Resilient St. Vrain Project - City Reach 3 Conceptual Design Options (Final)

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Background and Purpose

St. Vrain Creek, which flows through the City of Longmont (City), experienced a major flood event in September 2013. Rain fell over a period of a week in the upstream watershed and caused extensive flooding in many areas, including areas within the City limits. The flow in the City exceeded the channel capacity, causing water to overflow the banks in several locations, resulting in significant flooding and damage. The Resilient St. Vrain Project (RSVP) has been undertaken by the City to repair damage caused by the flood, improve the channel to provide more resiliency to future flood events, and complete the improvements in the most environmentally sensitive manner possible.

The purpose of this technical memorandum is to document the City Reach 3 Conceptual Design Options for future consideration. This reach begins at Airport Road at the upstream end, collects flow from Lykins Gulch, crosses Hover Street, continues through Roger's Grove Nature Area (Roger's Grove), and terminates at Sunset Street.

The City Reach 3 conceptual design documented herein was performed to address and provide the following:

- Incorporate the City's latest City Reach 3 options for future consideration.
- Develop a phased City Reach 3 approach to enable construction of project components as funding becomes available.
- Update the hydraulic models and corresponding floodplain limits.
- Determine land impacts.
- Update the construction cost estimates.

Per coordination with the City, this analysis focuses on the Airport Road area and south bank flooding from Lykins Gulch to Sunset Street. Other key components of the project outside of the City Reach 3 area are noted, as follows:

- Downstream of City Reach 3, flooding on the north bank of St. Vrain Creek is due to floodwaters exiting the northeast side of Izaak Walton Pond. This area is being investigated by the City and the U.S. Army Corps of Engineers (USACE) as part of a Section 205 project detailed below.
- The Beckwith Ditch diversion structure upstream of Lykins Gulch is a fish passage barrier on St. Vrain Creek. The City, Colorado Parks and Wildlife (CPW), and others may partner in the future to address the desired improvements near Beckwith Ditch.

Reach Naming Convention

As part of the RSVP, the creek corridor was separated into several reaches for analysis, design, construction, and consistency with grant funding, as follows:

- Sandstone Ranch Reach: County Line Road to the confluence of St. Vrain Creek and Boulder Creek.
- City Reach 1: Left Hand Creek to Main Street.
- City Reach 2: Main Street to Sunset Street, which includes the following sub-reaches:
    - City Reach 2A: Main Street to Colorado Way.
    - City Reach 2B: Colorado Way to approximately 500 feet upstream of the BNSF Railway Bridge.
    - Izaak Walton Reach 1: Approximately 500 feet upstream of the BNSF Railway Bridge to downstream of Boston Avenue.
    - Izaak Walton Reach 2: Downstream of Boston Avenue to Sunset Street.
- City Reach 3: Sunset Street to Airport Road.

2013 Flooding

During the 2013 flood, the overbank flooding was extensive and split flows occurred due to the lack of capacity in the St. Vrain Creek main channel. A split flow occurred approximately 1,500 feet upstream of Hover Street, and the flow continued to the south and east, overtopping Hover Street, Rogers Road, and Boston Avenue. This split flow caused significant problems in the City by preventing emergency access via Hover Street and by flooding low areas south of the creek that could not drain back to St. Vrain Creek. This split flow would be expected to occur in a storm with flows greater than the 50-year flow rate.

Both the Sunset Street bridge and the Roger's Grove pedestrian bridge were washed out during the 2013 flood. The Sunset Street bridge was replaced in 2016, and a pedestrian bridge salvaged from a downstream reach was installed in Roger's Grove the same year.

St. Vrain Creek Hydrology

Following the September 2013 flood, the Colorado Department of Transportation (CDOT) requested a study of several of the flooded tributaries, including St. Vrain Creek. The study, entitled "*Lower St. Vrain Watershed Phase 2 Hydrologic Evaluation Post September 2013 Flood Event*" (CDOT Hydrology Report), was finalized in July 2015 (Jacobs, 2015). It is noted that this report was issued by Jacobs prior to the merger of Jacobs and CH2M HILL. The study was officially adopted by the Colorado Water Conservation Board (CWCB) in July 2015 as the new effective flow rates for St. Vrain Creek. The flow rates have also been adopted by the Federal Emergency Management Agency (FEMA) as the best available data for St. Vrain Creek and should be used for all floodplain modeling efforts. As a result of the study, the 100-year flow rates for St. Vrain Creek increased approximately 50% at several locations. The 100-year flow rates at key locations in City Reach 3 are presented below in **Table 1**, per Table 7 of the CDOT Hydrology Report.

Table 1. 100-Year Flow Rates (per CDOT Hydrology Report Table 7)

Description / Location	100-Year Flow Rate (cfs)
St. Vrain Creek at Airport Road	13,200
St. Vrain Creek at Golden Ponds	14,400
St. Vrain Creek at Hover Street	14,500
St. Vrain Creek Above Dry Creek #1 Confluence	14,500
St. Vrain Creek at BNSF Railway	15,200

City Reach 3 Current Development Conditions

In the upstream portion of City Reach 3, the creek is bound on both the north and south banks by existing ponds. Upstream of Hover Street, developed properties are located on both the north and south sides of the creek. Downstream of Hover Street, Roger's Grove is located to the south and the BNSF Railway is located to the north. The creek is bound by partially developed land east of Roger's Grove to Sunset Street. This reach is generally highly vegetated, especially in Roger's Grove. **Figure 1** illustrates the current development conditions and identifies private parcels per the 2018 Boulder County Assessor database.

Previous Investigations and Deliverables

2014 Conceptual Design

Prior to the 2013 flood, the existing St. Vrain Creek channel did not have capacity to convey the 100-year flow rate. During the 2013 flood, flooding occurred beyond the floodplain limits shown on the FEMA Flood Insurance Rate Map (FIRM) for the City. Due to the flooding and erosion throughout the watershed, the flood deposited sediment in reaches of St. Vrain Creek within the City limits that further reduced the capacity of St. Vrain Creek.

