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Water Level Change and Pit Drain Evaluation in the Vicinity of the NCCI Pit, Ft. Lupton, Co.

Prepared for
The City of Thornton, Colorado

November, 2020

Project No.: J&T(Zadel)

McGrane Water Engineering, Inc. provides accurate, cost-effective groundwater solutions to municipal, industrial, mining, and recreational water providers using experienced professionals and appropriate technologies.

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The technical material in this report was prepared by or under the supervision and direction of the undersigned, whose seals as a Professional Geologist and Professional Engineer in the State of Colorado are affixed below:

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Table of Contents

List of Figures

List of Tables

Table of Contents – Appendices

Appendix A - Hydrogeology

List of Figures

List of Tables

Appendix B – Model Construction and Calibration

List of Figures

Table of Contents – Appendices (continued)

Appendix B – Model Construction and Calibration (cont.)

List of Tables

Appendix C – Monitoring Well Data and Plots

Tables and Plots

BACKGROUND

McGrane Water Engineering, LLC (MWE) was retained by J&T Consulting, Inc. (Fort Lupton, Colorado) to evaluate the effectiveness of installing a perimeter drain around the NCCI gravel mine pits after dewatering ceases this year.

The mine is located near Fort Lupton, Colorado and is owned by Northern Colorado Constructors Inc., (NCCI) and is being purchased by the City of Thornton (City). The pits are sometimes referred to as the "Zadel" pits, after Chris Zadel, the owner of NCCI. The pits consist of a main "south" pit and a smaller "north" pit. Dewatering ceased at the NCCI north pit in 2020, and it was partially filled with tailings. According to JC York (J&T Consulting), by January, 2021, the water levels in the NCCI north pit and vicinity wells have nearly recovered.

The NCCI south pit is currently being mined and has been dewatered by pumping for approximately the last 10 years. In 2021, NCCI is planning to install a clay liner around the inside of the pit to prevent groundwater from entering. Once the liner is installed, pumping will cease and the water table outside the pit will recover. Water will then be stored inside the liner for municipal use. Potential impacts caused by a liner include a rise in the water table on the up-gradient side (mounding), and water level declines in the down-gradient side (sometimes referred to as "shadowing"). The City of Thornton is concerned that, in the future, nearby land owners may complain about water level changes resulting from the lining. Potential impacts caused by liners or slurry walls on the up-gradient side include flooded basements, soft ground due to waterlogging, or increased phreatophyte growth if the water table mounds close to the ground surface. On the down-gradient side, large capacity water wells could be impacted by decreasing the saturated thickness of the aquifer.

To mitigate potential impacts, the City would like to restore groundwater levels to pre-mine conditions. To accomplish this, a subsurface drain could be installed on the up-gradient side of the pit to collect and direct mounded groundwater from the up-gradient side to the down-gradient side where it would re-infiltrate into the aquifer.

Between June and November 2020, MWE met with J&T Consulting, Inc., Chris Zadel, the City of Thornton, and the City's consultant, RJH Consultants, Inc., to discuss the evolution of our pit evaluation and to direct our work.

Report Format

Conclusions and recommendation are included in the executive summary after short descriptions of the study area and gravel pit development history. The main body of the report then sequentially addresses:

- Site hydrogeology;
- Pre-development groundwater conditions around the NCCI pit site;

- Seasonal groundwater level changes caused by recharge from nearby Little Dry Creek and the Lupton Bottom Ditch;
- Groundwater level conditions over the past decade while the pit was being mined and dewatered;
- Groundwater level changes caused by other nearby lined pits;
- Groundwater level changes expected from potentially lining the NCCI pit; and
- The effectiveness of various perimeter drain configurations.

Report figures are included at the end of the report. Three appendices provide additional detail on the hydrogeology (**Appendix A**), model setup (**Appendix B**) and monitoring well data and plots (**Appendix C**). Appendix figures have the prefix "A" or "B" accordingly, and can be found at the back of each appendix. Some figures are repeated after the main text to simplify finding them.

Study Area

Figure 1 shows the location of the mine in Sec. 24, Twn. 2N, Rng. 67W (6^{th} PM) located approximately two miles north of Fort Lupton, Colorado on the west side of the South Platte River (SPR). The study area surrounding the pits includes nine square miles in sections 18, 19, 30, and 31 in Twn. 2N, Rng. 67W, and sections 13, 24, 25, 35, and 36 in Twn. 2N, Rng. 68W. The SPR meanders northward approximately one mile to the east. The gravel pits are located within sand and gravel deposits that extend approximately 1 to 2 miles on either side of the river. Little Dry Creek (LDC) is tributary to the SPR from the west on the south side of the study area. Once LDC reaches the modern SPR floodplain, it jogs northward and becomes channelized. After flowing past the west sides of the NCCI pits, LDC eventually joins the South Platte River.

Several gravel pits have historically pumped dewatering discharge water directly into LDC, similar to the NCCI south pit currently. The Lupton Bottom Ditch (LBD) is located approximately 1,000 to 2,000 ft west of LDC on older terrace deposits. The LBD provides seasonal recharge to the alluvial aquifer and is close enough to the NCCI pits to cause significant seasonal fluctuations in the water table.

Gravel Pit Development

We grouped vicinity pits based on their location relative to the NCCI pits. Figure **4** shows the location of the NCCI pits between a "northern" group of pits and LG-Everest (LGE) pits to the south. The NCCI pits (#1 and #2) were first permitted in 2001 and later amended in 2008.

The "northern" pits include the Keonig pit (#5) which was first mined by Weld County in 1980 then lined in 1999. The Heit Pit (#4) was first developed in 2003 for mining and lined in 2007. The Lupton Meadows Pit (#3) was mined starting in 2016 and lined in 2018. After lining, we believe the water table likely recovers within 6-months to one year depending on the proximity to recharge.

The LGE pits were first developed in 1999 and are all located south of County Road 18. Several amendments to these mining permits have been approved adding additional area for mining with the most recent amendment being approved in 2012. The amendments added a property adjacent to, and east of, the NCCI pits along CR 25 and several properties extending south of the existing LGE pits that abut CR 14.5. All the LGE pits except #10 and #15 have been lined. Pit # 6 was most recently lined in 2019.

There are other properties on the north and east of the NCCI pits that could be permitted in the future for gravel mining which were not considered as part of this study.

EXECUTIVE SUMMARY

During this evaluation, we:

1. Evaluated the hydrogeology of the alluvial aquifer in a nine square-mile area along the SPR and along LDC;
2. Built a steady-state groundwater model to evaluate the incremental and cumulative impacts caused by other gravel pit groups, including the NCCI pit and other pits located to the north and south;
3. Evaluated pit dewatering pumping rates and water levels over the past 10 years;
4. Evaluated aerial photographs available on Google Earth to identify wet ground conditions prior to NCCI pit development; and
5. Constructed a transient groundwater model to evaluate seasonal water level changes and to estimate drain flows for various drain configurations.

Observations and inferences include:

1. Based on aerial photographs taken prior to NCCI pit development, the water table east of the NCCI pit was likely shallow and fluctuated close to the ground surface due to seasonal recharge from LDC and LBD and other irrigation ditches.
2. Well construction reports filed over time suggest that aquifer levels away from the NCCI pits have not significantly changed over time. This is because seasonal pumping is quickly replenished by surface water recharge from nearby rivers, streams, canals, and laterals.
3. Seasonal recharge from the LBD creates fluctuations as large as 8 feet in monitoring wells Z1 and Z2 which are located between the NCCI south pit and the LBD.
4. Historical records show that NCCI south pit dewatering rates increase in the summer, likely due to increased seasonal leakage and recharge from LDC and LBD.
5. Over the past decade, dewatering the NCCI pits may have benefited shallow groundwater areas located east of the pits by dampening seasonal recharge fluctuations.
6. The area of phreatophyte growth (mostly cattails) in LDC located west of the NCCI pit has expanded in the last decade despite the water table being lowered by NCCI south pit dewatering. This indicates that the phreatophytes in the LDC channel depend on infiltrating surface water and not groundwater.
7. Pits located north of the NCCI pits have had a minor impact on water levels around the NCCI pits.
8. LGE lined pits to the south have caused approximately three to four feet of ground water decline (shadowing) on the east side of the NCCI south pit which overshadows local impacts caused by NCCI pit lining.
9. The steady-state model indicates that a NCCI south pit liner will create a one-foot rise in water levels on the west side and up to a one-foot decline on the east side compared to predevelopment conditions (attributable to the NCCI pit alone, not including impacts from

other pits). For comparison, monitoring data suggests that water levels in this area fluctuate seasonally by 4 to 8 feet which is large and likely overshadows all pit liner impacts.

10. Monitoring well data and steady-state and transient modeling suggest that there is a vertical gradient (no hydraulic connection) between LDC and the groundwater table.
11. A drain could be installed at the predevelopment water level to reduce the expected mounding on the west sides of the NCCI pits and drain the water off to the east sides of the pits.
12. To design the perimeter drain, we used a transient groundwater model to allow us to consider the design flow rate based on the seasonal peak recharge (highest groundwater) conditions.

Based on model runs, we conclude:

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1. That the cumulative changes in the water table caused by all lined pits in the vicinity of the NCCI Pit are less than a 2 foot increase in the west and approximately 3 feet of decline in the east. The decline is a result of shadowing caused by the LGE pits to the south. Even if a drain is installed, it will only reduce the shadowing by about 1 foot.

2. Because there is a hydraulic disconnection between LDC and the water table, we do not expect the area of phreatophytes (and therefore the amount of evapotranspiration) in the LDC channel next to the NCCI to change in the future regardless if a drain is installed around the NCCI pit.

3. Although there is one high capacity irrigation well located within the area of long-term shadowing, the forecast decline in production is less than 10 percent which is insignificant compared to seasonal water table fluctuations.

4. If a drain is installed around the NCCI *south* pit, it should be installed at the predevelopment water level (approximately 5 feet below ground level), and at a grade having a drop of at least one foot from the northwest to northeast corners. The pipe should be sized to not have greater than approximately 1 foot of head loss at the design flow rate (300 to 350 gpm).

5. The modeling suggests that a drain around the NCCI north pit would have negligible benefits because: i) modeling suggests that the water levels there will only be about a foot above pre-existing conditions (**Figure 8**); ii) the summer water table is also less than a foot above pre-existing conditions (**Figure 14**); and iii) if a drain were installed around the northern pit, then it would overlap with the purpose of a drain around the NCCI southern pit.

Discussion

The change in water levels caused by the sum of all pit development, compared to pre-development conditions, is approximately a 1-ft rise on the up-gradient side and 3-ft decline on the east side. These impacts will likely be overshadowed by 4 to 8 feet of seasonal water table fluctuations. In addition, the groundwater levels in this area have historically been very shallow. Therefore the 3 feet of shadowing east of the NCCI south pit may be benefiting existing property owners who may have experienced seasonal wet ground due to high seasonal water levels before NCCI south pit dewatering began. We are concerned that the installing a drain could be perceived as a greater problem than not installing the drain.

If high water levels ever do pose a problem in the future, we believe localized mitigation such as installing a tile drain, French drain, or sump pump at the area of concern will be more cost-effective than installing a large, expensive, passive perimeter drain system.   Also, if phreatophytes become a future nuisance, it will likely be more cost effective to improve the LDC surface channel to drain standing water than to attempt to lower the water table from below. Current observations suggest that the phreatophyte area may remain wet even if a perimeter drain were installed.

Recommendations

We recommend to not install a drain around both the NCCI north or south pits because:

1. There will be minimal changes compared to predevelopment conditions, and the changes compared to current existing conditions may not be favorably received;
2. The gradient to drive flow through the drain and around the pits (a large drain run) is so low that it may require large diameter (more expensive) pipe to flow passively;
3. Less expensive localized mitigation of mounding (local tile drains, French drains or sump pumps) are likely more cost effective;
4. The amount of common approximation error in our model (approximately +/- 2 ft) is close to the predicted impacts which sheds doubt on whether the expense of a drain is justified.

Regardless of whether a drain is installed around the NCCI south pit or not, we recommend that monthly monitoring continue using existing monitoring wells for some period of time. The data could be used to document changes and evaluate future groundwater conditions, seasonal water level changes, and the effectiveness of the pit lining or drain (if installed). Such data could also be used to refine this model in the future, if necessary.

HYDROGEOLOGY

We evaluated the hydrogeology as a first important step before creating a groundwater model. We compiled hydrogeologic data from:

- Existing reports from the U.S. Geological Survey and Colorado Division of Water Resources (see sources below);
- Well permit completion reports from 148 registered alluvial wells available from the State's well database (CDWR, 2019); and
- Water level data from 61 monitoring wells located around the NCCI pit.

Appendix A contains tabulated well data for both CDWR wells and gravel pit monitoring wells (**Table A1**). We pulled the completion reports for the CDWR wells and compiled location, depth, depth to bedrock, depth to water, pumping rate, and calculated saturated thickness values which are plotted on maps discussed below.   **Appendix A** also includes a detailed description of how groundwater moves through the alluvial aquifer and is affected by the geology, topography, and surface water.

