provide a positive cutoff. If the underlying bedrock has significant fracturing and is leaky, this will need to be identified in the early stages of the investigation as it could play a significant role in making a go, no-go decision. Packer tests in a few of the holes penetrating bedrock can provide a good indication of seepage through the bedrock.

The engineering properties of the soils also need to be used to design the optimum slurry mixture to be used in construction. Specialized testing that uses varying percentages of bentonite slurry mixed with the native soils will give an indication of the amount of uptake into the trench walls that can be expected during installation. The cleaner the alluvium is with fewer fines, the more bentonite will be used.

We recommend using a dam safety approach in evaluating reservoir slopes. Typically, a stability analysis will evaluate reservoir slopes under normal operation, rapid drawdown, and potentially earthquake loadings.

The requirement for shoreline protection for a gravel pit reservoir is dependent on the amount of wave action impacting the slopes. If the longest width of the water is aligned with the prevailing winds, larger wave run-up might be expected and require riprap protection on the leeward side of the reservoir. One unique property of gravel pit reservoirs with respect to wind impacts is that because they store water below grade, the wind effects drop off quickly as a reservoir is emptied. Wind tends to blow over the top and not penetrate below grade into the water. This can reduce the amount of shoreline protection (riprap) needed to only the top portion of the reservoir, if it is deemed necessary.

Gravel pit reservoirs that are adjacent to rivers can be subject to damage from flood flows. The geomorphology of large river systems in particular can play an important role in determining the feasibility and design concepts used in constructing a gravel pit reservoir. It is generally considered good practice to provide side channel spillways into gravel pit reservoirs adjacent to rivers. This gives protection in allowing the reservoir to fill and equalize with river water levels without damaging the embankment slopes. If the river breaches into a gravel pit reservoir, it can create the potential for completely relocating the river channel into the gravel pit reservoir. This can start a process of headcutting in the river channel caused by the reservoir floor being lower than the river channel thalweg. In Colorado, the 2013 flood in the South Platte River basin saw many gravel pits damaged from breaches of that nature.

Permitting

The State regulatory agencies should be consulted to determine what permits or reviews might be required for a lined gravel pit. There are typically no dam safety issues if the reservoir has no above grade embankment. However, in Colorado, we have seen the Dam Safety branch take jurisdiction of gravel pit reservoirs particularly in light of several breaches that occurred during the 2013 floods. Since the purpose of the reservoirs is to have dominion and control of water releases back to the river, there may be some interactions with the DNR required to prove the liner achieves that purpose.

Federal permits may include FEMA if a gravel pit reservoir impacts the floodplain. There may also be Clean Water Act permits with the Army Corps of Engineers involved if any construction is done in jurisdictional waters of the U.S.

Construction

Technology

Slurry wall technology relies on getting the correct relationship between the specific gravities of the muds and fluids in the slurry trench. The bentonite slurry mixture is heavier than the groundwater. The excavated trench is backfilled with the slurry mixture to displace groundwater and keep fluid pressure on the trench walls so they do not collapse from groundwater flowing into the trench as it is excavated. Once the filter cake is formed, the slurry trench is relatively impermeable. The next step is to backfill with overburdens that were removed from the excavated trench. During the excavation process some bentonite slurry is also placed into the excavated trench material and subsequently mixed with those soils for use as backfill. The backfill that is pushed into the trench displaces the slurry and should be slightly heavier than the bentonite slurry. This process displaces the remaining slurry in the trench that has not become filter cake and pushes it to follow the track hoe excavation. This approach optimizes the amount of slurry used per linear foot of trench. If the backfill is too light, it will fold into the bentonite entrapping the slurry mixture into the overburden and carrying the bentonite to the bottom of the trench. This requires using more bentonite than necessary and results in higher construction costs. The relative viscosity of the slurry mixture is measured using a Marsh funnel which times how fast a specified volume of slurry takes to empty from the funnel. The percentage of bentonite used can vary based on the existing fines in the overburdens and the overall gradation of the soils. (See Figure 3)

