FINAL REPORT

Prepared for
Colorado State Land Board
Ecosystem Services Program

Streamflow Augmentation Feasibility Analysis of Colorado State Trust Lands along the South Platte River

DUCKS UNLIMITED

Brown AND Caldwell

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1. INTRODUCTION

Ducks Unlimited (DU) has been successfully designing and constructing streamflow augmentation projects in the South Platte River basin for nearly 30 years. DU augmentation projects utilize groundwater recharge ponds to retime streamflow and are inherently multi-beneficial; creating or enhancing habitat for wildlife; providing recreational bird watching and hunting opportunities; and retiming streamflow for maximum beneficial use by Colorado municipalities, agricultural communities, and industrial water users. With the recent creation of the Ecosystem Services program, the Colorado State Land Board (SLB) is expanding its efforts to create new revenue through augmentation project development on existing land assets. Revenue generation in the form of augmentation credits, increased capital asset value of lands, and increased recreational value are all being explored. This feasibility study, sponsored by the Colorado Water Conservation Board (CWCB), the SLB, and DU, is an investigation into the augmentation potential of several SLB-owned properties, and provides the conceptual design and recommendations for water management on the best suited piece of land.

2. OBJECTIVES

The overall objective of this project was to evaluate over 18,000 acres of SLB properties in the South Platte River basin for streamflow augmentation project suitability, and to conduct field investigations of the top properties indicative of recharge credit generation. The process for evaluating and investigating properties was broken down into the following four tasks:

- **Task 1** – Perform desktop analysis of all SLB properties in the South Platte River Study Area using the Wetland Recharge Location Model (WRLM).
- **Task 2** – Perform preliminary field investigations of the top five to ten SLB sites to determine the most suitable sites for detailed investigation.
- **Task 3** – Perform detailed site investigations of the top three to five SLB sites to determine suitability for streamflow augmentation
- **Task 4** – Submit the Final Report and conceptual design of the top one to three project sites.

3. RECHARGE MODEL ANALYSIS

The SLB parcels evaluated for this project were selected using the WRLM. The WRLM is a Geographic Information System (GIS)-based decision support tool that was developed by Ducks Unlimited in 2013 with assistance from Brown and Caldwell and Harvey Economics. The WRLM is a decision support model that facilitates strategic targeting of specific areas within the South Platte River basin that could benefit from new or additional wildlife habitat and help meet local recharge demands.

The process used by the WRLM for identifying strategic parcels for wetland development includes two tiers of information and analysis. The first tier of decision criteria lend themselves to a GIS-based analysis. The first tier process includes identifying geographically variable factors important for determining locations for future recharge wetland sites, ranking the importance of those factors relative to each other, assigning a scoring system based on predetermined criteria, and using GIS to translate the ranked factors to a spatially oriented grid. Factors included in the first tier analysis include the following:

- Alluvial aquifer properties
- Availability of water supply
- Land ownership and the availability of public access
- Proximity to developed urban areas

Factors that do not easily lend themselves to spatial alignment, but are important in determining recharge wetland locations were considered in a second tier of decision criteria. These factors include:

- Value of the water and land
- Suitability of the land
- Need for recreational opportunities
- Comparative economic returns to water
- Funding partners

The first tier factors were evaluated, mapped, ranked, and scored as a part of the WRLM development process. The factors, their ranking, and the basis for favorable scoring with respect to wetlands construction are described in Table 1 below.

The results of the ranking and scoring process are shown in Figure 1. The figure highlights the locations along the South Platte River that scored in the top 20 percent (as indicted by the yellow and red coloring) with regard to the favorability of constructing wetlands for recharge purposes.

Table 1. First tier factors and scoring considerations

Factor	Relative Importance Ranking	Basis for favorable scoring
Depth to groundwater	1.0	Depth to groundwater greater than 20 feet
Ability to recharge the alluvial aquifer	0.9	Within the mapped alluvial aquifer
Availability of water supply	0.8	Can be supplied by an irrigation ditch that delivers to other recharge facilities
Proximity to urban areas	0.7	Not within mapped urban area boundary
Presence of existing wetlands	0.6	Near other existing wetlands (can enhance existing wetland complexes)
Land ownership	0.4	Land owned by SLB, Department of Wildlife, or U.S. Bureau of Reclamation
Presence of existing recharge ponds	0.2	Existing recharge ponds are present, but could use enhancement
Lag time characteristics	0.1	50% of the water recharged emerges as stream flow with 12 to 24 months

Lands that scored in the top 20 percent for augmentation pond construction and are owned by the SLB were identified and are shown in Figure 2. Initial discussions regarding favorable wetland locations under this project centered on these lands.

The identification of favorable locations for augmentation pond construction was further refined by the second tier factors described previously. Currently, there is a need for recharge facilities that can retime water supplies (either existing supplies or supplies derived from a junior water right) in the reach of the South Platte River downstream of Greeley and upstream of Brush, Colorado. In addition, economic returns for water and other second tier factors are generally favorable in this reach of the river given competing municipal and industrial demands for limited water resources. The project focused on sites in this reach of the South Platte River given the favorability of second tier factors.

The first tier factors shown in Table 1 describe lag time characteristics (i.e. the amount of time it takes for recharge to enhance stream flow) as the factor of lowest importance. The relative importance of the criteria shown in Table 1 was developed based on a generalized overall ranking when considering the South Platte Basin as a whole. However, the lag time characteristics are more important in the Greeley-to-Brush reach of the river when considering the market for water. To account for this, the importance ranking for lag time characteristics was increased from 0.1 to 0.8 in the WRLM tool. The favorability scoring for wetland construction on lands owned by the SLB was reevaluated using the WRLM tool considering the increased importance of lag time characteristics, and the results are shown in Figure 3. The locations shown in Figure 3 were then further investigated during the course of this project to evaluate the feasibility of constructing high-functioning augmentation ponds.