Figure 2 shows the well data locations with permit number. The shapes represent various well uses including agricultural, domestic, stock, municipal, and monitoring wells. The well water levels were used to calibrate the steady state groundwater model used in this report and discussed in **Appendix B**.

Figure 3 shows the location of nine monitoring wells belonging to NCCI (green), four belonging to the City of Thornton (orange) and fifteen belonging to LG-Everist (LGE) who owns over a dozen gravel pits located south of the NCCI pit (blue). Monitoring well data are compiled in tables and shown in plots in **Appendix C**. Seasonal water level changes in monitoring well Z1 and Z2 were used to calibrate the transient groundwater model discussed below.

Z1 and Z2 were used because water levels in other monitoring wells were clearly dominated by dewatering activities while Z1 and Z2 were further from the pits and closer to the creek and to the Lupton Bottoms Canal. Therefore, when calibrating the model to seasonal water level fluctuations, Z1 and Z2 where the best calibration targets. Additionally, since other monitoring wells were dominated by pit dewatering and nearby pit lining, calibrating to that data would have required more year-to-year detail about lining progress and status of both the NCCI pit and neighboring pits. In our opinion, focusing our calibration on the seasonal fluctuations to Z1 and Z2 data gives us confidence that our drain design for seasonally high conditions is accurate for key flow conditions. Therefore, other water level time series data was not used for model calibration.

Phreatophyte Growth

The historical presence, and a possible later increase, in phreatophytes in the “wet” area located west of the NCCI south pit should be noted. As previously stated, lined pits block groundwater flow. Alluvial groundwater gets blocked (causing mounding), and then is deflected around LGE pits to the west side. Based on our review of aerial photographs along the south side of the NCCI north pit, phreatopyte growth has grown over the past decade <u>despite</u> lower groundwater conditions caused by NCCI pit dewatering. This is an important point because it is evidence that the NCCI pits has not contributed to phreatophyte expansion and will not in the future regardless of whether or not a drain is installed.

Wells

Appendix A includes tabulated well data from 148 registered alluvial wells and 61 permitted monitoring wells. Depth to bedrock at the water wells ranges from 20 to 73 feet and averages 43 feet. Well yields range from 4 gpm for domestic wells to 2000 gpm for irrigation wells. The depth to water ranges from 2 to 40 feet and averages 15 feet. The calculated saturated alluvial thicknesses range from 2 to 50 feet and average approximately 26 feet.

Hydrologic Maps

Appendix A includes detailed descriptions of the following hydrologic maps:

- Surficial geology (**Figure A3**);
- Pre-development water table (**Figure A4**);
- Elevation of bedrock (**Figure A5)**;
- Alluvial aquifer saturated thickness (**Figure A6**);
- Alluvial aquifer permeability (**Figure A7**); and
- Aquifer transmissivity, the product of saturated thickness and permeability (**Figure A8)**.

MODELING

Groundwater models are used by hydrogeologists to simulate groundwater flow through the subsurface. We first used a steady-state model to evaluate general groundwater level changes caused by the NCCI and nearby pits. We then constructed a transient groundwater model from the steady-state model to evaluate the effectiveness of various perimeter drain configurations under the influence of seasonal water table fluctuations.

Appendix B contains more details on model construction, input parameters, calibration, and run mass balances.

Pre-development groundwater conditions

The "pre-development" water table represents pre-mining conditions and serves as the measure for impacts caused by pit lining. It was generated by the steady-state model described in **Appendix B** and shown in **Figure B1.** The objective of evaluating changes compared to predevelopment conditions is to determine potential negative impacts to nearby property owners who may be affected or perceive effects from by mounding or shadowing in the ways previously described.

The pre-development "average" gradient across the pit footprint is approximately 1 foot. The head difference increases to about 4 to 5 feet across the pit footprint once the NCCI pit is lined. The steepened gradient created by pit lining and seasonal recharge are critical factors in determining potential drain flow.

Groundwater level changes caused by gravel pits

Impacts caused by lining gravel pits were computed by applying the principal of superposition (Reilly, et al, 1987). The principal states that solution to individual problems can be added to obtain solutions to more complex problems. It also means that if precipitation recharge and evapotranspiration are not expected to change significantly, then their influence can be ignored in the evaluation because they are the same in both the before and after cases.

Using superposition, we evaluated the effects of three groups of pits described in **Table 1** and shown on **Figure 4.** We conducted individual model runs to evaluate water level changes (relative to pre-development conditions) caused by each group. We did this by successively turning off the pit group model cells for each run (making those lined pit cells impermeable or "no-flow" cells) and then subtracting model head outputs in the new run to determine incremental head changes caused by the pit-group changes.

Precipitation and evapotranspiration are not considered in the model runs because we do not expect there to be a significant change in either of these parameters resulting from pit lining or installing a drain. Therefore, it is unnecessary to spend additional time to understand and simulate them.

Since both the pre-pit and post-pit steady-state runs represent average groundwater conditions, the differences shown in the figures below are average differences. As we will discuss later, these changes are small compared to the average monthly water table fluctuation. Therefore, if the water table is generally dropping downgradient from the pit, that decrease may actually benefit downgradient water users by dampening what was a natural increase in water levels. For this reason, we need to keep the discussion of steady-state impacts in perspective compared to seasonal changes discussed later in the report.

Northern Pit Group Impacts

Figure 5 shows the mounding caused by the three existing lined pits located north of the NCCI pits. The positive contours show "mounding" on the up-gradient sides of the pits (light blue contours) and the negative contours show "shadowing" on the down-gradient side (red contours). The black contour represents no change. Observations include:

- Mounding of up to 2 feet, but only 0.5 to 1.5 ft of mounding extends to the location of the NCCI north pit and only approximately 0.5 feet of mounding reaches the NCCI south pit, and
- Shadowing north of the Northern pit group does not affect the NCCI pits.

  As we will see later when we combine the impact of mounding caused by the northern pit group with shadowing caused by the NCCI and LGE pits to the south, the impacts actually cancel each other out to some extent. We are uncertain whether this provides an actual benefit to landowners located north of the NCCI pit or not since the predevelopment water table was generally high in that area.

South (LGE) Pit Impacts

Figure 6 shows water level changes caused by existing LGE pits. Observations include:

- Up to 8 ft of mounding on the west and south sides of LGE pits, with mounding over two feet extending one mile south of the LGE pits; and
- Shadowing up to 3 ft on the east and west sides of the NCCI south pit, and 1 ft of shadowing on both sides of the NCCI north pit.

We conclude from this map that most of the shadowing on the east side of the NCCI pits is caused by lined LGE pits and the LGE pit shadowing tends to mitigate mounding caused by the NCCI pits discussed below.

NCCI Lined Pit Impacts

Figure 7 shows water level changes caused by just the NCCI pits, including:

- Mounding from 0.5 to 1.5 ft on the west side of the NCCI north pit;

- Mounding 2 - 4 ft on the west side of the NCCI south pit; and
- Less than 1 ft of shadowing east of the of the NCCI pits.

We conclude from this map that the "fines" placed in the north NCCI pit create very little impact to the water table, but the mounding caused by the NCCI south pit could be significant. However, as discussed above, the overlapping shadowing caused by the LGE pits in that area will likely cancel that impact, This is shown in the combined pit impact maps below.

Combined Pit Impacts (Northern, LGE, and NCCI)

Figure 8 shows water level changes caused by all existing pit groups, including:

- Mounding up to 1.5 ft west of the NCCI pits;
- Mounding up to 8 ft west of the LGE pits;
- Mounding up to 6.5 ft south of the LGE pits; and
- Shadowing up to 3 ft to the east and north of the NCCI pits.

By comparing **Figure 8** with **Figure 2** (DWR wells), there is only one high capacity irrigation well (permit no. 5746-F) located on the north edge of the NCCI south pit within the 2 ft shadow forecast. According to the Colorado Division of Water Resources well database (URL: https://dnrweblink.state.co.us/dwr/DocView.aspx?id=1620836&dbid=0), the well is 32 feet deep; had a reported depth to water of 4 feet in 1964; and reportedly produced 1200 gpm for irrigation purposes. The saturated thickness of the aquifer prior to pit mining was 28 ft (32'-4'). The summer irrigation season drawdown (**Figure 11**) is approximately 18 feet. This would mean the summer aquifer saturated thickness was approximately 10 feet (32-18-4 ft). Since well yield is proportional to the aquifer saturated thickness, the expected well yield should be approximately 400 to 500 gpm [1200 gpm * (10'/28')] the reported yield. According to JC York (J&T Consulting), there have not been any complaints of reduced well yield by the well owner. This is likely because recharge from the existing dewatering canal that runs past the well on the north side of the NCCI south pit likely keeps the well running at an acceptable rate. In the future, the theoretical reduction in well yield is also expected to be proportional to the decline in saturated thickness due to shadowing (approximately 2 feet). Therefore the expected decline of the well is only 7% (2'/28') which is insignificant.

Impact Summary

In summary, lining the NCCI pits is projected to cause over 3 ft of mounding on the west side (**Figure 7**), but most of it is cancelled out by LGE pit's shadowing (**Figure 6**). The NCCI south pit contributes about a foot of shadowing on the north and east sides, which when added to the LGE pit shadowing (Figure **6**) totals approximately 3 ft (Figure **8**). We do not expect any high capacity wells to be effected by changes in water levels caused by pit lining.

Transient Groundwater Modeling

We used the transient model to evaluate various drain locations, depths, and discharge options. We built the transient model from the steady state model, so it has many of the same boundary conditions. We incorporated recharge during summer months to match higher seasonal dewatering rates and simulate expected higher drain flows during the irrigation season. The transient model utilizes two stress periods per year (summer canal season and the off-season) and 12 model time steps per season. To gain confidence in the model projections, we focused the transient calibration on observed NCCI pit dewatering rates and observed water levels in monitoring wells Z-1 and Z-2 (see **Appendix B)**. These two wells are far enough from the NCCI south pit to show the seasonal recharge fluctuations which are not apparent in the other monitoring wells due to pit dewatering. We therefore chose to calibrate to the seasonal fluctuations apparent Z-1 and Z-2 instead of the annual dewatering trends shown in the other wells.

Summer Water Table Baseline Run

We focused on the highest drain flow condition for drain design (gradient, depth, and flow design parameters). This occurs when seasonal recharge on the upstream side of the NCCI pit is highest from recharge from LDC and LBD. To model this, we needed to expand the modeling beyond using a steady state model that used average water level conditions with no seasonality. We therefore created a model using transient recharge that was calibrated to actual seasonal pit pumping amounts (**See Appendix B**). This allowed us to focus on a seasonal water table fluctuations at a more local scale. We again used a predevelopment run with no pits present for a baseline reference case (pre-development conditions). We selected the late July 2019 water table as the baseline month for the change comparison (**Figure 9**) since late summer is when we expect the highest water levels west of the NCCI pits due to recharge from LDC and LBD which is also when we expect the highest drain flow. This is the baseline against which changes are evaluated in the remainder of this report.

To validate this map, we compared it to a map of seasonally high water table conditions created by the Colorado Water Conservation Board as part of their South Platte Decision Support Project. (SPDSS (CDM-Smith, 2013, Fig. 4-3). Although we did not do a cell-by-cell comparison, the contours appear to be within a few feet. We attribute this difference to our use of more accurate ground control and accuracy of the modeling using the more refined grid. We then compared the baseline summer water table (no NCCI pit liner or drain) to the following scenarios:

Current Summer Pit Drawdown

The purpose of this run is to first consider what conditions neighbors may have become accustomed to during the last 10 years during NCCI pit dewatering. The run includes current NCCI pit dewatering without a liner under existing pit development conditions (with lined LGE and Northern pit groups in place). The results (**Figure 10**) shows tight water table contours around the north and south NCCI pits that generally agree with measured monitoring well elevations. In an attempt to calibrate the transient model to the 4861 foot levels measured at Z1 and Z2, we increased streambed leakance parameters of LDC and increased recharge from Lupton Bottom Ditch. Those changes also affect future modeled drain flow. **Appendix B** includes more information on the transient model calibration. We then subtracted the water levels with and without pit pumping to create the NCCI pit summer drawdown map (**Figure 11**). The maps shows over 20 feet of drawdown at the NCCI north and south pits. The drawdown extends away from the pits such that there is: i) 11 to 15 feet of drawdown west of the NCCI south pit underneath Little Dry Creek (LDC); ii) up to 18 feet of drawdown north of the NCCI south pit; and iii) and up to 17 feet of drawdown east of the south pit. This supports our conclusions that:

- During current dewatering, there is a hydraulic disconnection (i.e., vertical gradient) between LDC and the aquifer west of the NCCI pit; therefore any vegetation located along the east side of the pit is being supported by surface water and not groundwater; and
- The pit drawdown on the east side of NCCI pits today has existed for several years, and far exceeds the long-term shadowing impacts caused by pit lining

When considering potential impacts, the City of Thornton and NCCI pit operators should consider there are several homes visible behind the contours in **Figure 11** who have not complained and therefore have likely "accepted" the lower groundwater condition. If a drain were installed, and mounded groundwater was routed around to the east side of the NCCI pit and allowed to recharge, then the resulting increase in water levels may be considered undesirable even though it does not quite return to predevelopment conditions.