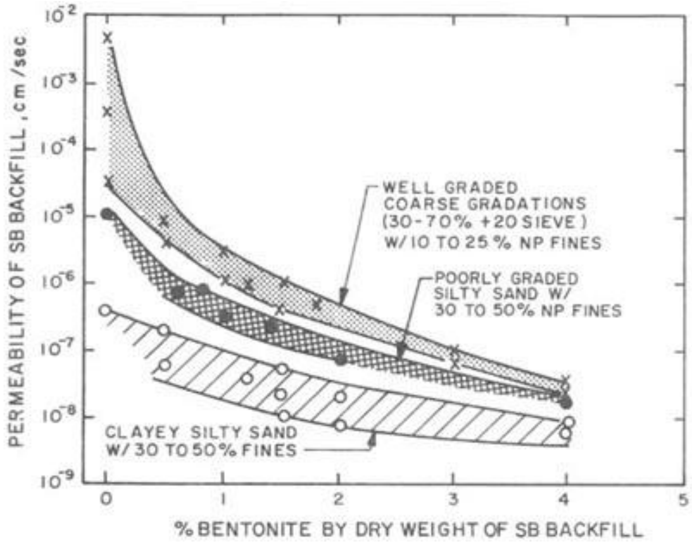

Figure 3- Example of Bentonite Slurry Mixtures

Other technical considerations relate to the deformation of cutoff walls and the adjacent ground after construction. Granular soils mixed with the bentonite trench backfill have lower compressibility and reduce trench settlement and adjacent ground deformation. Testing of specific on-site materials and design recommendations will address this issue.

Many slurry walls have been constructed using track hoes with extended booms. This approach can reach to depths of approximately 50 feet. It requires great operator skill to dig in the blind through a slurry mixture and key into bedrock. An alternate construction method uses a large scale trencher that injects bentonite directly into the excavation and mixes it in the trench. This may be a viable alternative in the Nebraska area because of the sandy nature of the soil and lack of rock obstructions (see Figure 4). This approach greatly reduces the construction footprint needed and appears to allow for better quality control of the soil bentonite barrier.

Figure 4 - Alternate slurry trenching equipment

Slurry walls to depths up to 125 feet are possible according to the construction company that uses this approach.

Costs

The cost is variable depending on site specific conditions as is true for most construction projects. A rough rule of thumb for cost is to use about \$5.00 to \$6.00 per face foot of slurry wall. A face foot is one square foot on the face of the slurry trench. Therefore, if a slurry wall is 50 feet deep including keying into bedrock, the cost per linear foot would be estimated at \$250.00 per linear foot. The total cost then becomes the product of the perimeter length of the slurry wall surrounding the reservoir multiplied by the linear foot cost. A 3,000 linear foot slurry wall project would cost \$750,000 using these numbers. This does not include ancillary costs such as pump stations, electric service, land costs, mitigation, floodplain issues, etc. Costs can vary depending on the project size with longer slurry walls costing less per face foot.

Key Areas for Success
Key areas for maintaining the quality of the construction include:

1. Having a solid bedrock formation underlying the gravel pit to form a horizontal barrier to groundwater.
2. Keying the slurry trench into the bedrock formation to provide a positive cutoff to groundwater flow.
3. Making sure that any trench wall collapses that occur during construction are adequately repaired to remove sand lenses that may have formed thorough the slurry wall.
4. Making sure any corners in the slurry wall perimeter are completely connected vertically with adequate overlap of the trench excavation.
5. Having good information about the depth to bedrock at regular intervals so that the excavation depth can be cross checked as meeting design. (Good Quality Assurance/ Quality Control program)
6. Designing the reservoir interior slopes to be stable under drawdown conditions and to maintain an adequate setback from the slurry wall to protect its structural integrity.
7. Having an adequate setback for the slurry wall from the reservoir shoreline slopes to protect structural integrity in the event that there is slope movement.
8. Having a reliable testing program at the end of construction to determine if seepage standards have been met. This is particularly critical to verify within the warranty period of the construction work.