W Y O M I N G

N E B R A S K A

L A R I M E R

W E L D

B O U L D E R

J E F F E R S O N

D E N V E R

A D A M S

A R A P A H O E

D O U G L A S

E L B E R T

L I N C O L N

L O G A N

S E D G W I C K

P H I L L I P S

M O R G A N

W A S H I N G T O N

Y U M A

K I T C A R S O N

Legend

- Grid Outline
- Reservoirs and Lakes
- Streams

Final Weighted Scores

- < 4.50
- 4.50 - 9.00
- 9.00 - 13.50
- 13.50 - 15.75
- 15.75 - 18.00
- 18.00 - 20.25
- > 20.25

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Brown AND Caldwell

Ducks Unlimited

State Land Board Property Wetlands

Date: May 2015
Project: 146491

N

0 60,000 120,000 Feet

Notes:
1. Projection: UTM Zone 13, 1983 North American Datum (Meters)
2. Data Sources: Colorada Division of Water Resources, Colorado Department of Transportation, Natural Heritage Program - CSU, United States Geological Survey, Brown and Caldwell, Bureau of Land Managment, Colorado Division of Wildlife, and U.S. Census Bureau.

Figure 1

Summation Grid Final Weighted Scores

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Brown AND Caldwell

Ducks Unlimited

State Land Board Property Wetlands

Date: May 2015
Project: 146491

N

0 45,000 90,000 Feet

Notes:
1. Projection: UTM Zone 13, 1983 North American Datum (Meters)
2. Total Area of SLB Lands in priority areas: 14,560 acres.

Figure 2

State Land Board Priority Areas

R64W R63W R62W R61W R60W

T5N T4N T3N

Legend

Selected SLB Sites

DSS Score

- 17.1 - 17.5
- 17.6 - 18.1
- 18.2 - 19.5
- 19.6 - 20.5

Streams
Major Canals
Major Reservoirs
SLB Properties
Counties
Interstate Highways
U.S. Highways
State Highways
Rail Lines

Crow Creek
Riverside Intake Canal
Latham Ditch
Empire Intake Canal
Box Elder Creek
Riverside Reservoir
Riverside Canal
South Platte River
Bijou Canal
Lost Creek
Empire Reservoir
Kiowa Creek
MORGAN
144
76
6
WELD

[BCDENFP01]: \\bcdenfp01\projects\Data\GEN\Ducks Unlimited\State Land Board Prop\GIS_MAPDOCs\Figures for Julia's report\Figure3_PotSLBWetlandSites_Scenario2_v10_2015

Brown AND Caldwell

Ducks Unlimited

State Land Board Property Wetlands

Date: May 2015
Project: 146491

0 8,000 16,000 Feet

N

Notes:
1. Projection: UTM Zone 13, 1983 North American Datum (meters).
2. Scenario 2 uses the a modified scoring output from the wetland DSS tool to highlight favorable SLB sites. The new scoring scheme places a higher priority on return flow timing.

Figure 3

Potential State Land Board Wetland Sites - Scenario 2

4. PRELIMINARY FIELD INVESTIGATIONS

Recharge model analysis of SLB properties in the Greeley to Brush reach of the South Platte River alluvial valley identified seven sites for preliminary field investigation by the project team (Table 2). Preliminary field reconnaissance was conducted at each location prescribed by the WRLM to gain a better understanding of individual site topography as it pertains to the construction of recharge ponds and water conveyance to the sites. Historically, DU has taken advantage of natural landscape depressions for recharge pond development to minimize site disturbance and the earthwork necessary to build small levees and pond water. Each site was also evaluated for any potential limiting factors to successful project implementation such as major underground infrastructure, close proximity to above ground structures and homes, and areas of high groundwater not visible from aerial imagery.

Table 2. Preliminary field investigation sites ordered from highest to lowest model score

Site Name	County	PLSS (Township, Range, Section)	Model Score*
Empire Reservoir Intake	Weld	4N, 61W, Sec. 29	High (19.6-20.5)
Riverside Canal	Weld	5N, 61W, Sec. 36	Moderately High (18.2 – 19.5)
Lost Creek - 1	Weld	4N, 62W, Sec. 26	Moderately High (18.2 – 19.5)
Riverside Reservoir Intake - 1	Weld	4N, 62W, Sec. 4	Medium (17.6 – 18.1)
Riverside Reservoir Intake - 2	Weld	4N, 62W, Sec. 3	Medium (17.6 – 18.1)
Crow Creek	Weld	5N, 63W, Sec. 6	Moderate (17.1–17.5)
Lost Creek - 2	Weld	4N, 62W, Sec. 25	Moderate (17.1–17.5)

*Model Score Range: 2.2 – 22.5

4.1 Empire Reservoir Intake Site

The southeast quarter of Section 29 in T4N, R61W received the highest model score (>19.6) amongst the list of top 20 percentile sites in the study reach. The Empire reservoir intake canal runs north and east through the parcel and could potentially provide a close source of water without having to run a pipeline up from the river and bore under both Highway 34 and the Bijou canal. Canal fed recharge sites are common in the South Platte Basin but are limited to operating during months with above freezing temperatures and in-priority under Colorado's Prior Appropriation Doctrine.

During the site visit it was noted that three homes have been established within a quarter mile of the Empire Reservoir intake canal and the ideal recharge pond locations, in the southern half of Section 29. Developing recharge sites upgradient of the structures would result in increased groundwater elevations near the home sites, which could potentially result in flooded

basements or crawl spaces. Based on the close proximity to existing structures, this site was determined to hold little potential for augmentation site development.