Pre-Drain Water Table and Gradient

For a drain to work properly, there needs to be an adequate gradient (head difference) between the west side of the pits and the east side. **Figure 12** shows the summer water table after the NCCI south pit liner is installed and the pit recovers. The water table elevation on the south end of the NCCI north pit and the northwest corner of the NCCI south pit (near the "wet" area along LDC) is approximately 4860 ft. The water table elevation at the northeast corner of the NCCI south pit is 4856 ft, creating only a 5-ft gradient across the south pit. From a design standpoint, the low gradient can be compensated for by using a larger pipe that reduces friction loss. Based on conversations with J.C. York (J&T Consulting, Inc.) five feet is enough gradient to make the drain work in the summer, but considering the +/- 2 feet of estimated uncertainty in the model (see Uncertainty Section below), and the likeliness of a flatter gradient during months with less recharge, we are uncertain whether water will move from west to east every month of the year. This also brings into question the need for the drain.

The role for a drain around the NCCI pit was further evaluated by subtracting the summer water table without a drain (**Figure 12**) from the "baseline" summer run (**Figure 9**). The resulting **Figure 13** shows that without a drain, the summertime water table (relative to pre-mining conditions) is expected to:

- rise approximately 12 feet on the west side of the LGE pits to the south;
- rise up to 7 feet on the south side of the LGE pits;
- rise less than one foot on the west side of the NCCI south pit and 0.5 to 1.0 ft along the west side of the NCCI north pit (*this minor change suggests that a drain may not be necessary*);
- decline up to 4 feet on the east side of the NCCI south pit; and
- decline of less than 1 ft on the east side of the NCCI north pit.

Figure 14 zooms into the NCCI pit in Figure 12 to emphasize that even without a drain, there is expected to be minimal mounding on the west side of the NCCI pit and under 4-ft of shadowing on the east side of the southern NCCI pit. We believe these impacts are small and that a drain to move water from the west side to the east side does not have a clear purpose and, therefore, may not be cost-effective. This is because:

- The increase in water levels on the up-gradient side of the NCCI pit is approximately one foot which is likely less than the accuracy of this model (see "Uncertainty Section");
- Natural groundwater fluctuations of four to eight feet caused by seasonal recharge far exceed the changes caused by the pit liners (See Monitoring Well Z1 and Z2 in **Figure B5**).
- A four foot drop in the water table on the down-gradient side of the NCCI pit results in less than a 20% decline in the pre-development saturated thickness (**Figure A6**). Since well yield is proportional to the saturated aquifer thickness, we would not expect a 20 percent drop to be noticeable unless an active irrigation well is present in that area. We recommend comparing **Figure 14** with the location of existing irrigation wells to see if any existing wells are located in the "shadow" area immediately east of the pit.

Drain Scenarios

We ran several drain scenarios (i.e., subsurface perforated pipe) around the south NCCI pit:

- Scenario 1 - A circular drain almost entirely around the south pit;
- Scenario 2 – A north-south drain along the west side of the south pit and along the east side of the NCCI north pit (on an existing road)that drains north into LDC; and lastly,
- Scenario 3 – A collector drain along 2,200 ft of the west side of the NCCI south pit which then re-infiltrates water though a perforated pipe along the north and northeast sides of the south pit.

Scenario 1 was rejected by the clients because the drain was too long and therefore cost prohibitive, plus if installed deep it arguably moved more water than is necessary, possibly resulting in water levels too low on the west side of the pit. Scenario 2 was rejected because the City of Thornton did not want to discharge groundwater to LDC, which would require additional permitting, and because the City did not want to have the pipe in the right-of-way along the east side of the NCCI north pit. The preferred location (Scenario 3), therefore, was around the south pit, but not installed completely around it as was the case in Scenario 1.

On-Site Drain Effectiveness

Figure 15 shows the location of the NCCI southern pit drain (Scenario 3) and the residual mounding and shadow relative to the baseline, summer water table (**Figure 9**). The south-to-north flowing perforated drain (2,200-ft long, black and yellow line) would collect and transport water to a 1,600-ft-long, eastward flowing perforated section, followed by a 500 ft south-flowing section extending southward from the northeast corner (black and gray). The total drain length is approximately 4,300 ft. The re-infiltration pipe gradient along the north side of the NCCI south pit is nearly flat between elevations 4858.5 and 4857.5 ft. This is because the exfiltration pipe becomes submerged as the water table rises, which limits its flow rate by reducing the gradient. **Figure 16** shows the residual drawdown compared to existing summer conditions if the on-site drain is installed. The on-site drain results in less than 0.5 feet of residual mounding on the west side of both NCCI pits. About 3 feet of residual drawdown remains on the east side of the south pit. Therefore the drain only reduced the shadowing by about 1 foot. As discussed earlier, residual shadowing on the east side of the NCCI pit was caused by LGE pits (**Figure 6**).

Figure 17 shows how re-infiltrating water essentially backs up the drain and reduces the flow rate through the drain pipe by reducing the gradient. The blue lines represent the theoretical drain inflow and outflow with no resistance to flow on the down-gradient side. Without resistance (caused by the back-up), the peak theoretical flow during the summer irrigation season is approximately 350 to 400 gpm. Note: the theoretical values are similar to what we found for the performance of a straight south to north drain discharging to LDC. However, with discharge being directed to the aquifer on the north and northeast side of the NCCI southern pit, the water table rises to the pipe and reduces flows. The dashed black line in **Figure 17** represents how much flow is expected to actually occur through a large diameter drain (approximately 300 to 350 gpm) because of the flattened gradient and backup. That flow is about approximately 50 gpm less than the free-discharge case.

Based on these evaluations, the exfiltration pipe should be large enough to convey the simulated flows at a nearly flat hydraulic grade. The actual sizing was beyond the scope of this study.

We did not conduct any drain scenarios around the NCCI north pit because modeling of the south pit drain suggests: i) the recovery is less than 1 foot above pre-existing conditions (**Figure 8**); ii) the summer water table is also less than a foot above pre-existing conditions (**Figure 14**); and iii) if a drain were installed then it's function would overlap with the function and effectiveness of a drain around the NCCI southern pit by lowering the gradient from west to east.

Model Sensitivity and Uncertainty

Subsurface data is always limited in spatial coverage and detail. Subsurface evaluations therefore involve several approximations and assumptions. A formal sensitivity analysis to compare a range of assumptions and combinations of assumptions would require a significant amount of time and budget, and yet there would still be some uncertainties.

Models include three types of error: 1) conceptual error (how the model is set up and what boundary conditions are used); 2) parametric error (how aquifer properties are measured and calculated); and 3) predictive error (which includes other influences such as seasonal recharge or climate change variations). It was beyond the scope of this project to quantitatively evaluate how the sum of these errors could affect the accuracy of our predictions. However, we feel the models are reasonably accurate and reliable because:

- The model aquifer input parameters (including ground and water table elevations, well data, and aquifer properties) were derived from reliable source such as State databases and US Geological Survey maps and reports;
- The aquifer boundary conditions and model conceptualization are relatively simple;
- The transient and steady state models used mostly the same boundary conditions, and both correspond reasonably well with reference maps and databases of water levels;
- We spent considerable time partially calibrating the transient model to seasonal monitoring well data and dewatering rates around the NCCI pit; and

- The models are consistent with other vicinity models we have created for other clients in that area.

Without an exhaustive and very expensive sensitivity analysis, our ability to provide uncertainty ranges for the modeled conditions is limited. If asked to speculate, however, we assume our model change results (mounding and shadowing) are accurate to within +/- 2 feet. Model accuracy for absolute elevations, however, is more difficult to predict since elevations depend on time of year and even year-to-year variations in weather, creek conditions, and nearby canal operations.

Finally, please note that actual construction, operation, and maintenance of a subsurface drain may be different than what is known or assumed at the time of our analysis. Future drain conditions are outside our scope and control.

CONCLUSIONS AND RECOMMENDATIONS

See the executive summary at the beginning of this report.

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REPORT FIGURES

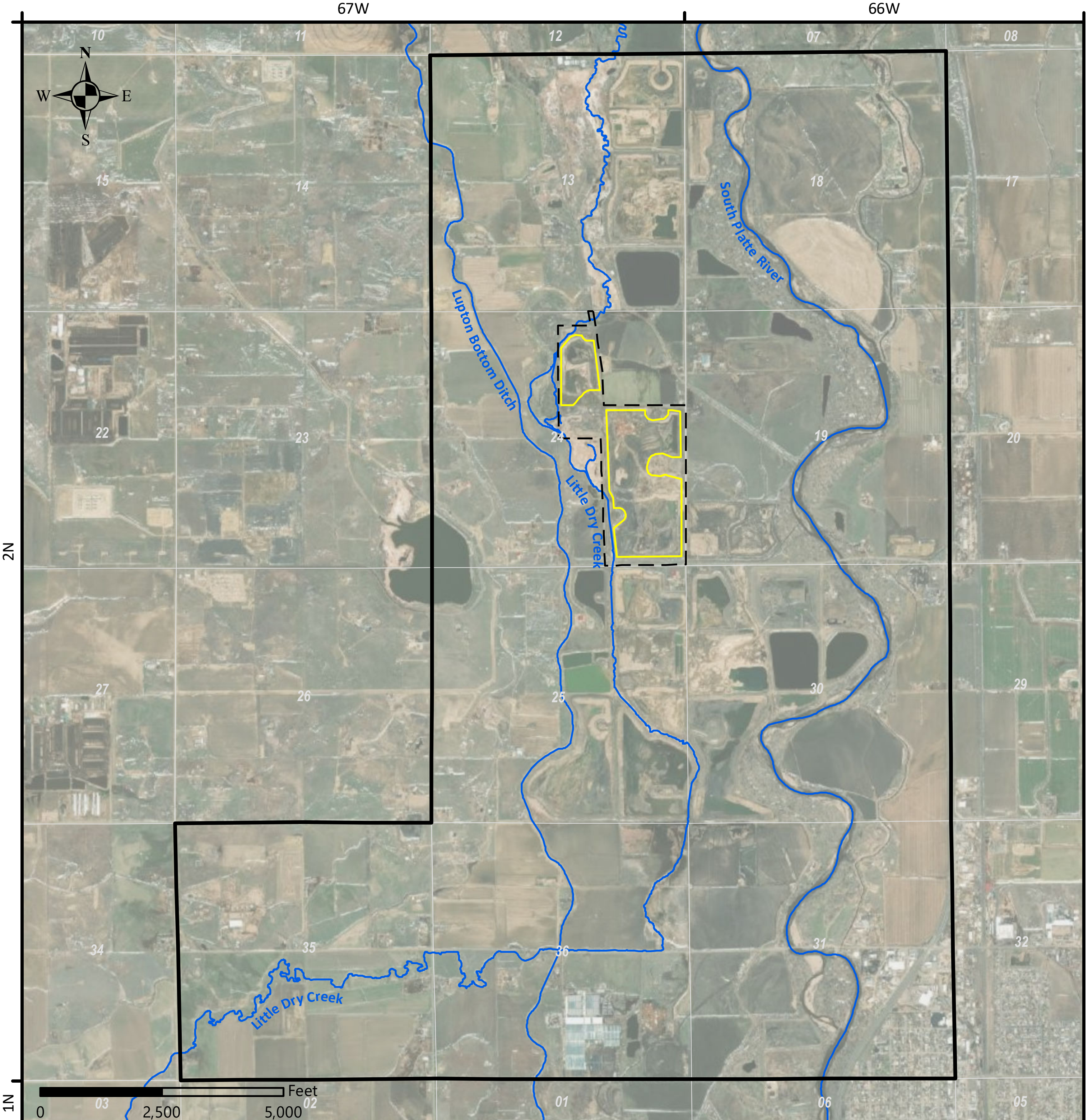


Figure 1
Study Area

NCCI Pit
Weld County, Colorado

Map Legend

NCCI Pit Study Area

Property Boundary

NCCI Pits

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), ESRI World Imagery (2018)

