CONSULTANTS, INC.

GEOTECHNICAL AND
WATER RESOURCES ENGINEERING

BASELINE GROUNDWATER MODEL REPORT

SOUTH BOULDER CREEK REGIONAL DETENTION PROJECT

BOULDER COUNTY, COLORADO

Submitted to
City of Boulder
1777 Broadway
Boulder, CO 80301

Submitted by
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July 2021
Project 16134

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Project Manager

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ACRONYMS AND ABBREVIATIONS

Term	Description
ASTM	ASTM International
Baseline Model	Baseline Groundwater Model
CDOT	Colorado Department of Transportation
CDSS	Colorado's Decision Support Systems
cfs	Cubic Feet per Second
City	City of Boulder
cm/s	Centimeters per Second
CU	University of Colorado
ESI	Environmental Simulations, Inc.
ft	Feet
ft^3	Cubic Feet
GIS	Geographic Information System
GUI	Graphical User Interface
HCLOSE	Head Change Criterion for Outer Iterations
HSU	Hydrostratigraphic Unit
Kh	Horizontal Hydraulic Conductivity
Kv	Vertical Hydraulic Conductivity
Laterals	Lateral irrigation channels
LiDAR	Light Detection and Ranging
MHFD	Mile High Flood District
MXITER	Maximum Number of Outer Iterations
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OSMP	Open Space and Mountain Parks
Project	South Boulder Creek Regional Detention Project
Reclamation	U.S. Bureau of Reclamation
Report	Baseline Groundwater Model Report
RJH	RJH Consultants, Inc.
RMS	Root Mean Squared
SBC	South Boulder Creek
SFR	Streamflow Routing Package
Ss	Specific Storage
Sy	Specific Yield
T&E	Threatened and Endangered
US36	U.S. Highway 36
USG	Unstructured Grid
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

RJH Consultants, Inc. (RJH) is providing engineering services for design of the South Boulder Creek (SBC) Regional Detention (Project). Project facilities could impact natural groundwater conditions in the vicinity of the Project, and RJH is developing a groundwater model to support design of facilities to mitigate groundwater impacts. The first step in the groundwater modeling process involves developing a baseline groundwater model (Baseline Model) to identify and document existing (pre-Project) groundwater conditions. The purpose of this Baseline Groundwater Model Report (Report) is to document development of the Baseline Model.

Groundwater modeling was performed using MODFLOW-USG and the Groundwater Vistas graphical user interface (GUI) software program. The modeled extent generally included the SBC alluvial valley extending from approximately State Highway 93 to Baseline Road. The data used to develop the model was obtained from a variety of sources including Project-specific data collected by RJH; publicly available data collected by the National Weather Service (NWS), Mile High Flood District (MHFD), and Colorado's Decision Support Systems (CDSS); irrigation information provided by Open Space and Mountain Parks (OSMP); and typical published data for similar hydrogeologic environments.

The Baseline Model consists of a steady-state component and a transient component that simulated conditions from November 2018 to October 2019. The model was calibrated to data collected by RJH from 32 monitoring wells throughout the Study Area, and model calibration focused primarily on irrigated OSMP fields near U.S. Highway 36 (US36). The general intent of the model calibration was to achieve similar drawdown behavior (i.e., mimic monthly groundwater level fluctuations) and to calibrate to the absolute head values observed in monitoring wells. The transient model component had an unweighted scaled root mean squared (RMS) error of 1.1 percent which is within the industry-acceptable limit of less than 5 percent.

The groundwater conditions simulated by the Baseline Model are consistent with our conceptualization of the hydrogeologic system within the Study Area. Groundwater levels decline towards the north through the aquifer, which follows the slope of topography and the flow of SBC. Groundwater flow rates of approximately 6,000 cubic feet per day are predicted to occur within the Study Area beneath US36, which is predominantly occurring through alluvium in the western portion of the Study Area. The alluvial aquifer in the Study Area does not appear to be either strongly gaining water from or strongly losing water to SBC. Seasonal groundwater fluctuations are influenced by natural conditions through the hydrogeologic cycle and irrigation applied to OSMP fields. Predominant components of the hydrogeologic system are inflow from recharge, outflow from evapotranspiration, and interactions with surface water in SBC.

RJH performed sensitivity analyses in general accordance with ASTM International (ASTM) D5611 (ASTM, 2016) and identified that the Baseline Model was most sensitive to irrigation recharge rates and the alluvium specific yield, which affect both heads and flows. Changes in hydraulic conductivity also strongly affect flows through the model but have lesser impacts on heads.