4.2 Riverside Canal Site

The southwest quarter of Section 36 in T5N, R61W was tied for the second highest model score (>18.2) within in the study reach and has two potential sources of water in the Riverside canal and a pipeline that could be run from the South Platte River without any major highways or canals to bore under. The initial site visit proved promising with sufficient room to construct multi-acre recharge ponds, no immediate structures downgradient of the site, and no obvious areas of high groundwater in the area. Given the positive site attributes, DU staff met with the Superintendent of Riverside Irrigation Company (Riverside) on August 18, 2015 to discuss the potential for partnering on a recharge project and supplying the site with Riverside Canal surface water. During the meeting it was discovered that this parcel contains two unbuilt augmentation sites that have already been decreed in Division One water court under Riverside's plan. Working with previously decreed sites could greatly expedite project completion and the start of operations because it alleviates the need for additional engineering studies and further water court processes. With Riverside expressing interest in utilizing the SLB parcel for recharge, if a hydrogeologic investigation proved that favorable surface soil and aquifer conditions exist, this location was designated for further investigation.

In addition to the Section 36 site, Riverside suggested another unbuilt and previously decreed augmentation site further downstream in Morgan County, northwest of Fort Morgan, CO. Although the site did not score high with the WRLM due to its close proximity to the South Platte River and subsequent short lag times for stream accretions, DU opted to conduct a site visit based on the conversation with Riverside. The site is located in Section 16 of T4N, R5W and contains three multi-acreage decreed sites down gradient of the Riverside canal. In addition to agricultural production and grazing, this SLB parcel also holds high recreational value based on the existence of two shallow water wetlands adjacent to the canal and a storage pond that supplies irrigation water to the center pivot and feed a small creek in the drainage below. With the increased value an augmentation pond will provide to a recreational property and relief from the obstacle and expenses associated with additional water court fees to decree a new augmentation site, DU also designated this Morgan County site for further soils investigation.

4.3 Lost Creek Sites 1 & 2

The eastern half of Section 26 in T4N, R62W was tied for the second highest model score (>18.2) and directly combines with the adjacent parcel (SW quarter of Section 25 in T4N, R62W) to create a large area for potential recharge pond development. A site visit to the properties revealed no visible depressions on the landscape and close proximity to Lost Creek, which would likely act as the primary stream boundary during accretion modeling, inhibiting direct groundwater flow to the South Platte River. With a small tributary acting as the receiving water body, accretion times would be short and hold very little value on the environmental market, therefore this collection of sites was not investigated further.

4.4 Riverside Reservoir Intake Sites 1 & 2

All three quarter sections north of the Riverside Reservoir intake canal and reservoir inlet bay scored moderate to medium in the WRLM (>17.1), indicating good recharge potential. During the previously described meeting with Riverside in August of 2005, it was noted that major canal and ditch companies prefer not to site recharge ponds directly upgradient of canals and/or ditches. Not only is it more difficult, if not impossible, to use gravity drainage to supply the ponds, but the prolonged wetting of soils near the surface does not allow for proper ditch maintenance during the off season. Based on water provider's preference for siting recharge ponds downgradient of the canal and the lack of a decreed augmentation site in any of the parcels, the Riverside Reservoir Intake sites were eliminated from further consideration.

4.5 Crow Creek Site

The southwest quarter of Section 6 in T5N, R63W received one of the lowest model scores (>17.1) within the study area but remained in the top 20% of overall sites in the South Platte Basin, indicating good recharge potential. With two potential sources of water (Crow Creek and the South Platte River) nearby to supply a project via pipeline, DU arranged a series of site visits with the surrounding landowners, Brown & Caldwell engineers, SLB representatives, and representatives from several energy companies who operate on the SLB parcels to determine project feasibility. In addition to the single parcel in Section 6 that scored positively on the WRLM, two nearby SLB parcels (Sections 4 and 8) in T5N, R63W were considered for project development during the field visits based on the responsive and courteous nature of the

surrounding landowners and energy companies, who were excited and open to the idea of developing recharge ponds in the sandy upland soils.

During the site visits and field meetings three major concerns arose. The first concern brought to DU's attention by the Brown & Caldwell engineers, is that only the southwest quarter of Section 6 is within the mapped alluvium. With Section 6 located in close proximity to Crow Creek, the accretion times would be sort and hold little value on the recharge credit market, so from a cost/benefit perspective, Sections 4 and 8 would make more sense to develop for recharge. But since those Sections are outside of the mapped alluvium, DU would need to demonstrate that there is a hydraulic connection between the SLB parcels and either Crow Creek or the South Platte River. To prove the continuity there would need to be a series of monitoring wells installed between the recharge ponds and the receiving water body (either Crow Creek or the South Platte River) to show that when recharge is being conducted, the aquifer between the recharge ponds and the river is a continuous conduit for delivering water back to the river.

The second major concern was routing a pipeline through the extensive network of underground infrastructure used by the oil and gas companies to extract, convey, and store their products onsite. DU staff held several meetings with Noble Energy, PDC Energy, and DCP-Midstream to gain a full understanding of the vast infrastructure in the area. For proprietary reasons, the energy companies asked DU not to publish the mapped infrastructure in any reports but it is widely understood that anywhere you see a road in the oil fields, there is likely underground infrastructure (Figure 4). Any water pipeline routed up from the South Platte River or Crow Creek would face many difficult obstacles. Re-engineering and moving oil and gas infrastructure for the purpose of recharge water delivery is expensive and would not make financial sense given the relatively low price augmentation credits fetch on the environmental market.