Date: November 17, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

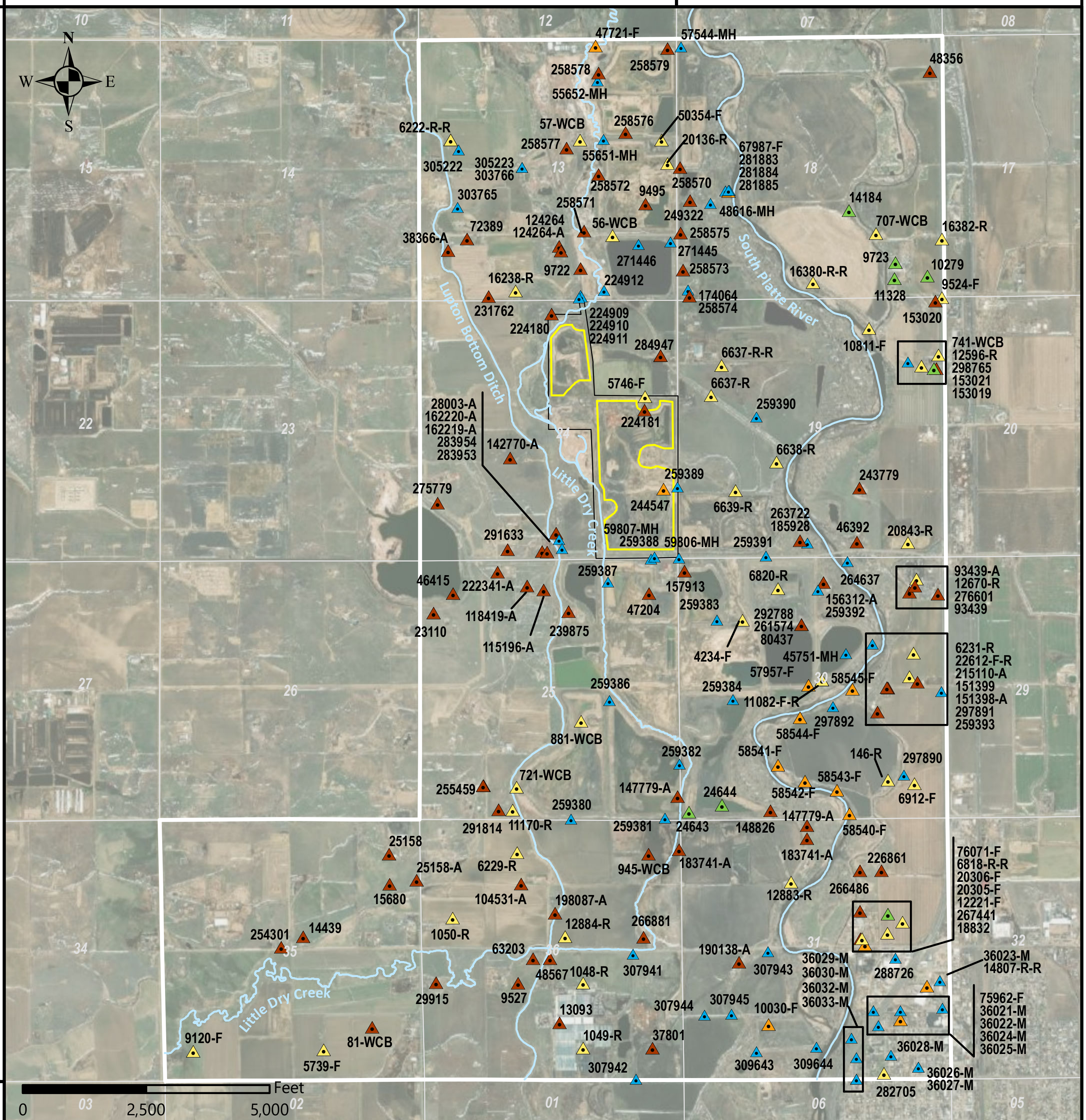


Figure 2
Study Area with DWR Wells

NCCI Pit
Weld County, Colorado

Map Legend

- NCCI Pit Study Area
- Property Boundary
- NCCI Pits

DWR Constructed Well (Well Type)

- Domestic/Household use only
- Municipal/Commercial/Industrial
- Irrigation
- Stock
- Monitoring/Sampling

Sources:
CDSS Well Permit Database 06.07.2020, J&T Consulting MW/Pit Location Drawings, NHD (photorevised), ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

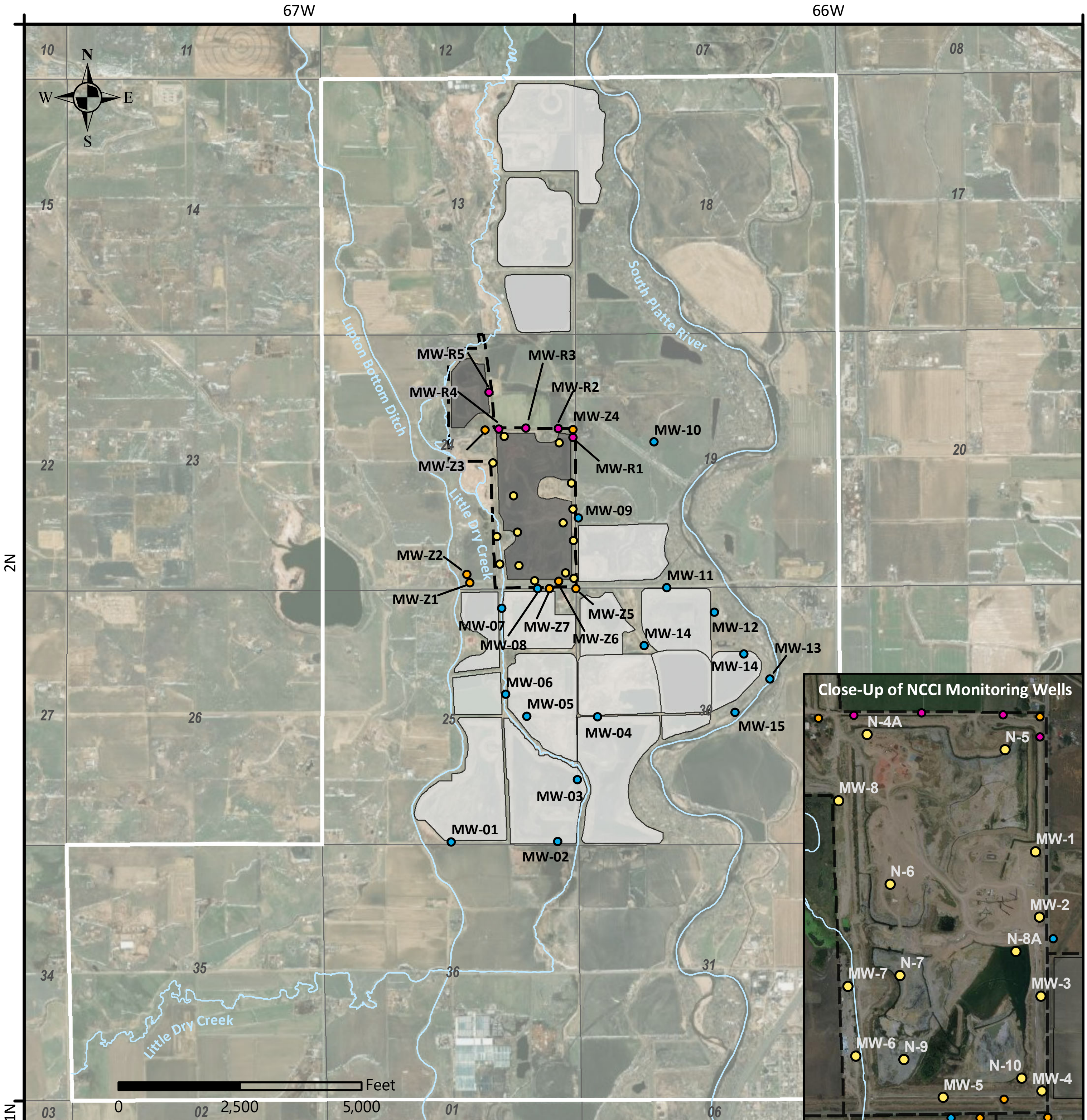


Figure 3
Monitoring Wells

NCCI Pit
Weld County, Colorado

Map Legend

- Property Boundary
- NCCI Pit Study Area
- NCCI Pits
- Adjacent Pit
- L.G. Everist Monitoring Well
- City of Thornton Monitoring Well (Z Wells)
- Rankin Monitoring Well
- NCCI Monitoring Well

Sources:
CDSS Well Permit Database 06.07.2020, J&T Consulting MW/Pit Location Drawings, NHD (photorevised), ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

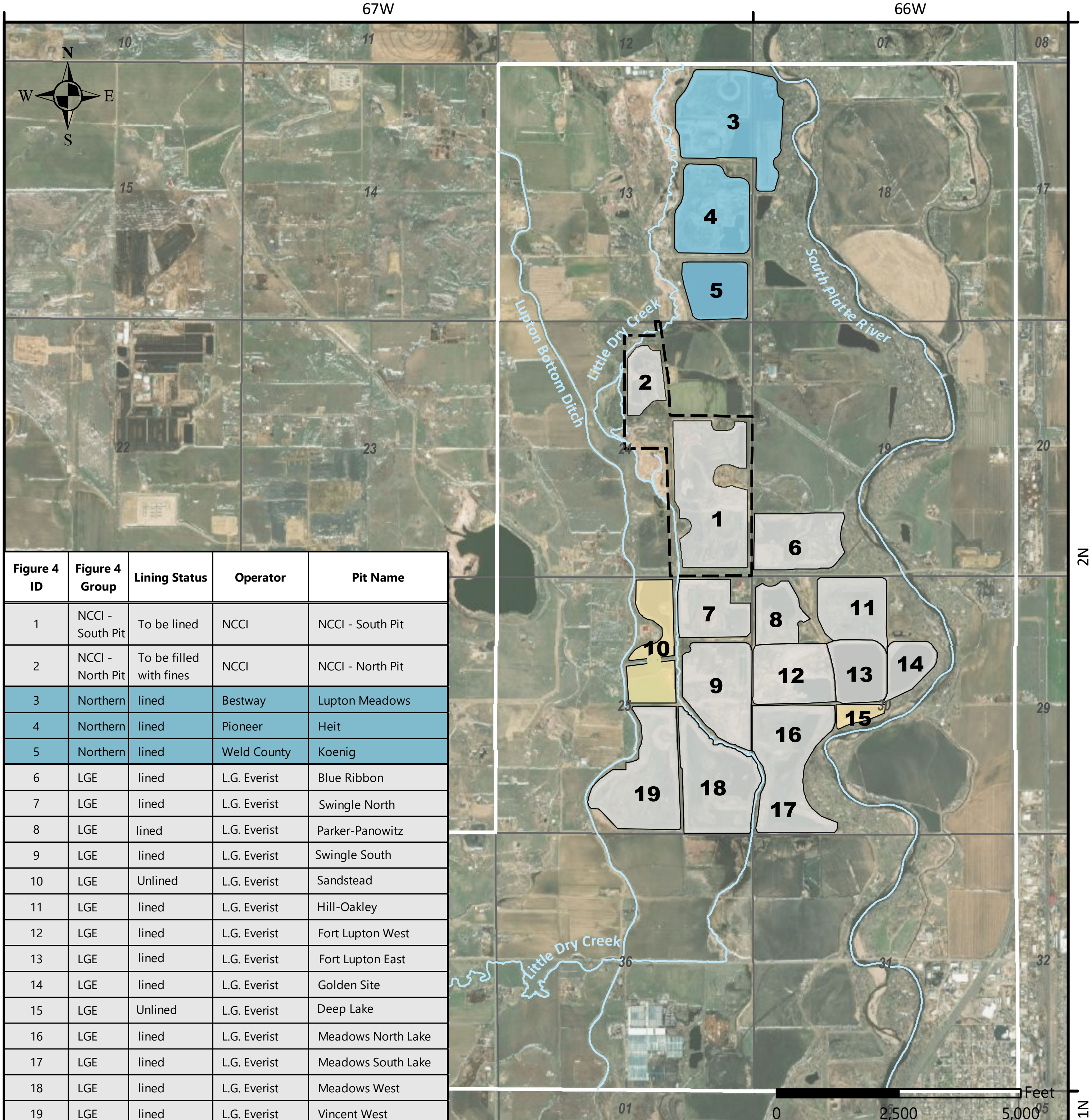


Figure 4 ID	Figure 4 Group	Lining Status	Operator	Pit Name
1	NCCI - South Pit	To be lined	NCCI	NCCI - South Pit
2	NCCI - North Pit	To be filled with fines	NCCI	NCCI - North Pit
3	Northern	lined	Bestway	Lupton Meadows
4	Northern	lined	Pioneer	Heit
5	Northern	lined	Weld County	Koenig
6	LGE	lined	L.G. Everist	Blue Ribbon
7	LGE	lined	L.G. Everist	Swingle North
8	LGE	lined	L.G. Everist	Parker-Panowitz
9	LGE	lined	L.G. Everist	Swingle South
10	LGE	Unlined	L.G. Everist	Sandstead
11	LGE	lined	L.G. Everist	Hill-Oakley
12	LGE	lined	L.G. Everist	Fort Lupton West
13	LGE	lined	L.G. Everist	Fort Lupton East
14	LGE	lined	L.G. Everist	Golden Site
15	LGE	Unlined	L.G. Everist	Deep Lake
16	LGE	lined	L.G. Everist	Meadows North Lake
17	LGE	lined	L.G. Everist	Meadows South Lake
18	LGE	lined	L.G. Everist	Meadows West
19	LGE	lined	L.G. Everist	Vincent West

Figure 4
Pit Modeling Groups

NCCI Pit
Weld County, Colorado

Map Legend

NCCI Pit Study Area
Property Boundary

Pit Modeling Groups
Northern Lined Pits
LGE Lined Pits
LGE Unlined Pits

Sources:
J&T Consulting Emails, NHD (photorevised), CO DRMS Database. ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