In 2014, CH2M performed a series of high-level analyses to calculate the potential flood conveyance capacity of St. Vrain Creek from Lykins Gulch to Left Hand Creek and determine a path forward for repair and replacement of damaged infrastructure and facilities. The 2014 analyses used post-flood topography and flow rates from the 2012 FEMA flood insurance study and determined that widespread flooding was expected not only in a 100-year storm, but also at more frequent flood recurrence events. After this initial analysis, the CDOT Hydrology Report was issued. The 2014 analyses were subsequently revised to incorporate the new flow rates.

The 2014 analyses determined that containment of the 100-year flow rate was feasible by constructing a larger channel and improving bridge capacities. The analyses were based on general parameters that would be refined in future design phases. The City Reach 3 channel capacity analysis was based on the following parameters:

- A channel longitudinal slope between 0.3 and 0.4 percent.
- Two large, grouted-boulder drop structures between Hover Street and Sunset Street to achieve the longitudinal slope and channel capacity.
- A multi-stage/tiered trapezoidal channel cross-section with bottom widths varying from approximately 200 feet to 600 feet and side slopes of 3 horizontal to 1 vertical (3H:1V).

The 2014 analyses are documented in the *St. Vrain Creek Through Longmont: 100-Year Analysis and Conceptual Design* (CH2M, 2014).

RSVP Alternatives Analysis

In June of 2015, an alternatives analysis of City Reach 3 was conducted as part of the RSVP, titled *Draft St. Vrain Creek Improvement Project – Alternatives Analysis* (CH2M, 2015a). At that time, the draft CDOT Hydrology Report had been published and flow rates were refined again for this analysis. Three alternatives were evaluated for St. Vrain Creek between Airport Road and Lykins Gulch. The alternatives included the following:

- Alternative 1-1 – Overtopping of Airport Road: Construct a new flood flow crossing of Airport Road in the south overbank of St. Vrain Creek. Construct a split flow path from the south overbank back to the main channel through pond overtopping and channelization.
- Alternative 1-2 – New Bridge Crossing: Allow Airport Road to overtop. Construct a split flow path from the south overbank back to the main channel through pond overtopping and channelization.
- Alternative 1-3 – Do Nothing Alternative: Do not construct improvements and allow Airport Road to overtop and capture downstream flooding in Lykins Gulch.

Four alternatives were analyzed for the creek between Lykins Gulch and Roger's Grove to eliminate the overtopping of Hover Street and flooding south of Roger's Grove. The alternatives included the following:

- Alternative 2-1 – Widening of Channel and Bridge: Increase the capacity of St. Vrain Creek and Hover Street bridge. This is similar to the single thread channel option described below.
- Alternative 2-2 – Split Flow and Flood Channel Crossing of Hover Street: Formalize split flows from St. Vrain Creek by conveying the flows through existing ponds south of the creek and constructing a new bridge at Hover Street approximately 1,000 feet south of the existing bridge.
- Alternative 2-3 - Split Flow and Crossing of Hover Street without Flood Channel: Construct a new bridge at Hover Street approximately 1,000 feet south of the existing Hover Street bridge, and do not construct channel improvements.
- Alternative 2-4 – Split Flow Through Lykins Gulch Pond and Flood Channel Crossing of Hover Street: Formalize split flows from St. Vrain Creek through a new high-flow channel, beginning just downstream of the St. Vrain Creek and Lykins Gulch confluence, through a series of existing ponds south of the creek and construct a new bridge at Hover Street.

As part of the alternatives analysis, the alternatives were analyzed for sustainability using the City's Sustainability Evaluation System and a high-level review of the national Envision process by the Institute for Sustainable Infrastructure. Considerations in the analysis included the extent of earthwork grading required, impacts to sensitive vegetated areas in Roger's Grove, property impacts, and possible regulatory levee or dam conditions. The alternatives analysis was documented in the *Draft St. Vrain Creek Improvement Project – Alternatives Analysis* (CH2M, 2015a). The draft report was not finalized, enabling future revisions to the alternatives.

In November of 2015, additional analysis was conducted for the Hover Street alternatives. The analysis was based on approximate hydraulic modeling and did not include grading plans or other refinements that are included in this analysis. Eleven alternatives were considered as summarized below and included in **Attachment A**.

- Alternative 1A: Single Thread With Levee
- Alternative 1B: Single Thread Without Levee
- Alternative 1C: Single Thread No Levee (with a large drop structure downstream of Hover Street)
- Alternative 2A: Split Flow Upstream of Hover Street With Levee
- Alternative 2B: Split Flow Upstream of Hover Street Without Levee [selected as a preferred alternative]
- Alternative 3A: Split Flow Downstream of Hover Street With Levee
- Alternative 3B: Split Flow Downstream of Hover Street Without Levee
- Alternative 3C: Split Flow Downstream of Hover Street (with a large drop structure downstream of Hover Street)
- Alternative 3D: Lowered Overbank Downstream of Hover Street (with a large drop structure downstream of Hover Street)
- Alternative 3E: Lowered Overbank Downstream of Hover Street (without a large drop structure downstream of Hover Street)
- Alternative 3F: Lowered Overbank Downstream of Hover Street (with additional northeast overbank grading) [selected as a preferred alternative]

The City determined at that time that Alternatives 2B and 3F were preferred. The analysis documented below builds upon that analysis and incorporates the City's latest preferences.

The alternative naming convention used in 2015 as described above does not correlate to the naming convention used in the revised alternatives described below.

RSVP Permitting

In 2016, as part of the RSVP, an Environmental Assessment was completed by FEMA pursuant to requirements of the National Environmental Policy Act of 1969 (NEPA), for projects funded or approved by federal agencies. A Finding of No Significant Impact (FONSI) was issued for the RSVP, including creek and infrastructure improvements from Airport Road downstream to Highway 119 near the confluence of St. Vrain Creek and Boulder Creek (FEMA, 2016). The NEPA process approved the following general proposed actions:

- Channel widening and stabilization
- Reestablishment of diversion structures
- Fish passage and bank stabilization
- Revegetation and water quality improvements
- Construction of park amenities and pedestrian bridges
- Utility and trail improvements
- Other related improvements

Specific to City Reach 3, two design options were evaluated as part of the NEPA proposed action:

Option 1 – Single Thread Channel was a single-thread, channel-widening project, including constructing a new Hover Street bridge and a new pedestrian bridge, lowering the overbanks in Roger's Grove, and preserving strategic high-value trees.