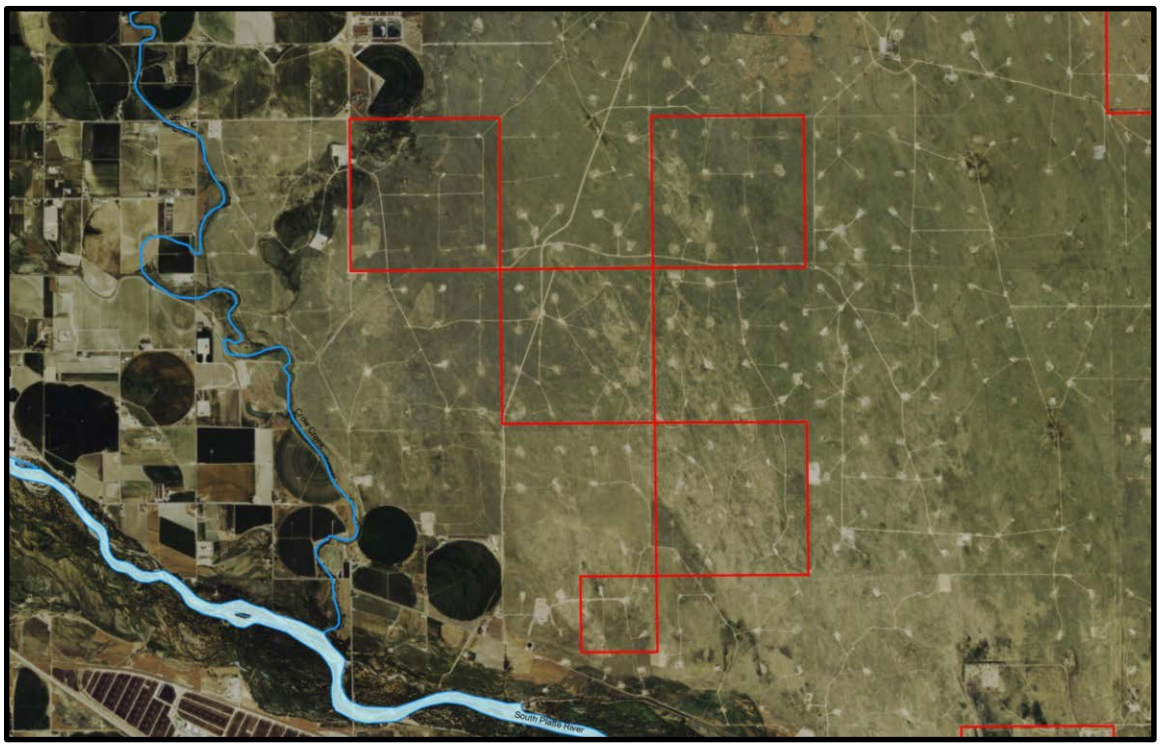

Figure 4. Aerial image of oil and gas development in the vicinity of Crow Creek

The third major concern is a firm source of water for the project since there is no water provider operating this far north of the river. For successful project completion, project partners would need to either file for a junior water right and risk being called out by senior water rights holders outside of the spring snowmelt period, or acquire a more senior water right, which could prove costly.

The Crow Creek sites remain an intriguing long-term prospect for recharge development if the alluvial connection can be proven to Sections 4 and 8. There is a high demand for recharge sites that can provide long accretion times (3-5 years) and DU's interest in these areas was driven by the favorable distance from Section 4 back to the South Platte River. With the vast amount of underground infrastructure in-place and the cost to install a water pipeline through the network, the energy companies will have to become a key partner in offsetting the cost. At the present time, the sites do not seem to be economically viable for recharge development and DU decided not to conduct any further soils investigations.

5. DETAILED SITE INVESTIGATIONS

Over a 14 month period the project team conducted site visits to each of the seven sites prescribed by the WRLM, held multiple field meetings with landowners and energy companies, and researched the unique characteristics and complexities that each site offered in order to determine which properties were best positioned to be successful, if a soils investigation proved favorable (Table 3).

Table 3. Site summaries and recommendations

Site	Favorable Conditions	Non-Favorable Conditions	Detailed Site Investigation	Recommendations
Empire Reservoir Intake	Canal based water source	Potential high groundwater issues surrounding 3 structures	No	Not suitable for project development
Riverside Canal - 1	Decreed augmentation site with excellent accretion lag timing	High groundwater and poorly draining soils	Yes	Potential to develop ponds and establish a recreational lease. Very limited augmentation credit yield
Lost Creek - 1	Canal based water source	Poor accretion times due to Lost Creek boundary proximity	No	Not suitable for project development
Riverside Reservoir Intake - 1	Good accretion lag timing	Upgradient of Riverside canal	No	Not suitable for project development
Riverside Reservoir Intake - 2	Good accretion lag timing	Upgradient of Riverside canal	No	Not suitable for project development
Crow Creek	Excellent accretion lag timing, and supportive landowners and industrial partners	Need to prove hydraulic connection with the river and substantial oil and gas infrastructure to avoid	No	Suitable for project development if oil and gas companies are a major partner
Lost Creek - 2	Canal based water source	Poor accretion times due to Lost Creek boundary proximity	No	Not suitable for project development
Riverside Canal - 2	Decreed augmentation site with natural playa capable of naturally ponding water	Short accretion times	Yes	Potential to develop for low yield augmentation credits and increased recreational value

Initially the Crow Creek sites were the most intriguing as the project team assembled a strong network of potential partners and cooperative landowners. But after multiple layers of complexity became too much for a cost effective recharge project to realistically overcome, the project team determined the best course of action was to investigate the two Riverside canal properties that were discussed during the meeting with Riverside Irrigation Company in August of 2015. The prospect of making relatively small modifications to existing infrastructure and delivering water to already decreed augmentation sites via gravity drainage was the best option when comparing the financial and logistical burdens of developing any of the other sites.