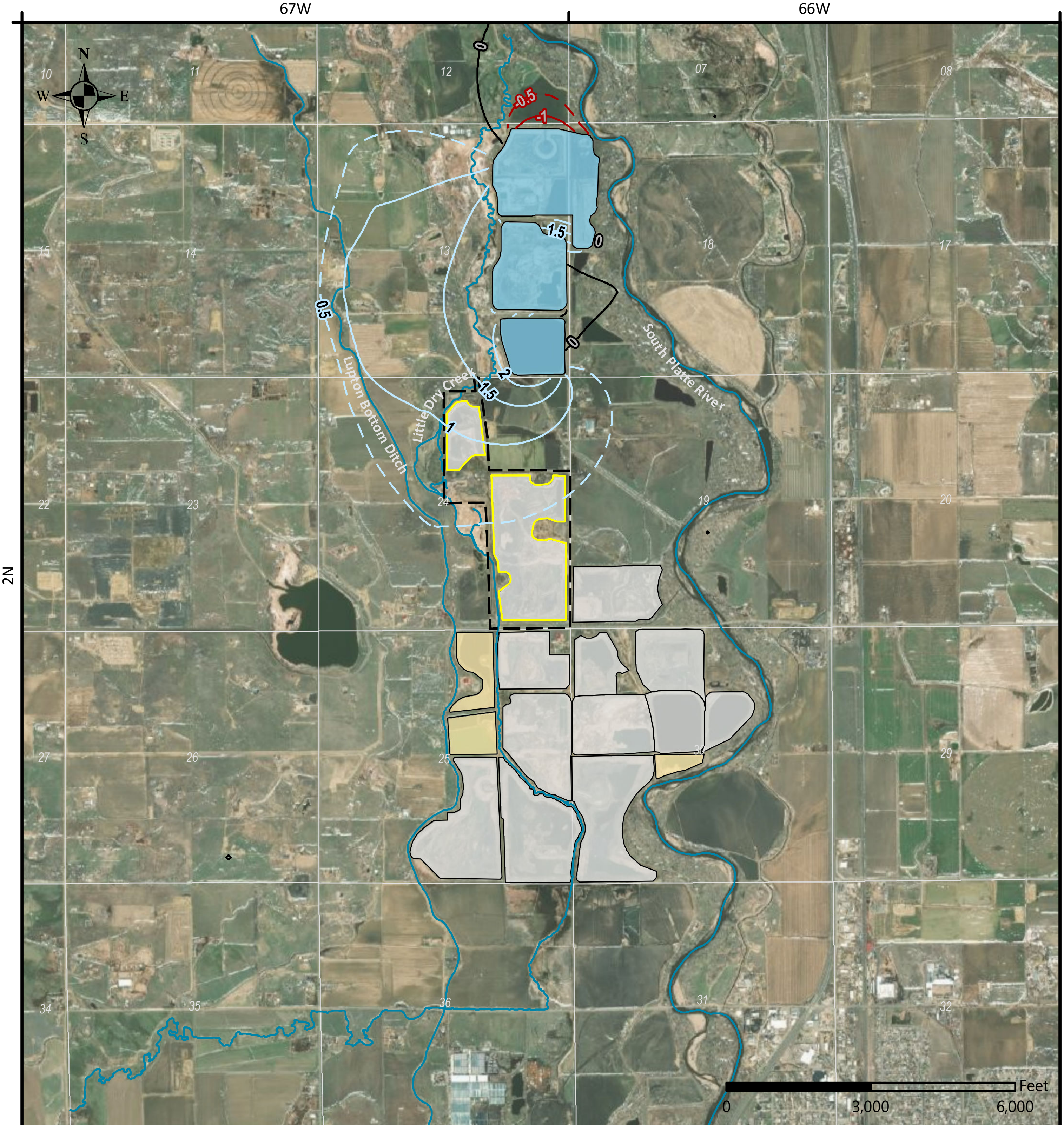


Figure 5
Water Level Changes Resulting from North Lined Pits (without NCCI Drain)

NCCI Pit
Weld County, Colorado

Map Legend

Property Boundary

NCCI Pits

Change in Water Level (feet)

- Water Level Decline
- No Change
- Water Level Increase

NCCI Pit and Adjacent Pits

- Northern Lined Pits
- LGE Lined Pits
- LGE Unlined Pits

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

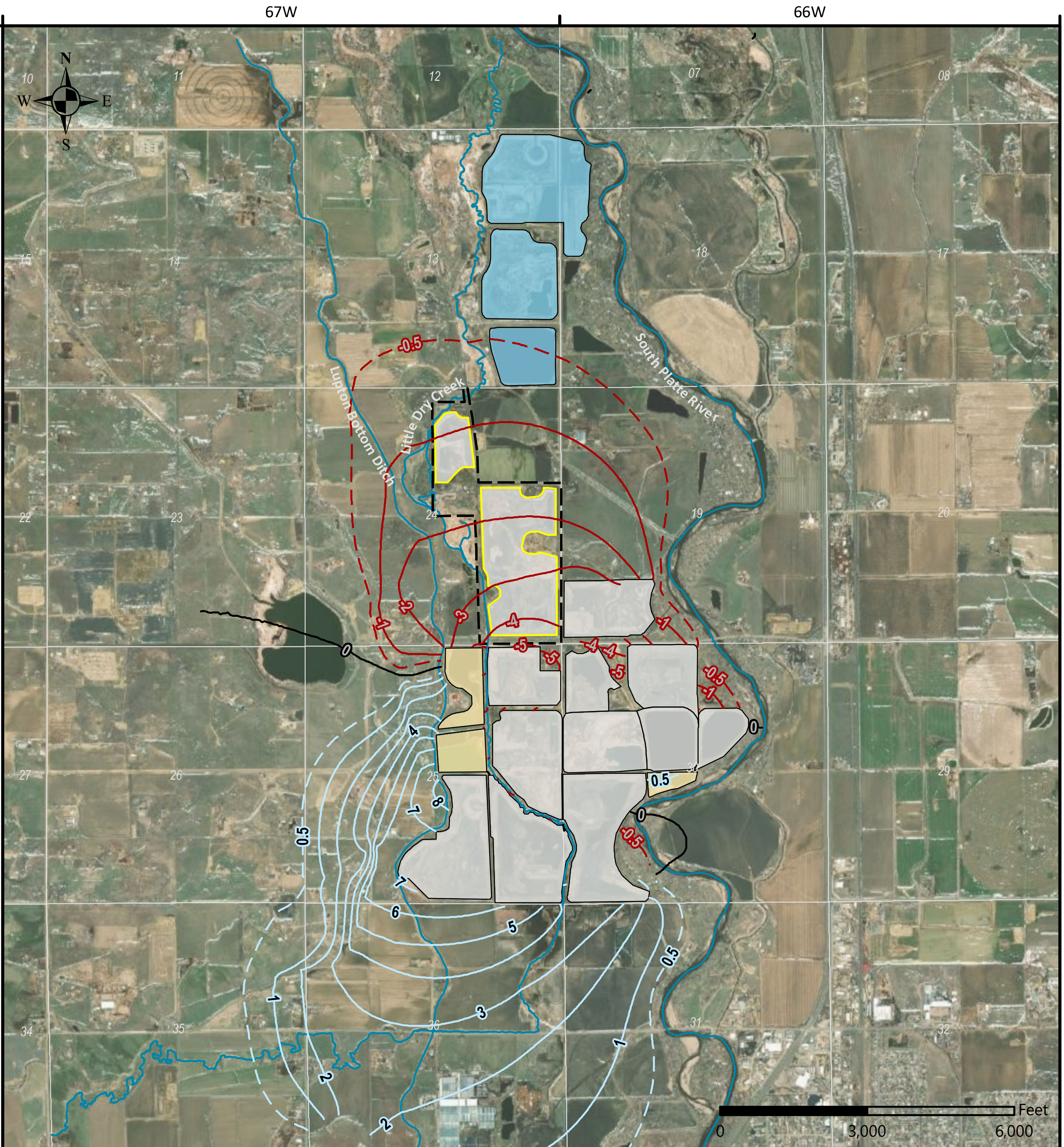


Figure 6
Water Level Changes Resulting from Existing LGE Pits (without NCCI Drain)

NCCI Pit
Weld County, Colorado

Map Legend

Property Boundary

NCCI Pits

Change in Water Level (feet)
- Water Level Decline
- No Change
- Water Level Increase

NCCI Pit and Adjacent Pits
- Northern Lined Pits
- LGE Lined Pits
- LGE Unlined Pits

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

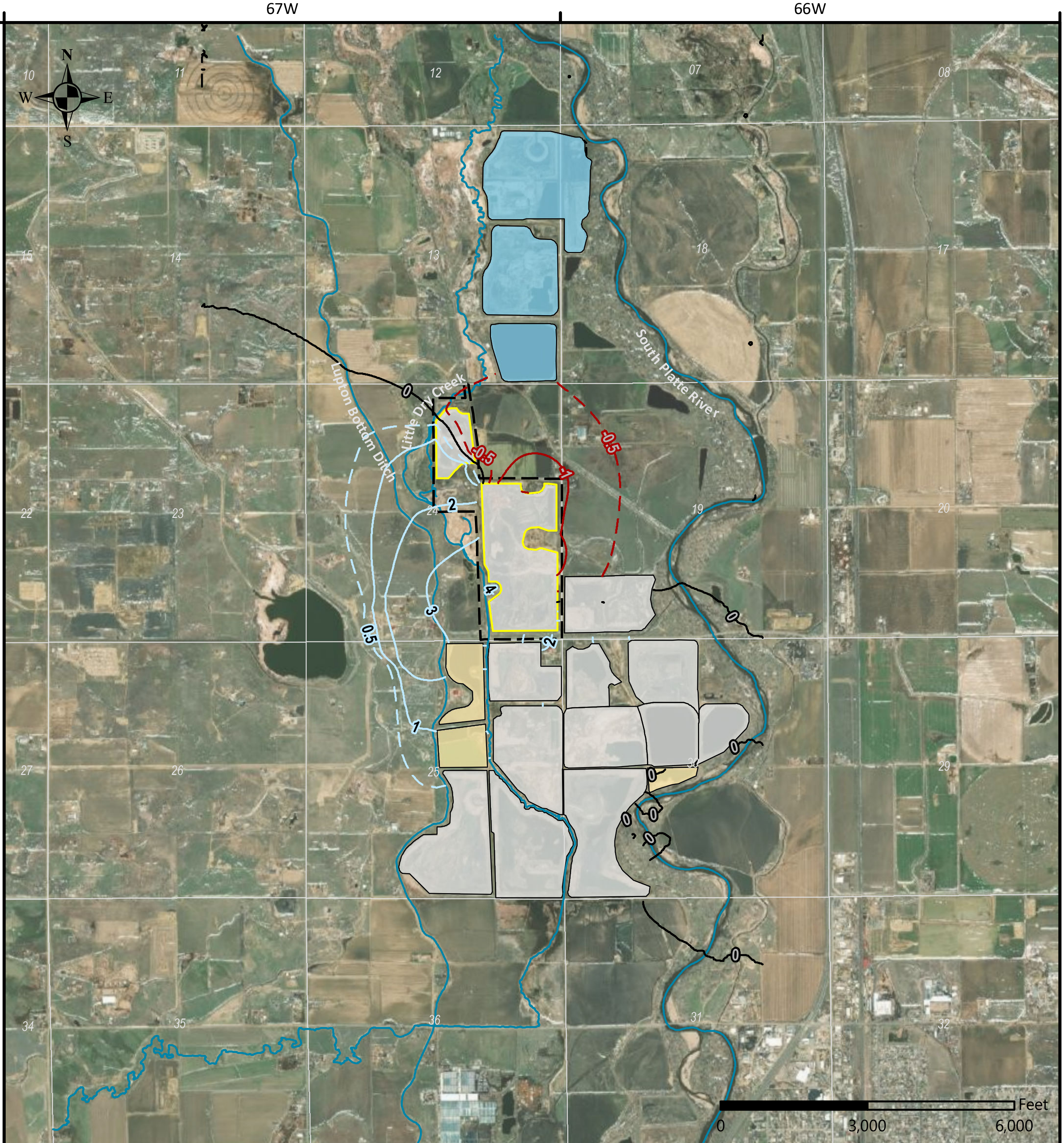


Figure 7
Water Level Changes Resulting from NCCI Lined Pits (without NCCI Drain)

NCCI Pit
Weld County, Colorado

Map Legend

Property Boundary

NCCI Pits

Change in Water Level (feet)
- Water Level Decline
- No Change
- Water Level Increase

NCCI Pit and Adjacent Pits
- Northern Lined Pits
- LGE Lined Pits
- LGE Unlined Pits