Option 2 – Split-Flow Channel was a split flow option that included a weir to split the flow to the south near Lykins Gulch, improvements to convey flow through the existing ponds west of Hover Street, and a new structure at Hover Street to connect the split flow channel to the Fairgrounds Pond and back to the main St. Vrain Creek channel.

Additional permits shall be obtained as needed for City Reach 3. These permits may include local or FEMA floodplain permits, Colorado Senate Bill 40 approval, USACE 404 permits, Colorado Department of Public Health and Environment 401 permits, stormwater and erosion control permits, permits related to dams or levees, permits and coordination if bird or raptor nests are present, utility or private infrastructure related permits, permits related to being near an airport, and other state and local construction permits. If possible, future improvements should be designed to avoid impacts to cultural and historic resources as identified in the NEPA Environmental Assessment. The project goals for the RSVP have been to perform the work in the most environmentally sensitive manner possible.

RSVP Geomorphology Report

The restoration and enhancement of the St. Vrain Creek channel will follow natural channel design principles. The St. Vrain Creek corridor is valued for its riparian habitat and natural environmental functions. CH2M prepared a geomorphology analysis to investigate St. Vrain Creek's natural channel processes and sediment transport to assist in developing natural channel design parameters. For City Reach 3, the targets for the low-flow channel geometry include a sinuosity of 1.1, a minimum channel side slope of 3H:1V, and a minimum low-flow channel bottom width of 35 feet. For additional information about the geomorphology investigation and recommendations, refer to the report *Resilient St. Vrain Project Geomorphology Analysis* (CH2M, 2016).

The City concluded that hard erosion protection, such as soil riprap, was not desired at the edges of the low-flow channel, enabling the low-flow channel to naturally meander over time. The City desires outer bank erosion protection to protect trails, infrastructure, and public and private lands.

HEC-RAS Modeling for CHAMP

As part of the RSVP, HEC-RAS modeling was conducted along St. Vrain Creek from Airport Road to Boulder Creek. This modeling has been provided to the State of Colorado and partners for incorporation into the Colorado Hazard Mapping Program (CHAMP), which is reassessing the hydrology and floodplain conditions on multiple Colorado front range streams. The CHAMP program will incorporate the RSVP model from Airport Road to Boulder Creek into the CHAMP overall model. It is noted that the RSVP model assumes that the 100-year flow is contained in the St. Vrain Creek channel upstream of Airport Road for the RSVP model's upstream boundary condition. The revised floodplain maps from CHAMP are anticipated to become effective in the year 2020.

City Reach 3 – Airport Road Area

During a 100-year flood, the St. Vrain Creek floodplain upstream of Airport Road extends north and south of the main channel due to lack of channel capacity and flat overbanks. HEC-RAS modeling of the area was conducted and assumed that the 100-year flow rate would be contained in St. Vrain Creek upstream of Airport Road. During the 100-year flow rate of 13,200 cfs, approximately 11,800 cfs is conveyed through Airport Road bridge and the remainder (approximately 1,400 cfs) exits the channel and overtops Airport Road. **Exhibit 1** illustrates the 100-year flood limits based on the above modeling.

Exhibit 1: 100-Year Flow Rate Flood Limits (assuming flow containment upstream of Airport Road)

The 100-year flood limits are further described as follows:

- At Airport Road, the total floodplain is approximately 1,870 feet wide
- The dry area along Airport Road within the floodplain limits is approximately 1,190 feet wide.
- The floodplain width near the Airport Road bridge on the main channel is approximately 230 feet wide. This is the flow generally contained in the channel. The preliminary modeling shows that the flow is very close to overtopping the road at the bridge location.
- Where overtopping of Airport Road occurs south of the main channel, the floodplain is approximately 450 feet wide with a depth of approximately 1-foot.

The land upstream of Airport Road is outside the City's municipal boundary and under the jurisdiction of Boulder County.

Airport Road Area Option 1 – Single Thread Channel

Without significant channel improvements upstream of Airport Road to contain the full 100-year flow rate in a single channel, a single thread channel option is not feasible. Extensive improvements would be needed upstream of Airport Road to increase the channel capacity and potentially construct interceptor channels or berms to convey overbank flows to the main channel. If the flow was contained upstream of Airport Road, the bridge at Airport Road would need to be replaced with a larger capacity bridge.

Airport Road Area Option 2 – Split Flow Channel

An alternative to the single thread channel is to provide improvements on Airport Road that allow the wide floodplain to cross the road in multiple locations. The 2015 Alternatives Analysis identified that a new box culvert or bridge approximately 1,500 feet south of the existing Airport Road bridge could decrease overtopping of Airport Road during the 100-year storm event. Through further analysis using a 2-Dimensional (2D) hydraulic model, it was determined that an additional single bridge or box culvert at any location in the south overbank would not completely prevent overtopping of Airport Road during the 100-year storm event. The flow in the south overbank is too wide for a culvert at any single location to eliminate the overtopping of Airport Road. In order for a single additional culvert location to prevent overtopping of Airport Road, the flow would need to be concentrated upstream of Airport Road by creating a channel and/or berm to direct flows to the new structure. It is noted that one or more additional culverts, without construction of upstream flow containment improvements, could decrease the flooding depth over Airport Road if desired by the City.