The Baseline Model provides a reasonable approximation of the existing groundwater system in the Project vicinity. In our opinion the Baseline Model is suitable for evaluating impacts that Project components could have on the hydrogeologic system, and supporting design of Project features implemented to mitigate impacts to the existing groundwater system.

SECTION 1 - INTRODUCTION

1.1 Purpose and Objectives

RJH was retained by the City of Boulder (City) and MHFD to provide engineering services for the Project. The purpose of the Project is to reduce risks to public safety and damage to residences, structures, and critical infrastructure in portions of the Frasier Meadows, Keewaydin Meadows, and East Boulder neighborhoods from floods originating along SBC up to a 100-year flood event that would overtop US36 and flow into these neighborhoods. Historically, flood waters that overtop the left (while looking downstream) bank of SBC upstream of US36 have flowed northwest across the site and have overtopped US36 near the intersection with Table Mesa Drive as shown on Figures 1.1 and 1.2.

Project facilities could impact natural groundwater conditions in the vicinity of the Project. RJH is developing a groundwater model to a) identify potential impacts to the natural groundwater conditions from proposed Project components and b) support design of facilities to mitigate those impacts. The overall goal during design of Project components will be to develop facilities that maintain the natural groundwater system (heads and flows) as similar as practicable to the pre-Project conditions in the vicinity of the Project.

The first step in the groundwater modeling process involves developing a Baseline Model. The objective of the Baseline Model is to identify and document existing (pre-Project) groundwater conditions. The purpose of this Report is to present the methodology, results, conclusions, and recommendations associated with the Baseline Model.

1.2 Background

The Project will consist of constructing a flood detention facility in southeast Boulder County, Colorado, adjacent to City limits. A site vicinity map is shown on Figure 1.1. The proposed facility is expected to include a jurisdictional dam comprised of an earthen embankment located along the northwest and west portion of the University of Colorado (CU) Boulder South campus and a spillway located on OSMP and Colorado Department of Transportation (CDOT) property. The Project will also include detention excavation on the CU Boulder South campus to provide the required flood storage volume. The detention excavation is anticipated to be less than about 20 acres in plan and the detained floodwaters are expected to be less than about 23 feet deep. The facility is expected to have a total capacity of about 40 to 50 acre-feet, which would be temporarily detained both within the detention excavation and the surrounding floodplain upstream of the detention facility. A plan of the proposed Project is presented on Figure 1.2.

The dam and reservoir will generally be dry during normal operating conditions. During a flood event, stormwater that overtops the west bank of the main channel of SBC will flow into the detention facility while stormwater in the main channel of SBC will flow through the US36 bridge unobstructed – generally consistent with pre-Project conditions. The detention facility will be configured to prevent overtopping of US36 from the design event. The detained water will be released to Viele Channel through an outlet pipe in less than 120 hours after the floodwaters recede in accordance with Colorado Office of the State Engineer regulations for temporary storage of floodwater.

The earthen embankment, spillway, and perimeter of the detention excavation could potentially include barrier walls that extend through the foundation soils and into bedrock to safely manage seepage at these facilities. These barrier walls are expected to impact the local natural groundwater conditions.

Several irrigation ditches extend through OSMP property in the vicinity of the Project site. Water in the ditches is used to flood irrigate portions of the OSMP property. Irrigation is seasonal and is typically performed between April to July depending upon water availability. The duration and spatial application of irrigation water to individual OSMP fields is highly variable throughout each irrigation season.

Natural groundwater conditions near the Project site are influenced by a complex combination of precipitation, irrigation durations and locations, evapotranspiration, interaction with surface water flows in SBC, and subsurface conditions.

1.3 Groundwater Modeling Stages

Groundwater modeling is being performed in stages to support the various phases of Project development (i.e., preliminary and final design). The stages of groundwater modeling are generally as follows:

- Stage A - Baseline Model: This model will be developed to reasonably represent the existing (pre-Project) conditions. The results from this model will then be used to support identification of probable Project impacts to the groundwater conditions and to support design of Project components.

- Stage B - Design Model: The Baseline Model will be updated to include Project components and facilities to mitigate impacts to groundwater conditions from the Project components.