Operations

Inlet/Outlet
The design of inlet and outlet structures will be dependent on water availability in specific stream reaches and releases needed to meet PRRIP goals. Technical considerations are outlined below and are based on past experience.

Rate of Fill/Drain
The operation of a lined gravel pit requires practices that are similar to those used in managing reservoirs with dams. The drawdown rate for a gravel pit should be controlled to roughly 1-foot per day. A higher rate of drawdown can result in excessive pore pressures as the shoreline slopes drain and could result in slope failures.

The rate of fill will be dependent on reservoir slope soil types but can probably be faster than the recommended drawdown rate. The diversion infrastructure into the reservoir will require a controlled outlet into the reservoir that extends to the bottom. This addresses filling the reservoir when it is drained and protecting the slope embankment from damage. The preferred method of filling a gravel pit reservoir is with a gravity operated structure such as an irrigation ditch or drain. This reduces energy consumption.

Pump Stations
There are examples of gravel pits that are filled by groundwater pumping. This approach requires more energy and annual operating costs, but if the pumping is immediately adjacent to the river, the impacts to river flows are immediate and can be treated as a surface type diversion. The water quality would probably be better in terms of reduced sediment as well.

In some areas there may be a series of gravel pits located adjacent to each other separated by berms. Depending on site conditions, a slurry trench might be used to ring the outside perimeter of all the pits with the interior berms being left as is. This would still give dominion and control of the stored water in the individual cells and reduce the cost of constructing reservoir liners for each pit. There could be some operational drawbacks with this approach for maintenance of individual cells (i.e., no ability to drain one cell for maintenance without equilibration of water levels between multiple cells). Having a series of individual pits adjacent to each other could also allow the interconnection of the cells to allow the construction of only one pump station. Gravel pit reservoir interconnects are regularly constructed using directional boring techniques.

A lined gravel pit has the bulk of its storage capacity substantially below grade and cannot drain by gravity. Pump stations that are either stationary on the reservoir shore or on a floating barge can be effectively used. Depending on the variation in pumping rates needed, the pumps can be designed in series with variable speed controls to give more precision. Skid mounted package pump systems have been used for many applications in gravel pit reservoirs. (See Figure 5)

Figure 5 - Gravel Pit Pump Station near Fort Collins, CO

Conclusion and Summary

The use of slurry walls for lining gravel pits is proven technology that has been used for many years. Based on the initial discussions held at my office on March 29, 2016, it appears that the basic requirements for using this approach exist in Nebraska along the Platte River corridor. This memo is not intended as an exhaustive research on the subject, but as a general guideline. Specific locations for reservoirs will have unique circumstances that may enhance or detract from the ability to develop a site as a lined reservoir.

The seepage design standards for a lined gravel pit have been established in Colorado purely from a water rights administration perspective. Developing seepage standards would be new territory to explore in Nebraska. The Nebraska goal seems to be centered on providing reliable storage for the PRRIP. The amount of seepage into or out of the reservoir can easily be calculated based on permeability assumptions used for slurry wall construction. We could work with the PRRIP to establish a basis for recommending a design standard to be used. This is recommended from the perspective of having some standard to measure the performance of the slurry wall both for construction and administration afterwards.

Once the survey and geotechnical data outlined above is collected, the design time needed to compile and complete plans and specifications for a gravel pit reservoir (ready for bidding and construction) will probably range in the 3 to 4 month time frame. This will depend on factors such as is it lining an existing pit or virgin ground, the environmental and floodplain issues and regulatory review or comment. At present we are assuming permitting issues will be minimal with little or no State regulatory oversight. Construction times can be estimated on a rough rule of thumb using 200 linear feet of wall per working day.

This concludes this short white paper. More detail can be provided on specific issues or tasks outlined above if desired.