Airport Road Area Conclusion

For the Single Thread Channel Option or the Split Flow Channel Option to function, improvements will be required that are upstream of Airport Road, which is outside of the City's municipal boundary and under the jurisdiction of Boulder County. Improvements would need to be coordinated with and require participation by Boulder County. One of the primary benefits of improvements in this reach would be to prevent Airport Road from being overtopped and closed to both general traffic and emergency access traffic during a flood event, which would benefit both City of Longmont and unincorporated Boulder County residents. Per the *Draft St. Vrain Creek Improvement Project - Alternatives Analysis* (CH2M, 2015a), the estimated costs for improvements from Airport Road to Lykins Gulch are between $15M and $17M. The estimated cost range does not include required channel improvements upstream of Airport Road, and those costs have not been estimated at this time.

City Reach 3 – Lykins Gulch to Sunset Street

In the 2013 flood, Lykins Gulch acted as an interceptor channel that captured flood flows in the south overbank and conveyed the flows back to the St. Vrain Creek main channel. Hydraulic modeling has confirmed that this is anticipated during the 100-year flow event. Given this existing hydraulic feature, the City is focusing on the reach from Lykins Gulch to Sunset Street for future improvements.

Previous Analysis

As noted above, alternatives analysis was conducted in November 2015 and the following options were selected as the preferred options:

- Alternative 2B: Split Flow Upstream of Hover Street Without Levee
- Alternative 3F: Lowered Overbank Downstream of Hover Street (with additional northeast overbank grading)

The analysis documented below builds upon that analysis and incorporates the City's latest preferences. The alternative naming convention used in 2015 as described above does not correlate to the naming convention used in the revised alternatives described below.

Conceptual Design Options Development

Two primary flood conveyance approaches have been identified for Lykins Gulch to Sunset Street, as described below and shown in **Attachment B**:

- A Single Thread Channel approach (Option 1) that consists of an increased capacity channel from Lykins Gulch to Sunset Street and a new Hover Street bridge.
- A Split Flow approach that allows south overbank flows to be conveyed in a southern secondary flow path. This approach can be sequenced from downstream to upstream over time as funding allows, as follows:
    - Option 2 – Fairgrounds Pond Outfall, including an increased capacity channel from the outfall to Sunset Street.
    - Option 3 – New Hover Crossing and Fairgrounds Pond Channel (Option 3 connects to Option 2).
    - Option 4 – Split Flow Channel from Lykins Gulch to New Hover Crossing (Option 4 connects to Options 2 and 3).
    - Complete Split Flow Channel Approach: The combination of Options 2, 3, and 4 results in the complete split flow channel from downstream of Lykins Gulch, across Hover Street, and through the Fairgrounds Pond back to St. Vrain Creek.

Each option above has two sub-options, where sub-option A consists of a single drop structure approach on the main channel and sub-option B consists of a series of small riffle drops on the main channel that are fish passable. For use in the floodplain models, the earthwork grading for each option was developed using three-dimensional terrain modeling software. The anticipated land impacts are illustrated by the proposed grading shown for each option in **Attachment B**.

Option Considerations

The following sections describe the major considerations used when developing and analyzing the options.

Fish Passage and Coordination with CPW

St. Vrain Creek is important to wildlife diversity and water quality and supports habitat for numerous fish species. The objective of a natural channel design approach is to preserve and enhance habitat within the corridor, while achieving the project's other goals. Native plant species provide habitat for native fish, birds, and other wildlife. In areas along St. Vrain Creek, protecting and restoring habitat can help native plant and animal species flourish. Invasive vegetation species removal and vegetation restoration with native species will increase habitat and improve diversity along the corridor.

As part of the RSVP, a riffle pool sequence was designed within the main low-flow channel to enhance habitat within the project reach. Riffle pool sequences enhance biodiversity at the fish community level, enabling various species to cohabitate. Based on coordination with the City and CPW, fish passage at drop structures is desirable, and root wad structures can be incorporated in pool areas to provide additional fish habitat, where feasible. For this analysis, it is assumed that a series of small riffle drop structures will allow fish passage and larger drop structures will not allow fish passage.

Potential Levee Conditions

In City Reach 3, the terrain and hydraulic modeling determined a potential for levee conditions in multiple areas of the reach. In some cases, a channel bank or berm may be capable of containing the 100-year flow rate, but due to low ground topography on the opposite side of the berm or bank, the floodplain will need to be mapped as if the bank or berm is not there. This has been informally referred to as the "wet water" (100-year flow containment) versus "paper water" (floodplain mapping per FEMA regulations) issue related to FEMA floodplain mapping and levees. The goal of future designs should be to avoid levee conditions if possible.

Potential levee conditions could exist in the following locations:

- **Potential Levee Condition at Golden Ponds Nature Area (Golden Ponds)**: A levee condition will exist at Golden Ponds if the water surface elevation (WSEL) in St. Vrain Creek exceeds the top-of-bank elevation of approximately 4,995 feet, adjacent to Golden Ponds. During future design phases, pond perimeter elevations should be used to confirm that no levee conditions or spill points exist at each pond.
- **Potential Levee Condition at Fairgrounds Pond**: The southeast corner of the Fairgrounds Pond is the low point of the pond's perimeter, and the floodplain could spill to the southeast if the WSEL in St. Vrain Creek is above 4,975 feet. As design progresses, the number, layout, and type of drop structures should be evaluated to attempt to avoid a levee condition and provide fish passage. This may be achieved by using smaller riffle drops in locations that lower the WSEL enough to avoid the levee condition while also providing fish passage (through either small riffle drops or fish ladders around large drops).
- **Potential Levee Condition Upstream of the Hover Street Bridge**: In the 100-year storm, the south bank of St. Vrain Creek upstream of Hover Street is overtopped and flow is conveyed to the south. This is a result of the lack of channel capacity. Even if flow is contained in an improved channel, a levee condition just upstream of Hover Street bridge may exist. More detailed analysis in this area can be conducted during future design phases if a single thread option is preferred.