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

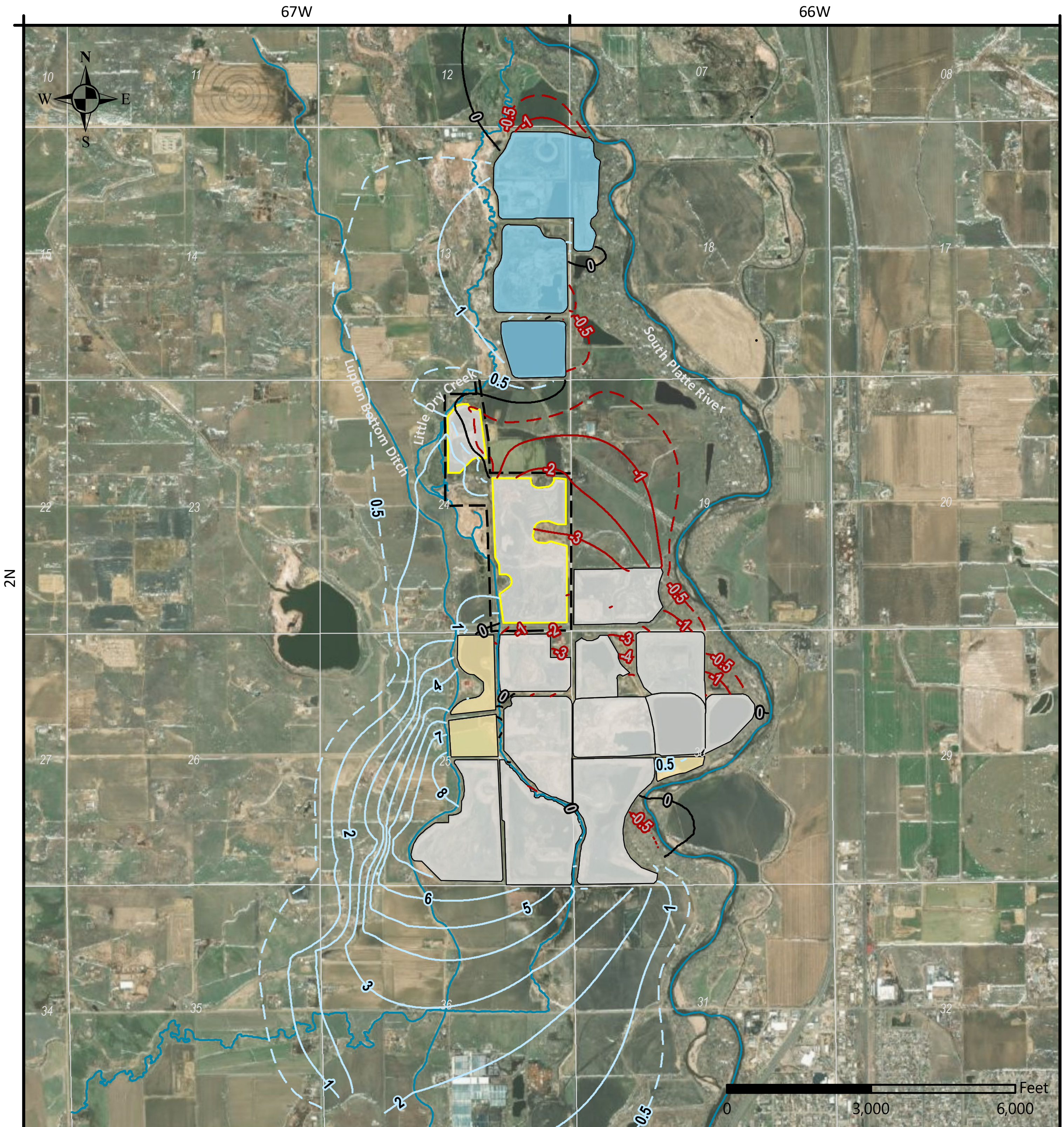


Figure 8
Water Level Changes Resulting from all Existing Pits - NCCI, North, and LGE (without NCCI Drain)

NCCI Pit
Weld County, Colorado

Map Legend

Property Boundary
NCCI Pits

Change in Water Level (feet)
- Water Level Decline
- No Change
- Water Level Increase

NCCI Pit and Adjacent Pits
- Northern Lined Pits
- LGE Lined Pits
- LGE Unlined Pits

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

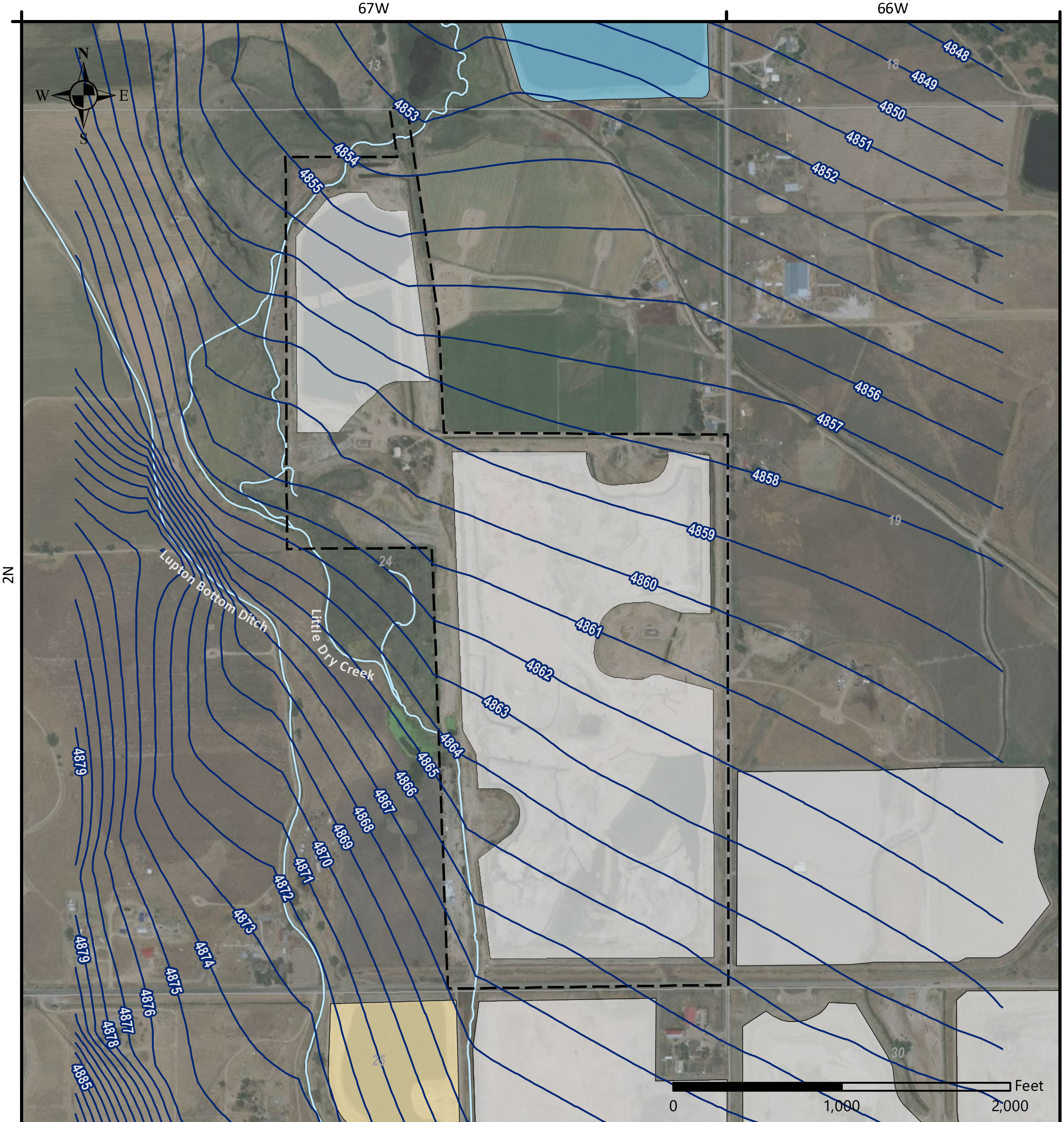


Figure 9
Baseline High (Summer)
Water Table

NCCI Pit
Weld County, Colorado

Map Legend

Property Boundary

Water Table Elevation Contour
Contour Interval = 1 foot

NCCI Pit and Adjacent Pits

Northern Lined Pit
LGE Lined Pits
LGE Unlined Pits

Note:
Map created from simulated July, 2019 water levels without NCCI pit pumping but with other lined vicinity pits.

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 17, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

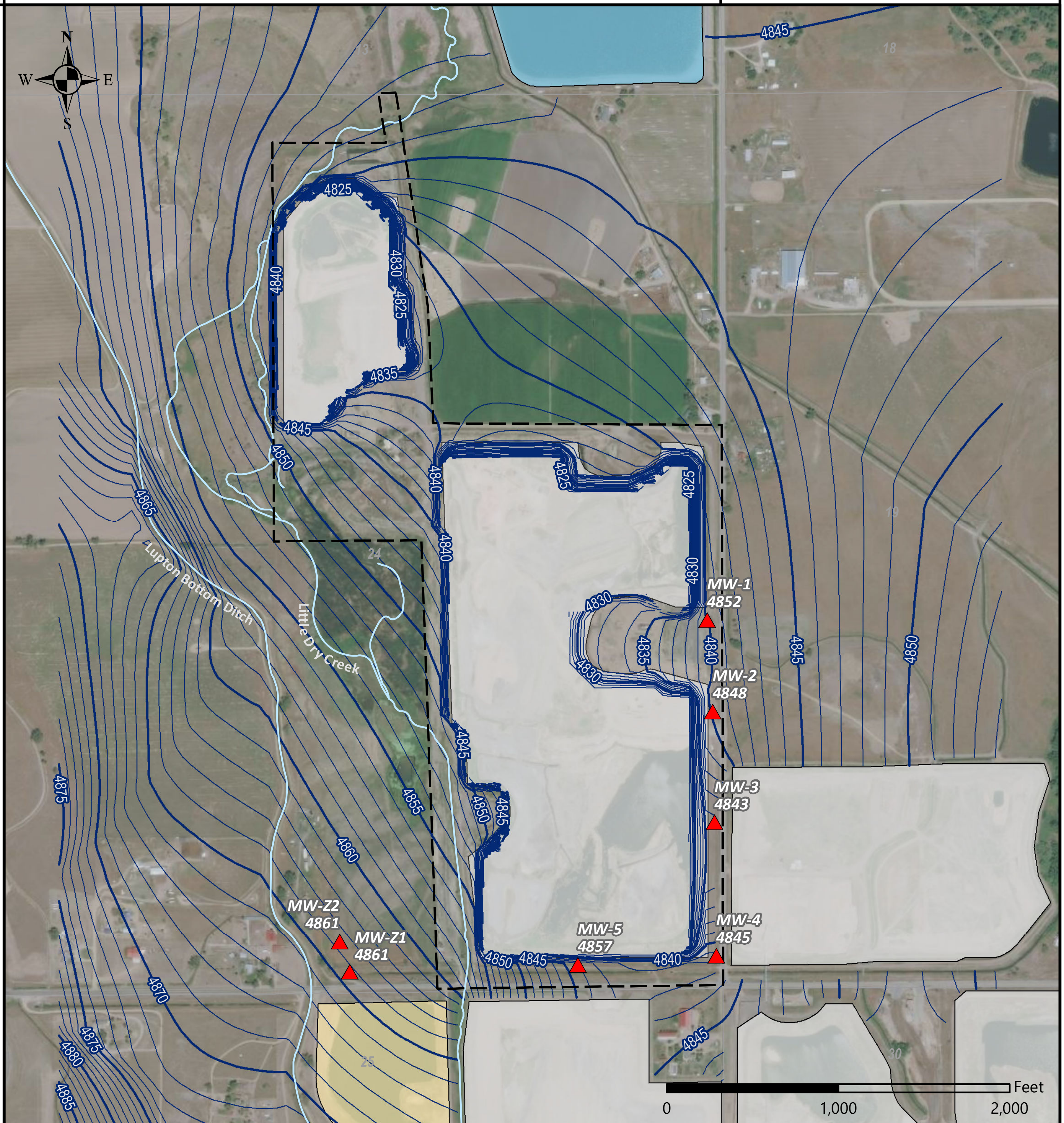


Figure 10
NCCI Pit Dewatering
Water Table -
Irrigation Season (Summer)

NCCI Pit
Weld County, Colorado

Map Legend

Property Boundary

Monitoring Well Measurement (July, 2019)

Water Table Elevation Contour
Contour Interval = 1 foot

NCCI Pit and Adjacent Pits

Northern Lined Pits

LGE Lined Pits

LGE Unlined Pits

Note:
Recent data shown from nearby monitoring wells at red symbols.
Extracted from transient model for July, 2020 time step.