To assess the soil conditions at both Riverside canal sites, DU enlisted the services of Natural Resource Conservation Service (NRCS) soil scientists from the Fort Morgan, CO field office. The soil scientists operate truck mounted Giddings Rigs, capable of pulling soil cores up to 12 feet deep. The soil cores are brought to the surface where detailed field analyses are performed to determine the various soil textures (percentages of sand, silt, and clay) throughout the profile, and the accompanying soil characteristics of each soil group, such as saturated hydraulic conductivity and permeability. The scientists provide an expert opinion on the ability of the soils to transport water vertically and the location of any horizontal confining layers that would inhibit further downward movement and influence the ability to recharge the aquifer effectively.

5.1 Riverside Canal Site 1 - Weld County: T5N, R61W, Section 36

The Weld County site, west of Jackson Reservoir, scored moderately high in the WRLM and has two decreed augmentation sites south of the canal (Figure 5). The court decree estimates the western pond to be up to ten surface acres and the eastern pond to be up to 40 surface acres. The land is currently used for grazing and small recharge ponds would likely have little effect on livestock production. The land lessees even mentioned that recharge ponds would help them get water to livestock who currently depend on access to the canal or small stock wells.

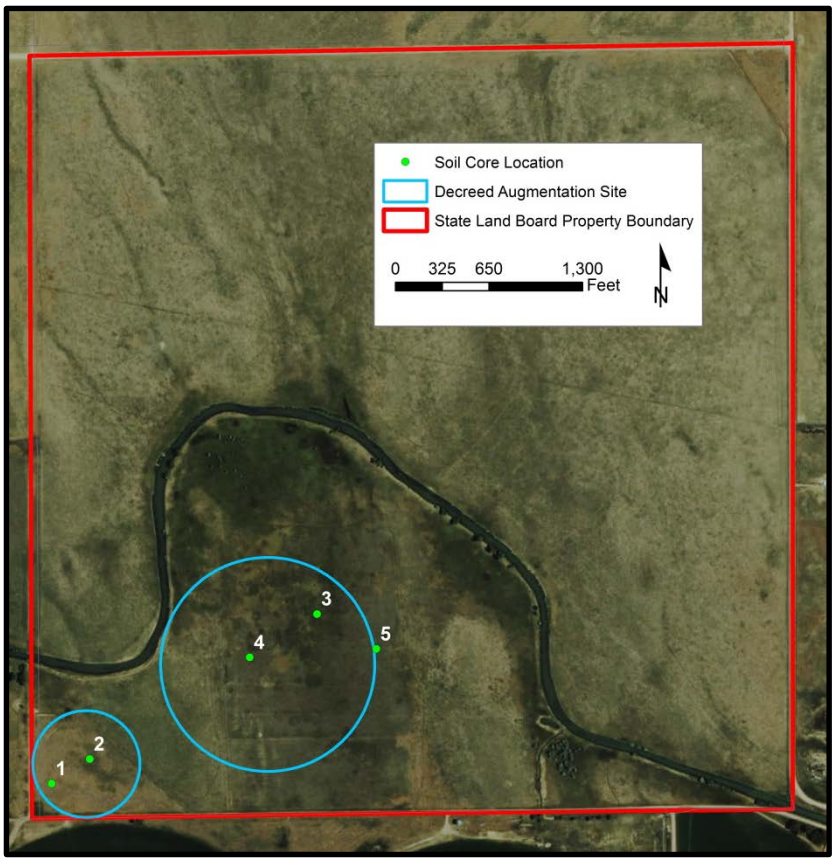

Figure 5. Weld County location (T5N, R61W, Section 36) indicating soil core locations within the decreed augmentation sites.

Two locations were sampled and analyzed from the smaller acreage western site, and are noted as Holes 1 and 2 on Figure 5. At both locations (Holes 1-2) an impermeable shale layer was encountered at between 7.18 feet and 7.87 feet with redoximorphic features found at 3.85 feet in Hole 2. Redoximorphic features are associated with poorly drained soils, resulting from the reduction and oxidation of iron and manganese compounds. Mottles are common redoximorphic features and inhibit the movement of water downward through the soil column. The thickness of shale is unknown but it has a very low permeability rating of 0 to 0.2 inches/hour (in/hr) and a low saturated hydraulic conductivity of 0 to 4.8 inches/day (in/d). The dominant soil texture above the shale is a sandy loam and various analogs (fine sandy loam, etc.), which have a permeability range of 2 to 6 in/hr and a saturated hydraulic conductivity range of 48 to 144 in/d.

Three locations were sampled and analyzed from the larger acreage eastern site, and are noted as Holes 3-5 on Figure 5. Hole 3 is a poorly drained soil with free water encountered at 4.5 feet from the surface. Redoximorphic features in the form of grey mottles and oxidized iron

masses were encountered at 1 foot from the surface. Holes 4 and 5 are well drained soils with no redoximorphic features encountered in the profiles. Hole 4 was cored a little higher on the landscape than 3 and 5 and was probed to a depth of 8.9 feet. Hole 5 was probed to a depth of 6.2 feet with very moist soils existing at 6 feet. Free water was expected any deeper in the profile. These three sites were in close proximity to each other and at approximately the same elevation. Although no shale was encountered at the eastern site, these three were not investigated as deeply. The presence of a poorly drained soil with free water in location 3 and very moist conditions at Hole #5 indicate that a shale layer would be encountered with increasing depth. Detailed data analyses of all five soil profiles are presented in Table 4.