Hover Street Considerations

The following conditions should be considered at Hover Street in future design phases:

- In the existing conditions, the 100-year flow rate overtops Hover Street (see figures in **Attachment B**). The low point in the roadway sag in Hover Street has a road elevation of approximately 4983 feet and is located approximately 200 feet north of the intersection of Hover Street and Rogers Road. The HEC-RAS model WSEL at Hover Street based on an average of the upstream and downstream cross sections is 4985 feet. Thus, the 100-year overtopping depth at Hover Street is approximately 2 feet.
- If the overtopping of Airport Road is not addressed through future projects and road closure will be required during large floods, then the Hover Street crossing of St. Vrain Creek is that much more important for providing roadway connectivity and emergency access in the western portions of the City during a flood.
- If a single thread option moves forward to final design, the low-flow channel through Hover Street and Roger's Grove should be designed to minimize disturbance to vegetation.
- The trail undercrossing at Hover Street floods frequently, causing trail closures. Lowering the low-flow channel may be feasible to increase the channel capacity without requiring changes to the bridge or trail elevation. A drop structure may be required upstream of Hover Street to transition the channel's vertical profile to a lowered channel section through the bridge.

Protection of Roger's Grove Trees

The Roger's Grove area is unique because it is a significant nature area and the City has the opportunity to protect the trees in this area. The City Reach 3 proposed options are intended to protect the majority of the trees in Roger's Grove. Option 1 – Single Thread Channel will use a lowered overbank downstream of Hover Street bridge to convey the 100-year flow rate, while protecting as many trees as possible. Options 2 through 4 will use split flow approaches to convey south bank flows around Roger's Grove and minimize impacts to the Roger's Grove trees.

Floodplain Modeling and Mapping

HEC-RAS 1D and 2D modeling was used to support the analysis presented herein. The modeling and mapping are based on the following:

- Flow Rates and Boundary Conditions:
    - 1D Model: The 100-year flow rate of 14,500 cfs from the CDOT Hydrology Report was used for the modeling.
    - 2D Model: The upstream boundary condition for the 2D model is based on a peak 100-year flow rate of 14,500 cfs. The HEC-RAS 2D model requires the system to be modeled as an unsteady flow; a hydrograph was created to reflect a peak flow rate of 14,500 cfs. A normal depth boundary condition was added at the downstream end of the project area, enabling flow to exit with a friction slope of 0.005. The computational settings used in the 2D HEC-RAS model were defined based on the guidance in the HEC-RAS 2D user's manual, as well as through modeling experience. The computational interval (10 seconds) and cell size (50 feet) were selected.
- Manning's n-Values:
    - 1D Model: The proposed channel roughness n-values were determined using the proposed vegetated conditions for the channel and overbanks. The methodology used to determine n-values for the project is documented in *St. Vrain Creek Improvement Project – HEC-RAS Modeling Manning's N-Value Computation Tool* (CH2M, 2015b).
    - 2D Model: For the 2D model, a Manning's roughness was set to a default value of 0.06 to represent an overall average roughness.
- Floodplain Mapping: The floodplain mapping in **Attachment B** is based on the raw model output then clipped and refined, per coordination with the City, to provide the best estimate of the future floodplain conditions. The 2D raw floodplain output should be reviewed during future design phases to provide insight into possible levee conditions, low areas that are potential spill points, and other features for future analysis.

Lykins Gulch to Sunset Street Option 1 – Single Thread Channel

Description and Considerations: Option 1 is a single thread, main channel option, containing the 100-year flow rate in a single main channel with no formalized split flow channels.

Major Features: This option includes the following major features:

- A new Hover Street bridge at the St. Vrain Creek main channel.
- Channel grading upstream of Hover Street.
- Lowering of the overbanks downstream of Hover Street to provide conveyance capacity while protecting the majority of the vegetation.
- Trail modifications.
- Drop structures downstream of Roger's Grove for conveyance capacity and to transition to the channel grading at the new Sunset Street bridge.

Modeling Approach and Results: A HEC-RAS 1D model was used to analyze Options 1A and 1B. The results show that the 100-year floodplain is greatly reduced and mostly contained within the new single thread channel, as shown in **Attachment B**. There is the potential for overtopping of the south bank upstream of Hover Street due to limitations on the allowable size of the new Hover Street bridge. Containment of all flows upstream of Hover Street should be investigated in future design phases.

Lykins Gulch to Sunset Street Option 2 – Fairgrounds Pond Outfall

Description and Considerations: Option 2 includes constructing an outfall on the northeast side of Fairgrounds Pond to convey south overbank flows crossing Hover Street back into the St. Vrain Creek main channel. This option requires the St. Vrain Creek main channel to be lowered at Fairgrounds Pond to have capacity to convey the 100-year flow while also achieving a water surface elevation in the pond that prevents or minimizes pond overtopping at the southeast corner of the pond.

There are several important elevations to note associated with the Fairgrounds Pond area, as follows:

- Existing St. Vrain Creek invert elevation north of Fairgrounds Pond: 4966.4
- Existing Fairgrounds Pond bottom elevation: 4955.4
- Existing Fairgrounds Pond normal water surface elevation: 4969.5
- Low point in the perimeter of Fairgrounds Pond at the southeast corner: 4972.8
- Proposed St. Vrain Creek invert elevation: 4960.7
- Proposed spillway crest elevation between the pond and St. Vrain Creek: 4966.9

Major Features: This option includes the following major features:

- Fairgrounds Pond outfall at the northeast corner of the pond, including a new pedestrian bridge over the outfall channel.
- A St. Vrain Creek large drop structure (Option 2A) or series of small riffle drop structures (Option 2B) between Roger's Grove and Sunset Street to lower the channel and WSEL adjacent to the low point of Fairgrounds Pond.
- Channel grading downstream of the pond for conveyance capacity and to transition to the channel grading at the new Sunset Street bridge.
- A new pedestrian bridge downstream of Roger's Grove with capacity for the 100-year flow rate.

Modeling Approach and Results: A HEC-RAS 2D model was used to analyze Options 2A and 2B. The results show that the 100-year floodplain is reduced, as shown in **Attachment B**. Flows continue to spill out of the Fairgrounds Pond to the southeast but have much less floodplain impact on parcels south of the creek.