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

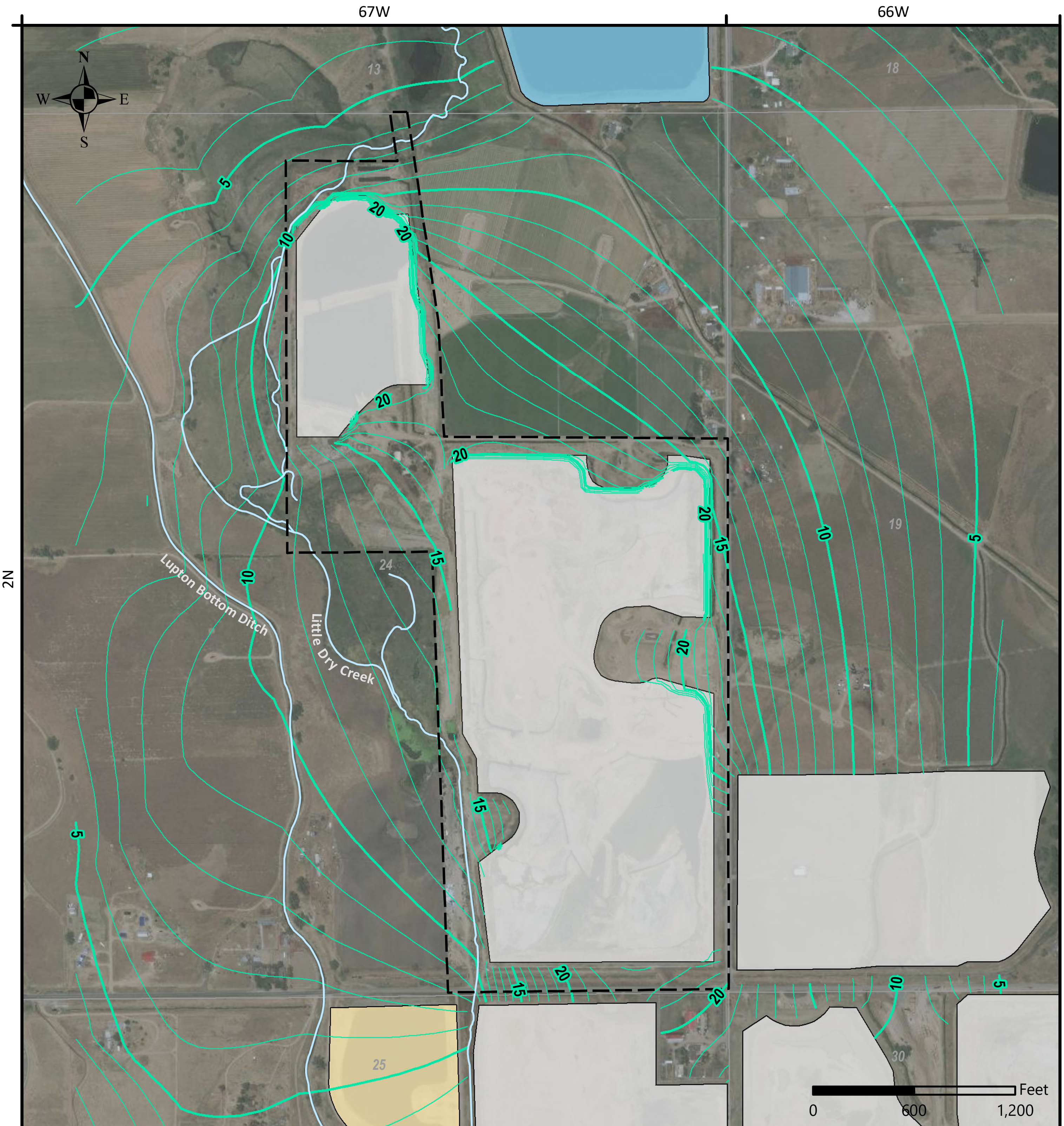


Figure 11
NCCI Pit Drawdown
Irrigation Season (Summer)

NCCI Pit
Weld County, Colorado

Map Legend

Property Boundary

Water Table Drawdown Contour (ft)
Contour Interval = 1 foot

NCCI Pit and Adjacent Pits

North Lined Pit
LGE Lined Pit
LGE Unlined Pit

Note:
Based on MWE "Baseline" Summer Water Table (Fig. 9) – "Dewatering" Water Table (Fig. 10).

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

Figure 12
NCCI Pit - Summer Water Table with Liner (no drain)

NCCI Pit
Weld County, Colorado

Map Legend

Property Boundary

Water Table Elevation Contour
Contour Interval = 1 foot

NCCI Pit and Adjacent Pits

Northern Lined Pits
LGE Lined Pits
LGE Unlined Pits

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

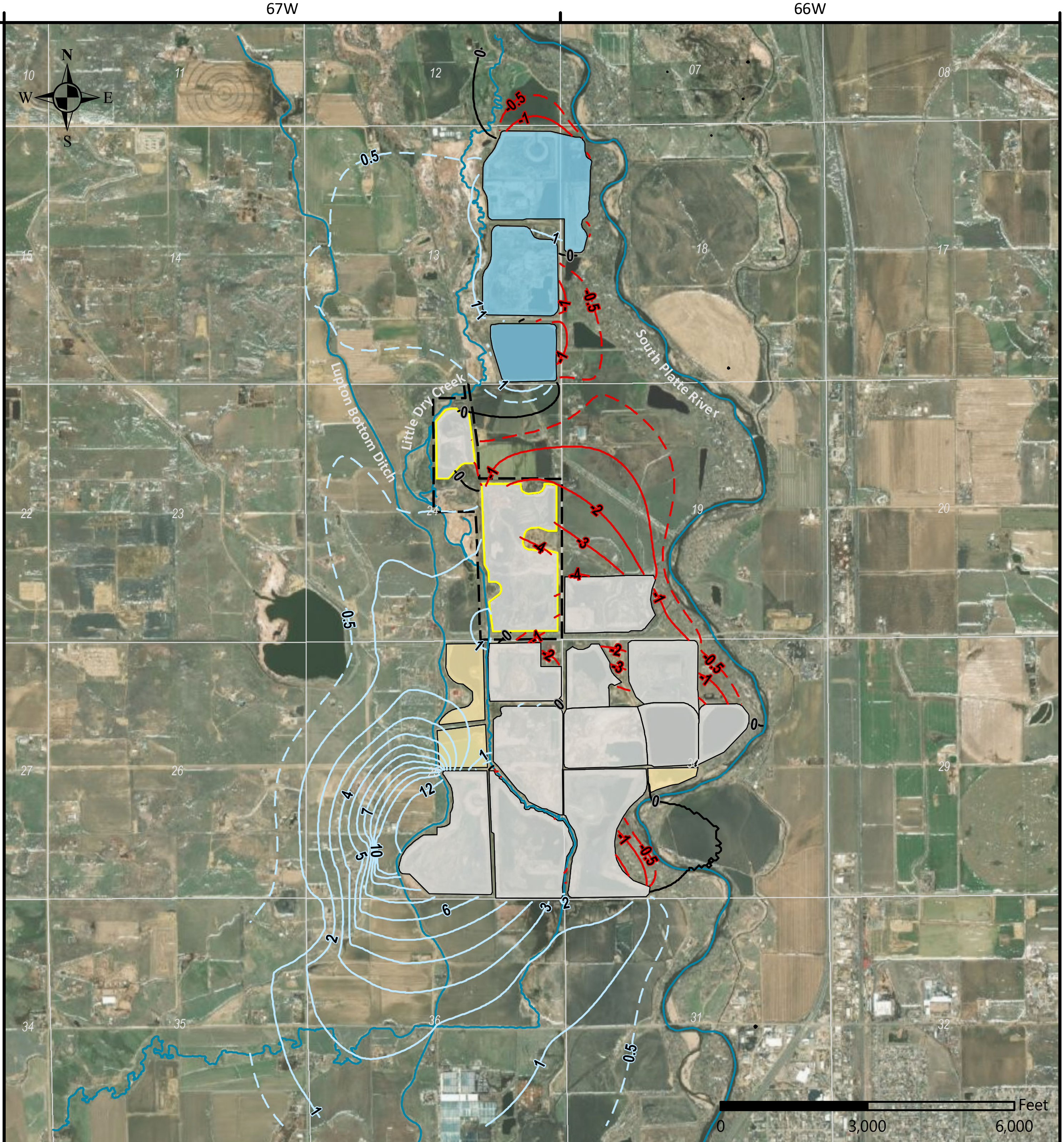


Figure 13
Summer Groundwater Level Change Caused by Existing pits (with NCCI liner, but no drain)

NCCI Pit
Weld County, Colorado

Map Legend

Property Boundary
NCCI Pit

Change in Water Level (feet)
- Water Level Decline
- No Change
- Water Level Increase

NCCI Pit and Adjacent Pits
- Northern Lined Pits
- LGE Lined Pits
- LGE Unlined Pits

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

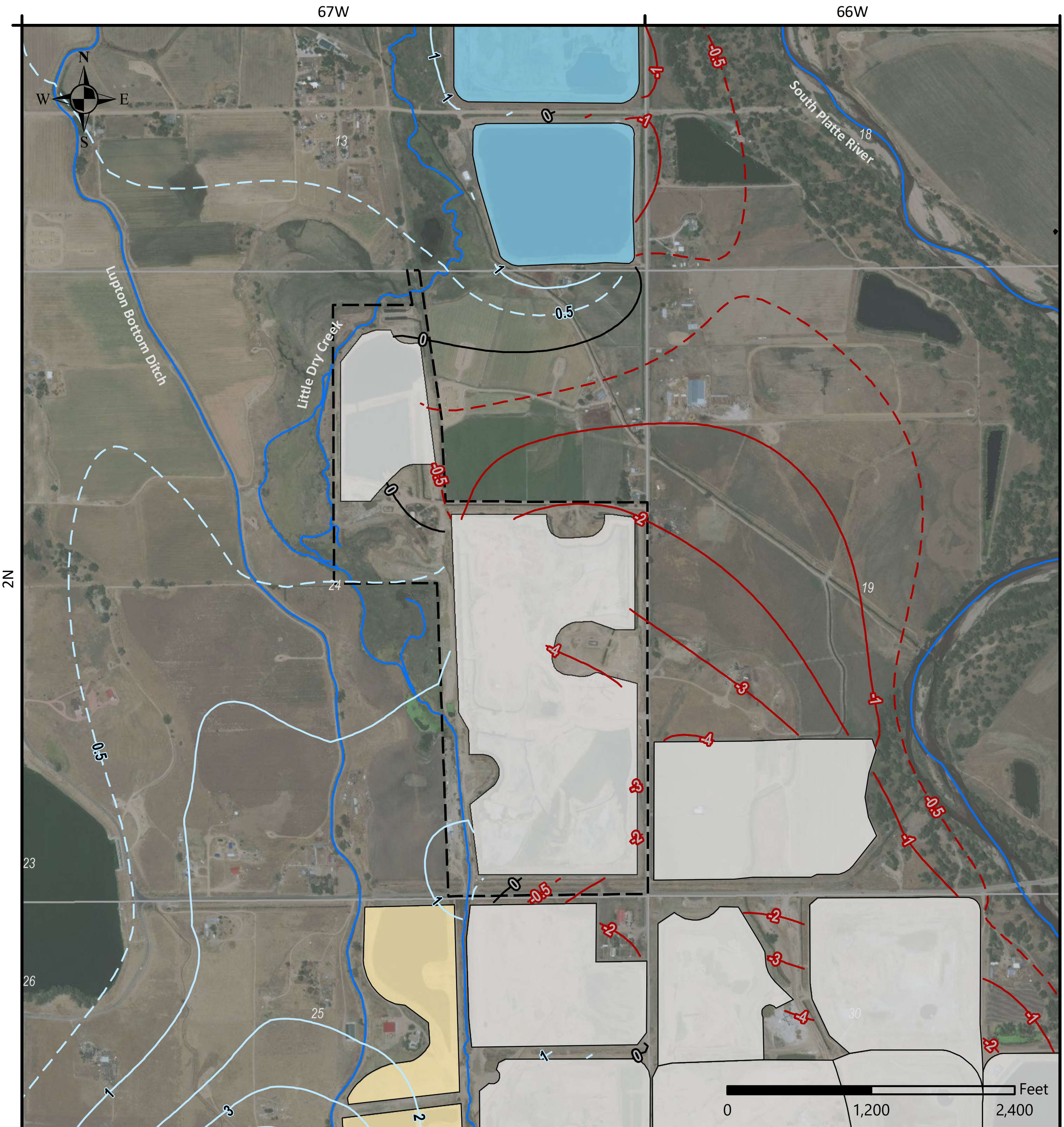


Figure 14
Summer Groundwater Level Change Caused by Existing pits (with NCCI liner, but no drain) – Zoomed
NCCI Pit
Weld County, Colorado

Map Legend

Property Boundary

Change in Water Level (feet)
- Water Level Decline
- No Change
- Water Level Increase

NCCI Pit and Adjacent Pits
- Northern Lined Pits
- LGE Lined Pits
- LGE Unlined Pits

Notes:
Contours show water level change in feet (model simulation) for summer (high) water level conditions. Red contours show decline (shadowing), light blue contours show rise (mounding).