Table 4. Soil characteristics of the five locations sampled at the Weld County location (T5N, R61W, Section 36)

Hole #	NRCS Soil Map Classification	Interval Depth (ft)	Soil Texture	% Clay	Saturated Hydraulic Conductivity (ft/d)	Permeability (in/hr)	Notes
1	Otero sandy loam, 1 to 3% slopes	0 - 0.62	fine sandy loam	8	4 -12	2.0 - 6.0	Redox features and platy structure indicates slow water movement vertically in the 7.18-9.51 ft. horizon. Water would tend to move laterally through the overlying horizons
		0.62 - 1.25	clay loam	32	0.4 - 1.2	0.2 - 0.6	
		1.25 - 3.11	very fine sandy loam	6	4 - 12	2.0 - 6.0	
		3.11 - 4.76	silt loam	10	4 - 12	0.6 - 2.0	
		4.76 - 7.18	silt loam	10	4 - 12	0.6 - 0.2	
		7.18 - 9.5	silty clay loam	30	0.4 - 1.2	0.2 - 0.6	
2	Otero sandy loam, 1 to 3% slopes	0 - 0.5	fine sandy loam	6	4 - 12	2.0 - 6.0	Redox features and platy structure indicates slow water movement in the 7.87-10.82 ft. horizon. Water would tend to move laterally.
		0.5 - 1.44	loam	25	1.2 - 4	0.6 - 2.0	
		1.44 - 7.87	fine sandy loam	6	4 - 12	2.0 - 6.0	
		7.87 - 10.8	silty clay loam	32	0.4 -1.2	0.2 - 0.6	
3	Otero sandy loam, 1 to 3% slopes	0 - 1.7	sandy loam	7	4 - 12	2.0 - 6.0	This is a poorly drained soil. Redox features were encountered at 1 ft. Free water table at 4.5 ft.
		1.7 - 2.62	sandy clay loam	22	1.2 - 4	0.6 - 2.0	
		2.62 - 4.49	sandy loam	12	4 - 12	2.0 - 6.0	
4	Otero sandy loam, 1 to 3% slopes	0 - 1.21	sandy loam	7	4 - 12	2.0 - 6.0	Heavy clay layer 1.2-2 ft. would inhibit downward movement of water
		1.21 - 1.96	silty clay	45	0.42 - 1.0	0 .06 - 0.14	
		1.96 - 3.01	silt loam	14	4 -12	2.0 - 6.0	
		3.01 - 8.85	fine sandy loam	4	4 - 100	2.0 - 14	
5	Otero sandy loam, 1 to 3% slopes	0 - 1.08	loam	18	1.2 - 4	0.6 - 2.0	Clay loam layer at 1.1 ft. -1.9 ft. would slow downward movement of water.
		1.08 - 1.87	clay loam	28	0.4 - 1.2	0.2 - 0.6	
		1.87 - 4.29	fine sandy loam	6	4 - 12	2.0 - 6.0	
		4.29 - 6.23	loamy fine sand	4	12 - 40	6.0 - 20	

5.2 Riverside Canal Site 2 - Morgan County: T4N, R58W, Section 16

The Morgan County site, east of Jackson reservoir, was not scored using the WRLM (Figure 2) because it lies downstream of the original focus area where economic returns for water are generally more favorable. Furthermore, accretion times back to the river will be short due to the relative distance, but there is significant upside with regard to the recreational value of the property with the additional water. The currently land use in the vicinity of potential recharge pond locations is cattle grazing. Similar to the Riverside Canal Site-1, recharge ponds should have little effect on livestock production, and may even be preferred by the land lessees as an easy source for livestock watering. The area contains three decreed augmentation sites with

estimated surface areas of 19, 15, and 6 acres (Figure 6). There is steep topographic relief on this parcel as one moves from the canal westward down toward the drainage.

Figure 6. Morgan County location (T4N, R58W, Section 16) indicating soil core locations within the decreed augmentation sites.

The largest decreed site (approximately 19 acres), adjacent to the canal, is a natural depression that appears to be a playa lake which acts as a localized collection and infiltration basin for natural precipitation to recharge the local groundwater. The site was sampled in two locations strategically chosen at the bottom of the natural depression where infiltration rates would be expected to be highest under a ponded water scenario with two to six feet of head. Both soil cores (Holes #1 and #2) indicate two distinct ages of eolian deposits consisting of sandy loam, loamy sand, and silt loam. The loamy sand layer encountered between 3.08 and 4.92 feet in Hole #1 has a relatively high hydraulic conductivity range of 12 to 40 ft/d due to the low clay content and transports water well. No redoximorphic features were found at this site, indicating well drained soils. A clay loam layer was encountered from 9.54 to 11.54 feet in Hole 2 that may slow the downward movement of water and force groundwater to move laterally to the south.

The second largest decreed site (15 acres) is situated downgradient of the 19 acre decreed site but is separated by a ridge that acts as a topographic high running north and south. This location is also a natural landscape depression and soil cores (Holes 3 and 4) were strategically

taken at the topographic lows where water would naturally collect and infiltrate the surface. Holes 3 and 4 contained moderately deep soils consisting mostly of sandy clay loams down to 2.3 to 2.8 feet, where clay shale was encountered. The downward movement of water would be impeded by the clay structures found in both holes, which would force lateral water movement to the south and west through the overlying soil.

The smallest decreed site (6 acres) lies directly west of the first two decreed sites and is perched above the natural drainage in fine sandy loam. A distinct shale layer was discover at six feet below the land surface in Hole 5, which similar to the previous site, would impede the downward movement of water and force it to move laterally through the overlying soil. It is DU's belief that if a large quantity of water were to be ponded at this location it would daylight 200-300 meters to the south on the adjoining land owner's property, and flow into the drainage; thus site development is cautioned. Detailed data analyses of all five soil profiles are presented in Table 5.