Lykins Gulch to Sunset Street Option 3 – New Hover Crossing and Fairgrounds Pond Channel

Description and Considerations: Option 3 builds on Option 2 by constructing an additional bridge or culvert on Hover Street west of Fairgrounds Pond. The new structure would convey flows from west of Hover Street to a new conveyance channel constructed in the Fairgrounds Pond. This conveyance channel would then connect to the Fairgrounds Pond outfall described in Option 2.

Major Features: This option includes the following major features:

- Grading west of Hover Street to capture St. Vrain Creek south overbank flows.
- Additional bridge or culvert on Hover Street west of Fairgrounds Pond, including a drop structure just east of the new bridge/culvert structure.
- Split flow conveyance channel through Fairgrounds Pond.
- Reconstruction of the remaining Fairgrounds Pond area into park area or a smaller pond.
- Trail modifications.

Modeling Approach and Results: A HEC-RAS 2D model was used to analyze Options 3A and 3B. The results show that the 100-year floodplain is reduced, as shown in **Attachment B**. Flows no longer spill out of the Fairgrounds Pond to the southeast, and the south bank parcels are removed from the floodplain from Hover Street to the BNSF Railway. Flooding remains upstream of Hover Street on the south overbank between St. Vrain Creek and the new bridge/culvert structure.

Lykins Gulch to Sunset Street Option 4 – Split Flow Channel from Lykins Gulch to the New Hover Crossing

Description and Considerations: Option 4 builds on Options 2 and 3 by constructing a formalized split flow channel from just downstream of Lykins Gulch to the new Hover Street crossing described in Option 3. The new split flow channel would convey flows in excess of the original Hover Street bridge capacity, so that the existing bridge would not have to be replaced.

Major Features: This option includes the following major features:

- A lateral weir on St. Vrain Creek's south bank and a new split flow channel through several existing gravel ponds; some of these ponds are privately owned.
- Construction of berms to separate the new split flow channel from the remaining gravel pond areas.
- Irrigation pipe aerial crossing of the new split flow channel.
- Connection of the new split flow channel to the New Hover Crossing described in Option 3.
- Trail modifications.

Modeling Approach and Results: A HEC-RAS 1D model was used to analyze Options 4A and 4B. The total 100-year flow rate at Hover Street is 14,500. The model shows that the main channel and Hover Street bridge have capacity to convey approximately 8,660 cfs, and the remainder (approximately 5,840 cfs) is conveyed by the split flow channel. The modeling results show that the 100-year floodplain is reduced, as shown in **Attachment B**. Flooding is removed upstream of Hover Street on the south overbank between St. Vrain Creek and the new bridge/culvert structure. Flows no longer spill out of the Fairgrounds Pond to the southeast, and the south bank parcels are removed from the floodplain from Hover Street to the BNSF Railway.

Summary of Options

The Lykins Gulch to Sunset Street options and associated future design considerations are summarized in **Table 2** and illustrated in **Attachment B**. Initial review and input from City staff have identified the Split Flow Channel Option as the preferred alternative due to the significant impacts that the Single Thread Channel Option would have on the riparian and native areas along the main channel both upstream and downstream of Hover Street. Variations to the options presented herein could be further investigated to ultimately determine the preferred option. For example, a hybrid approach to large and small drop structures with fish passage could result in avoiding levee conditions but may have slightly greater impacts related to the earthwork grading footprint, vegetation, or other important considerations that could be balanced during future design phases. Similarly, if additional riffle drops are constructed upstream of Fairgrounds Pond, the WSEL at the pond will be lower, resulting in additional floodplain benefits and potentially eliminating levee conditions. Another alternative to review in the future is a Fairgrounds Pond Outfall alignment that would direct flows in a more easterly direction, which may improve hydraulic or other benefits but may have additional impacts to private land.

Table 2. Lykins Gulch to Sunset Street Options Summary and Future Design Considerations

Option and Description	Fish Passage Restricted	Potential Levee Condition at Fairgrounds Pond	Channel Overtopping and Potential Levee Condition Upstream of Hover Bridge	Potential Levee Condition at Golden Ponds
Single Thread Channel Options				
Option 1A: Single thread with one large drop structure just downstream of Roger's Grove	Yes, due to single large drop	No, lower St. Vrain Creek to avoid	No, design channel capacity to avoid	No, design channel capacity to avoid
Option 1B: Single thread with small riffle drop structures just downstream of Roger's Grove	No, due to riffle drops	Yes, shift riffle drops to attempt to avoid	No, design channel capacity to avoid	No, design channel capacity to avoid
Complete Split Flow Channel Options				
Option 2A + 3A + 4A: Complete split flow channel from Lykins Gulch through the Fairgrounds Pond with one large drop structure just downstream of Roger's Grove	Yes, due to single large drop	No, design split flow channel to avoid	No, assuming split flow diverts adequate flows	Possible, depends on water surface elevation at start of split flow
Option 2B + 3B + 4B: Complete split flow channel from Lykins Gulch through the Fairgrounds Pond with small riffle drop structures just downstream of Roger's Grove	No, due to riffle drops	Yes, shift riffle drops to attempt to avoid	No, assuming split flow diverts adequate flows	Possible, depends on water surface elevation at start of split flow
Phased Split Flow Options				
Option 2A: Fairgrounds Pond outfall with one large drop structure just downstream of Roger's Grove	Yes, due to single large drop	Yes, confirm during design	Yes, due to lack of channel capacity	Yes, due to lack of channel capacity
Option 2B: Fairgrounds Pond outfall with multiple small riffle drop structures just downstream of Roger's Grove	No, due to riffle drops	Yes, shift riffle drops to minimize	Yes, due to lack of channel capacity	Yes, due to lack of channel capacity
Options 2A + 3A: Hover Crossing and Fairgrounds Pond channel and outfall with one large drop structure just downstream of Roger's Grove	Yes, due to single large drop	No, design split flow channel to avoid	Yes, due to lack of channel capacity	Yes, due to lack of channel capacity
Options 2B + 3B: Hover Crossing and Fairgrounds Pond channel and outfall with multiple smaller riffle drop structures just downstream of Roger's Grove	No, due to riffle drops	Yes, shift riffle drops to attempt to avoid	Yes, due to lack of channel capacity	Yes, due to lack of channel capacity

Earthwork and Engineer's Opinion of Probable Costs

A major cost component for each option is the amount of earthwork, including excavation and placement on-site, excavation and haul off-site, and import of material when required. The following sections summarize the earthwork and engineer's opinion of probable costs for each individual reach and if reaches are combined into a single construction project.