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

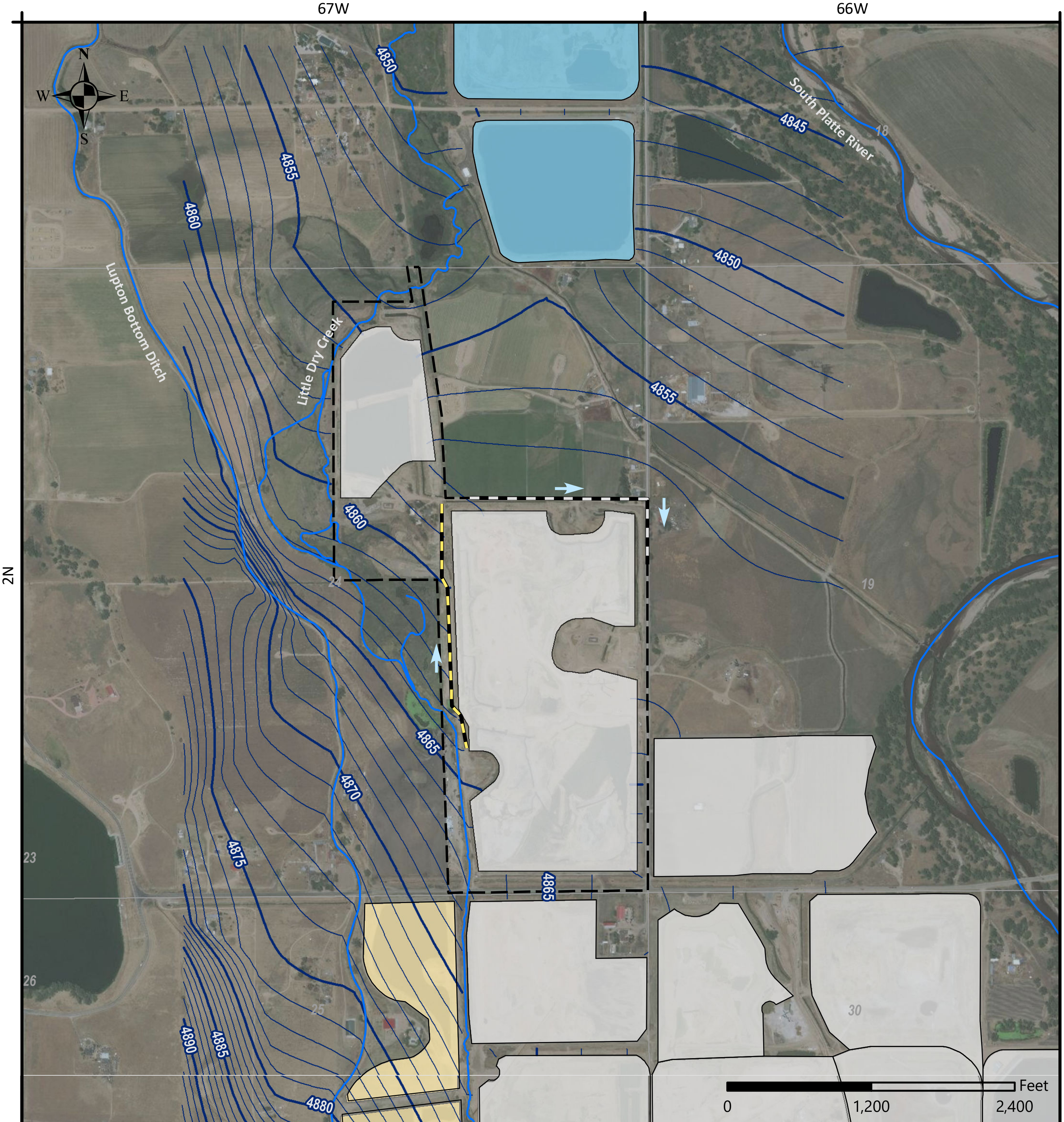


Figure 15
NCCI On-Site Drain - Summer Water Table

NCCI Pit
Weld County, Colorado

Map Legend

- Property Boundary
- Flow Direction
- Perforated Drain
- Perforated Re-Infiltration Pipe
- Water Table Elevation Contour
  Contour Interval = 1 foot

NCCI Pit and Adjacent Pits

- Northern Lined Pits
- LGE Lined Pits
- LGE Unlined Pits

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 13, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

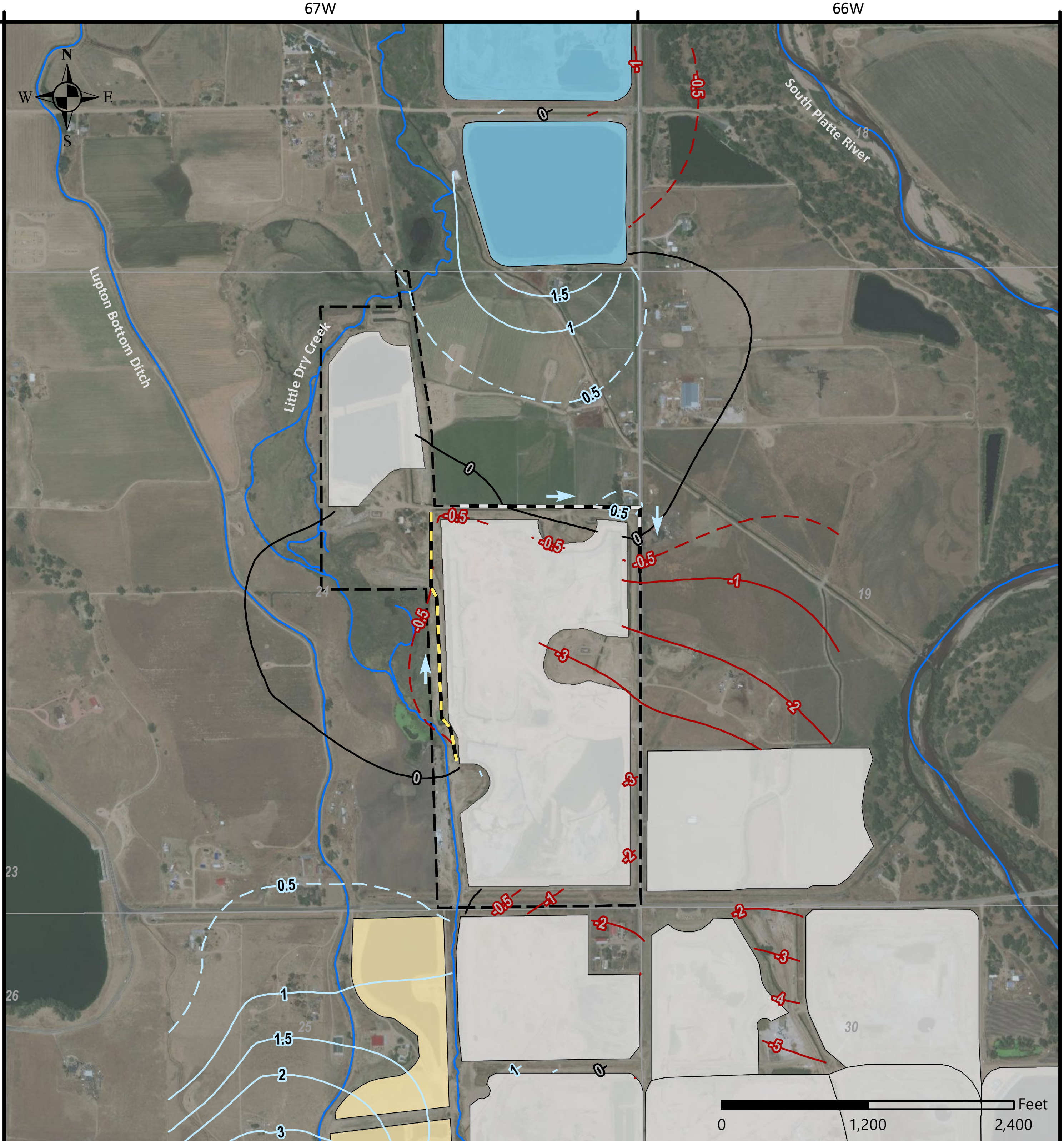


Figure 16
NCCI On-Site Drain -
Summer Residual Drawdown

NCCI Pit
Weld County, Colorado

Map Legend

Property Boundary
Flow Direction
Perforated Drain
Perforated Re-Inflitration Pipe

Change in Water Level (feet)
Water Level Decline
No Change
Water Level Increase

NCCI Pit and Adjacent Pits
Northern Lined Pits
LGE Lined Pits
LGE - Unlined PIts

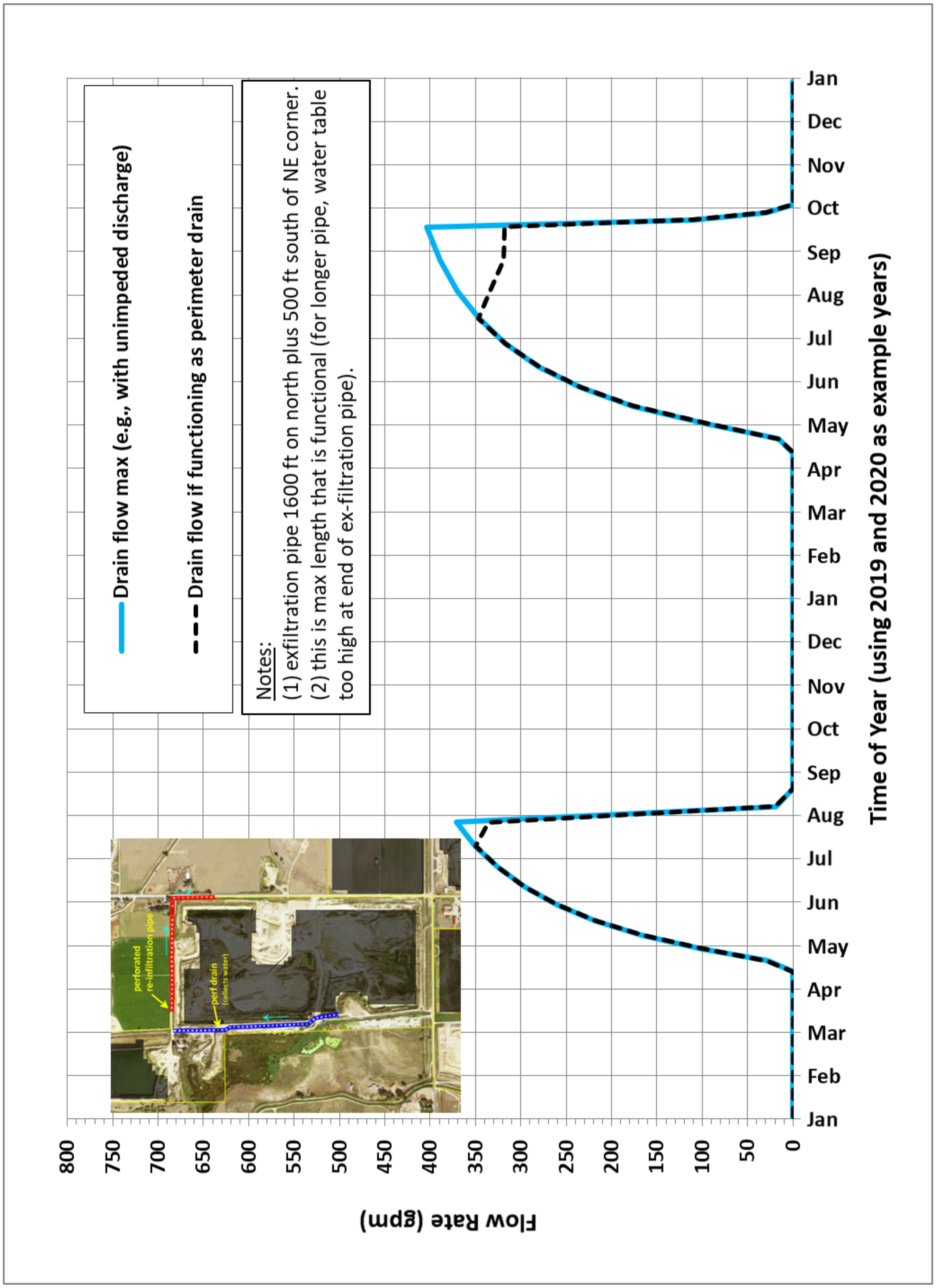
Note: Calculated by subtracting on-site drain run elevations from baseline summer water table (Fig. 15 - Fig. 9).

Sources:
J&T Consulting MW/Pit Location Drawings, NHD (photorevised), Modeling Contour Exports (20201112)
ESRI World Imagery (2018)

Date: November 17, 2020
Datum/Projection: NAD83/Colorado State Plane North, feet

McGrane Water Engineering, LLC

Figure 17 – Modeled Seasonal Drain Flow



REPORT TABLES

Table 1 – Pit Group Impacts

Figure 1 ID	Figure 1 Group Color	Operator	Pit Name
1	NCCI - South Pit	NCCI	NCCI - South Pit
2	NCCI - North Pit	NCCI	NCCI - North Pit
3	North - lined	Bestway	Lupton Meadows
4	North - lined	Pioneer	Heit
5	North - lined	Weld County	Koenig
6	LGE-lined	L.G. Everist	Blue Ribbon
7	LGE-lined	L.G. Everist	Swingle North
8	LGE-lined	L.G. Everist	Parker-Panowitz
9	LGE-lined	L.G. Everist	Swingle South
10	LGE-Unlined	L.G. Everist	Sandstead
11	LGE-lined	L.G. Everist	Hill-Oakley
12	LGE-lined	L.G. Everist	Fort Lupton West
13	LGE-lined	L.G. Everist	Fort Lupton East
14	LGE-lined	L.G. Everist	Golden Site
15	LGE-Unlined	L.G. Everist	Deep Lake
16	LGE-lined	L.G. Everist	Meadows North Lake
17	LGE-lined	L.G. Everist	Meadows South Lake
18	LGE-lined	L.G. Everist	Meadows West
19	LGE-lined	L.G. Everist	Vincent West

Source: J&T Consulting, LLC, personal communications, June-July 2020