Table 5. Soil characteristics of the five locations sampled at the Morgan County location (4T, 58R, Section 16)

Hole #	NRCS Soil Map Classification	Interval Depth (ft)	Soil Texture	% Clay	Saturated Hydraulic Conductivity (ft/d)	Permeability (in/hr)	Notes
1	Dwyer Sand, hilly	0 - 3.08	sandy loam	10	4 - 12	2.0 - 6.0	
		3.08 - 4.92	loamy sand	4	12- 40	6.0 - 20	
		4.92 - 8.79	sandy loam	16	4 - 12	2.0 - 6.0	
		8.79 - 12.6	silt loam	10	4 - 12	2.0 - 6.0	
2	Dwyer Sand, hilly	0 - 0.66	sandy loam	12	4 - 12	2.0 - 6.0	Clay loam layer at 9.35-11.54ft may slow downward water movement
		0.66 - 2.3	loam	25	1.2 - 4	0.6 - 2.0	
		2.3 - 9.35	sandy loam	16	4 - 12	2.0 - 6.0	
		9.35 - 11.5	clay loam	38	0.4 - 1	0.2 - 0.6	
3	Dwyer Sand, hilly	0 - 0.3	loam	24	1.2 - 4	0.6 - 2.0	Moderately deep soil to sandy and clayey shale. Downward movement of water would be impeded by clay and structure of shale.
		0.33 - 1.48	clay	43	0 - 0.1	0.06 - 0.20	
		1.48 - 2.79	sandy clay loam	32	0.4 - 1	0.2 - 0.6	
		2.79 - 2.79	sandy and clayey shale		0 - 0	0.0 - 0.2	
4	Dwyer Sand, hilly	0 - 0.3	loam	16	1.2 - 4	0.6 - 2.0	Moderately deep soil to sandy and clayey shale. Downward movement of water would be impeded by clay and structure of shale.
		0.3 - 1.12	sandy loam	12	3.4 - 12	2.0 - 6.0	
		1.12 - 2.23	sandy clay loam	22	1.2 - 4	0.6 - 2.0	
		2.23 - 2.23	sandy and clayey shale		0 - 1.41	0.0 - 1.41	
5	Dwyer Sand, hilly	0 - 1.48	sandy clay loam	26	1.2 - 4	0.6 - 2.0	Very deep soil to sandy and clayey shale at 6.06 ft which would impede water movement downward
		1.48 - 6.07	fine sandy loam	6	4 - 12	2.0 - 6.0	
		6.07 - 6.07	clayey shale		0.4 - 1	0.2 - 0.6	

6. RECOMMENDATIONS AND CONCEPTUAL DESIGN

Based on the results of the soils investigation of the Weld County property (T5N, R61W, Section 36), neither decreed site appears to hold good potential for recharge pond development. The prevalence of redoximorphic features throughout the soil profiles and free water encountered as high as 4.5 feet from the land surface indicates considerable canal seepage is inundating the property and raising the groundwater level throughout the irrigation season. The abundance and

vibrant health of the tall meadow grasses that are under a steady grazing schedule also provide additional qualitative proof of high groundwater elevations downgradient of the canal. From a waterfowl habitat standpoint, this area could prove to be an excellent site for the development of a shallow water wetland complex, which would greatly improve the recreational value of the land, but developing groundwater recharge ponds is not a recommendation at this time.

The results of the soils investigation on the Morgan County property (T4N, R58W, Section 16), contain a greater degree of variability than the Weld County site. The lower two sites have moderately deep to deep soils sitting on top of a shallow shale confining layer that will inhibit the downward movement of water. Water continuously applied to the land surface would saturate the pore spaces of the overlying soils and then begin to move laterally across the shale to the southwest, where it would eventually daylight on the adjacent property to the south, therefore neither site is recommended for recharge development at this time.

The largest decreed augmentation site on the Morgan County parcel, adjacent to the Riverside canal, is believed to be an old playa lake, meaning that it fills with water after precipitation events and naturally recharges aquifer. The soil cores taken from two the topographic low points in the playa show no signs of redoximorphic features and groundwater was not encountered, indicating the soils are well drained and capable of transporting water downward through the soil profile. With this site located in close proximity to the Riverside canal, field staff expected to find seepage water in the lower depths of the cores since the canal had been conveying water for a full irrigation season, but none was encountered. The clay loam layer from 9.35 to 11.5 feet below the land surface in soil core #2 indicates there is some heterogeneity within the site that could slow downward movement of water in areas but it does not appear to be a continuous layer. Based on these field observations and soils data, DU is comfortable recommending this site for recharge pond development.

With the site situated in a natural landscape depression, a five acre recharge pond can be created without the need for constructing levees, by utilizing the 4,442 foot elevation contour line as the full pool wetted perimeter (Figures 7 and 8). The possibility exists to enlarge the surface area to 7.4 acres by constructing two levees along the east side to keep water off the toe of the canal embankment, and potentially a third levee on the south side of the pond to keep water from running onto the adjoining land to the south. Conceptually, a screw gate would be installed level with the canal invert and then a buried pipeline would connect to the diversion structure and convey recharge water from the canal to the pond.