Future Design Note Regarding Option 4

It is noted that Option 4 below shows a net haul off-site, which is expected to not be accurate. This is due to the lack of underwater topography at the ponds in Option 4. Additional fill, which is not currently accounted for, will be required at the following locations:

- Lykins Gulch Pond, located at the confluence of Lykins Gulch and St. Vrain Creek
- The private pond located immediately south of Lykins Gulch Pond.

If Option 4 is to be pursued, underwater survey of the associated ponds should be performed to refine the earthwork quantities and the engineer's opinion of probable costs.

Earthwork Estimates

A summary of the estimated earthwork for each individual option is provided in **Table 3**.

Table 3. Earthwork Summary for Individual Options

Option	Excavation (CY)	Fill On-Site (CY)	Haul Off-Site (+) or Import (-) (CY)
1A	372,612	15,802	356,809
1B	281,512	26,870	254,642
2A	283,571	18,823	264,749
2B	192,472	29,891	162,581
3A	73,246	218,394	-145,148
3B	73,246	218,394	-145,148
4A*	162,275	91,244	71,031
4B*	162,275	91,244	71,031

** See Future Design Note Regarding Option 4.*

A summary of earthwork for combined options is provided in **Table 4**.

Table 4. Earthwork Summary for Combined Options

Combined Options	Excavation (CY)	Fill On-Site (CY)	Haul Off-Site (CY)
1A	372,612	15,802	356,809
1B	281,512	26,870	254,642
2A	283,571	18,823	264,749
2B	192,472	29,891	162,581
2A + 3A	356,817	237,217	119,600
2B + 3B	265,717	248,285	17,433
2A + 3A + 4A*	519,093	328,461	190,632
2B + 3B + 4B*	427,993	339,529	88,464

** See Future Design Note Regarding Option 4.*

Conclusions related to the earthwork summary tables:

- Option 1 increases floodplain conveyance capacity throughout the reach and results in a significant quantity of material to be excavated and hauled off-site.
- Option 2 includes floodplain conveyance improvements from Sunset Street to Fairgrounds Pond, resulting in a significant quantity of material to be excavated and hauled off-site.
- Option 3 is a net fill reach due to the construction of berms on both sides of the channel through Fairgrounds Pond and filling Fairgrounds Pond north of the new channel. The new segment of channel through Hover Street and upstream of Hover Street is in cut, which can be used to partially fill Fairgrounds Pond.
- If Options 2 and 3 are constructed together, the cut from Option 2 can be used as fill for Option 3. Option 2B + 3B nearly balances on-site (only 17,433 of haul off-site).

Engineer's Opinion of Probable Costs

The engineer's opinion of probable costs for each City Reach 3 option—including construction costs, non-construction costs, land costs, and contingency—is summarized in **Table 5**, with additional detail provided in **Attachment C**.

Table 5. Summary of Engineer's Opinion of Probable Costs for Complete Approaches

Complete Approach	Sub-Option A: Large Drop Structure	Sub-Option B: Riffle Drop Structures
Single Thread Channel	$31,122,180	$27,986,527
Split Flow Channel (Options 2 + 3 + 4 constructed as one single project)*	$34,487,699	$31,402,761

** See Future Design Note Regarding Option 4.*

The engineer's opinion of probable costs for individual and combined options is shown in **Table 6.**

Table 6. Summary of Engineer's Opinion of Probable Costs for Individual and Combined Options

Individual and Combined Options	**Sub-Option A:** **Large Drop Structure**	**Sub-Option B:** **Riffle Drop Structures**
Individual Option 2 - Fairgrounds Pond Outfall to Sunset Street	$14,893,452	$11,821,817
Individual Option 3 - New Hover Crossing to Fairgrounds Pond Outfall	$17,728,763	$17,736,234
Individual Option 4 - Split Flow Channel to New Hover Crossing*	$11,083,643	$11,116,345
Combined Options 2 + 3 (constructed as one single project)	$23,361,102	$20,283,723

** See Future Design Note Regarding Option 4.*

The above estimates are preliminary and based on the best available data at this time. The final costs of the project and resulting feasibility will depend on final design, actual labor and material costs, competitive market conditions, actual site conditions, final project scope, implementation schedule, continuity of personnel and engineering, and other variable factors. Therefore, the final project costs will vary from the estimate developed using the information in this document. Taking these factors into consideration, project feasibility, benefit/cost ratios, risks, and funding needs must be carefully reviewed prior to making specific financial decisions or establishing project budgets, to help ensure proper project evaluation and adequate funding.

Future Considerations

The following items should be considered and addressed during future design phases:

- If Lykins Gulch to Sunset Street Option 4 is to be pursued, underwater survey of the associated ponds should be performed to refine the earthwork quantities and the engineer's opinion of probable costs.
- Regulatory levee conditions should be avoided if possible. Levee conditions would require regulatory compliance for the levee and would have a FEMA floodplain mapping impact, as the downstream side of a non-certified levee is required to be mapped within the floodplain.
- State Engineer's Office (SEO) regulatory dam conditions should be avoided if possible. For City Reach 1, the north bank of the creek was widened to avoid the berm being considered a regulatory dam by SEO. This approach should be considered as the design progresses near other ponds. An SEO regulatory dam classification would have major impacts to the project, including the possible requirement to remove large vegetation adjacent to the creek and ponds.
- Delineations of Waters of the U.S. and Wetlands – For City Reach 1, the water treatment plant pond was approved by USACE as a preamble water, which means it was not under the regulatory review of USACE and did not require a USACE 404 permit or associated mitigation. This approach should be considered as the design progresses near other ponds.