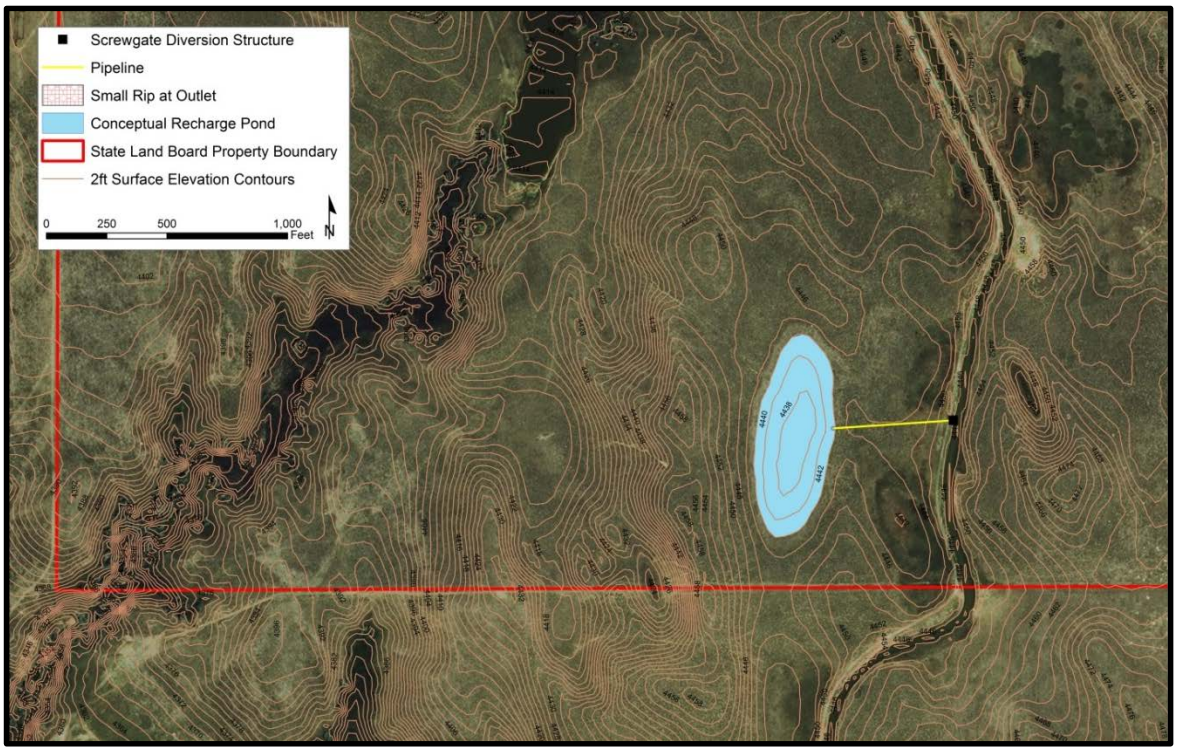

Figure 7. Conceptual recharge pond design and associated infrastructure

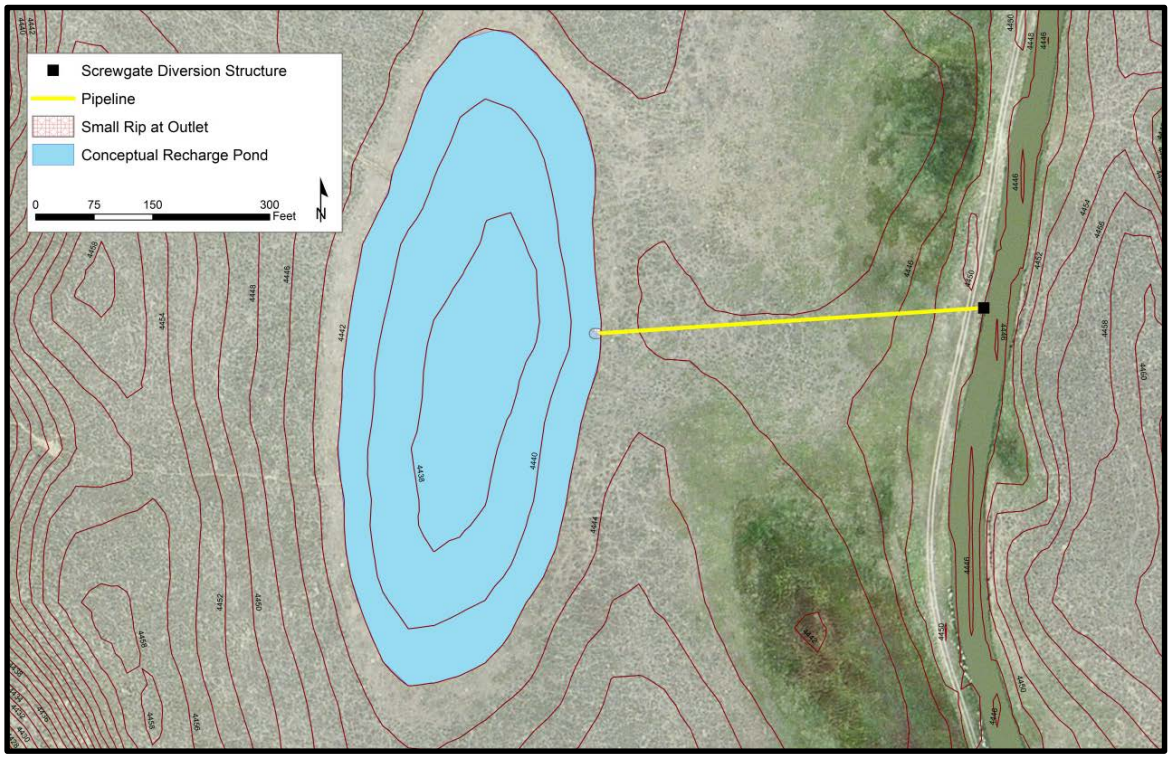

Figure 8. Conceptual recharge pond design and associated infrastructure with a closer view of the canal seep wetlands

WATER MANAGEMENT

Ideally, DU engineers would like to conduct a multi-day pump test at the site to better determine the quantity of water that can realistically be applied to the pond over a prolonged period of time. If the SLB decides to move the project into Phase II, then DU would either work out an agreement with Riverside to conduct the test or work with Riversides engineers to make sure the project is operating within its capacity. DU engineers recommend starting with a conservative volume of water (100-300 acre-feet per year) to make sure the underlying soils and aquifer can accept the recharge water as expected before increasing the volume discharged to the pond.

During the August 2015 meeting between DU and Riverside it was communicated that for any augmentation site developed under Riverside's decree, an established augmentation credit sharing ratio of 60:40 (Riverside : Landowner/Project Developer) has been pre-approved by the Board of Director's. It was also communicated that if the sites are built, Riverside will apply recharge water on them when in priority, and when the diversion of water does not interfere with other canal objectives, solely at the discretion of Riverside. If the SLB decides that this is a site worthy of development, DU can explore several options for funding the infrastructure and construction.