- The City and USACE are currently working on a Section 205 project for a portion of St. Vrain Creek, including portions of City Reach 3. Section 205 of the 1948 Flood Control Act authorizes USACE to study, design, and construct small flood control projects in partnership with non-Federal government agencies, including cities. CH2M has not been actively involved in the Section 205 Project. Information from the City's 205 project should be included, as needed, as design progresses in City Reach 3.
- Work on unincorporated Boulder County land could require additional permits, such as a 1041 permit. Permitting for the City Reach 3 preferred option(s) should be reviewed during future design phases.
- Lykins Gulch to Sunset Street Options 2 through 4 allow improvements to be phased as funding becomes available.

References and DVD Contents

The following references are cited in this Technical Memorandum and are included on the DVD in **Attachment D**.

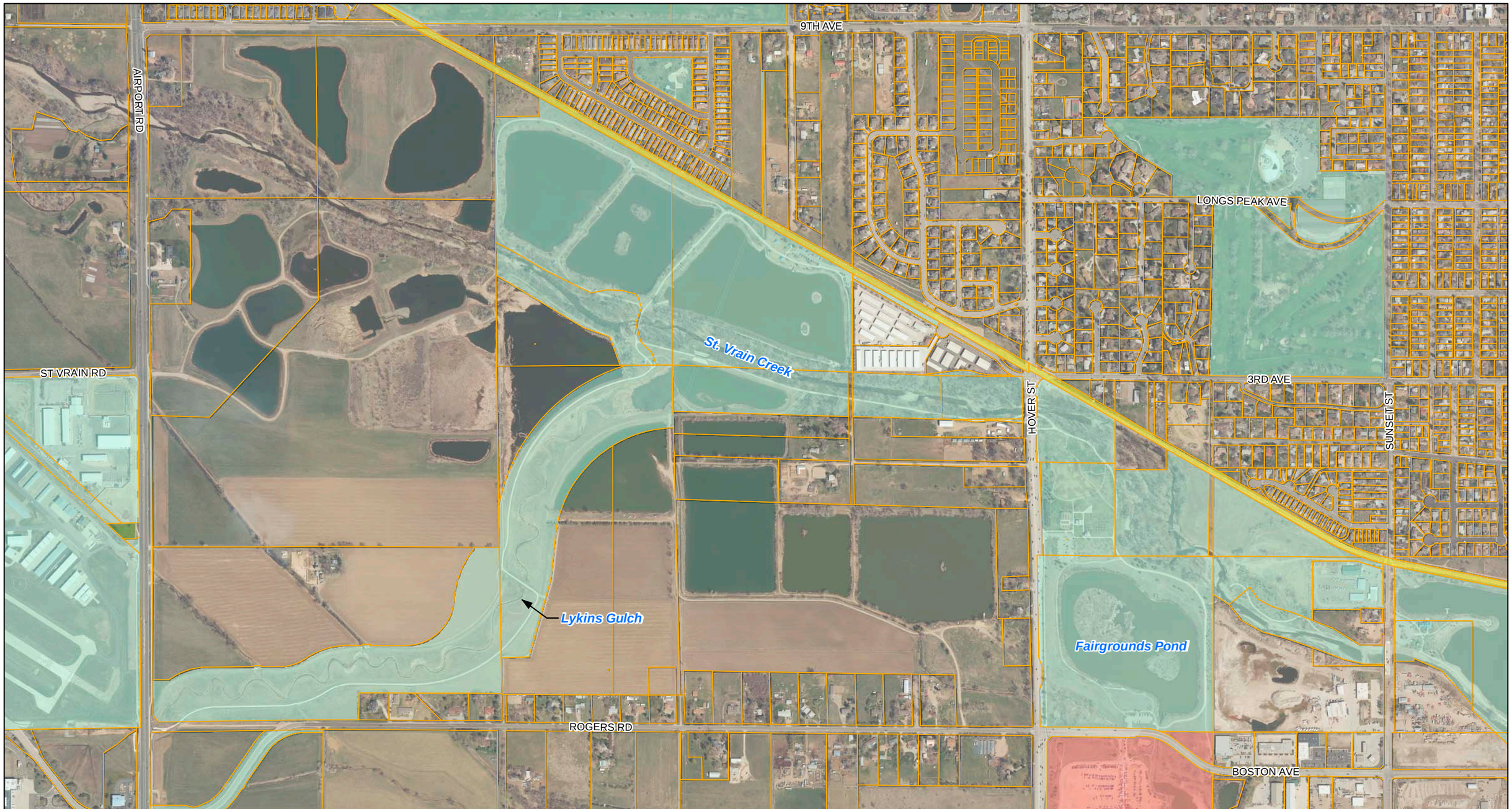
CH2M HILL Engineers, Inc. (2014). *St. Vrain Creek through Longmont: 100-Year Analysis and Conceptual Design*. Prepared for City of Longmont, Colorado.

CH2M HILL Engineers, Inc. (2015a). *Draft St. Vrain Creek Improvement Project – Alternatives Analysis*. Prepared for City of Longmont, Colorado.

CH2M HILL Engineers, Inc. (2015b). *St. Vrain Creek Improvement Project – HEC-RAS Modeling Manning's N-Value Computation Tool*. Prepared for City of Longmont, Colorado.

CH2M HILL Engineers, Inc. (2016). *Resilient St. Vrain Project Geomorphology Analysis*. Prepared for City of Longmont, Colorado.

Federal Emergency Management Agency (2016). Finding of No Significant Impact, Resilient St. Vrain Project, Longmont, Colorado.



Legend

- Parcel Boundary
- City of Longmont
- County
- Northern Colorado Water Conservation District
- Private
- Railroad

Source:
Boulder County Assessor, August 2018

N

0 350 700
Feet

Figure 1
Resilient St. Vrain Project
City Reach 3 Land Ownership

ch2m

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