This Report provides information on development of the Baseline Model (Stage A). Possible impacts from Project components and facilities to mitigate those impacts will be provided in subsequent design documentation. Water detained within the proposed facilities is not expected to have significant impacts to the surrounding groundwater system because of the short-duration loading; this will be evaluated during the Design Model (Stage B) analyses.

1.4 Baseline Model Development

Development of the Baseline Model is divided into two primary tasks: conceptual modeling and numerical modeling. Conceptual modeling provides a qualitative representation of the groundwater system in terms of hydrogeologic units, system boundaries, and temporal durations and is used to identify a framework for developing the numerical model. Numerical modeling consists of using mathematical techniques to implement the framework identified in the conceptual model.

The numerical modeling process was divided into two primary tasks: steady-state modeling and transient modeling. The Baseline Steady-State Model simulates groundwater conditions when irrigation was not occurring and was used as initial conditions for the Baseline Transient Model. The Baseline Transient Model simulates seasonal groundwater changes and includes both irrigated and non-irrigated time periods.

The Baseline Model was developed for an area (Study Area) that extends a) north to south from South Boulder Road (S. Boulder Rd.) to State Highway 93 and b) west to east from a geologic contact between bedrock/surficial soils to SBC. Project facilities will be constructed near the middle of the Study Area. Additional information regarding the Study Area is provided in Section 4.

1.5 Scope of Work

RJH performed the following services for the Baseline Model:

- Collected and reviewed available Project and published data from near the Study Area.
- Developed a Hydrogeologic Conceptual Model that identified the following:

  - Hydrogeologic units and their geometry and hydraulic characteristics.
  - Major sources of groundwater inflow and outflow.
  - Quantified ranges of parameter values as a basis for selection of inputs to the numerical model.
- Performed three-dimensional control volume finite difference (i.e., numerical) groundwater modeling using the U.S. Geological Survey (USGS) MODFLOW-USG code (Panday et al., 2013) and the Groundwater Vistas GUI software program (Environmental Simulations, Inc. [ESI], 2020).
- Developed boundary conditions along SBC with the streamflow routing (SFR) package using 21 segments to represent the creek.
- Estimated preliminary spatial and temporal distributions of irrigation recharge based on ditch diversion data from the CDSS database (CDSS, 2020), geographic information system (GIS) shapefiles provided by the OSMP, and RJH's field observations.
- Developed and calibrated a steady-state groundwater model to simulate existing conditions during a portion of the non-irrigation season (Baseline Steady-State Model) and to provide initial conditions for the Baseline Transient Model.
- Developed and calibrated a transient groundwater model to simulate transient water level changes associated with seasonal variations, and non-irrigation and irrigation seasons (Baseline Transient Model).
- Performed site visits to observe and document irrigation limits and relative irrigation diversion flows.
- Utilized a technical expert to perform quality assurance reviews of the groundwater models.
- Retained Dr. Mary Hill to perform an independent technical review of this Report. Her opinions on the suitability of the Baseline Model to support Project design are provided in Appendix L.
- Prepared this Report.

1.6 Authorization

This work was performed in general accordance with the terms and conditions of the Professional Services Agreement between the City and RJH dated September 26, 2016, and Contract Modification Requests dated March 22, 2019 and June 8, 2020.

1.7 Project Personnel

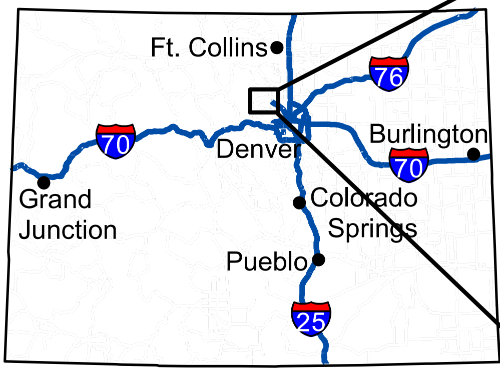
The following personnel are responsible for the work contained in this Report:

Project Manager:	Robert Huzjak, P.E. (RJH)
Project Engineer:	Eric Hahn, P.E. (RJH)
Lead Geotechnical Engineer:	Adam Prochaska, Ph.D., P.E., P.G.(1) (RJH)
Staff Engineers:	Jacquelyn Hagbery, P.G.(1), E.I. (RJH)
	Adam Merook, E.I. (RJH)
Senior Technical Advisor:	Michael Gabora, R.G.(1) (FloSolutions, S.A.C)
Independent Technical Review:	Mary C. Hill, Ph.D., P.E. (RJH)

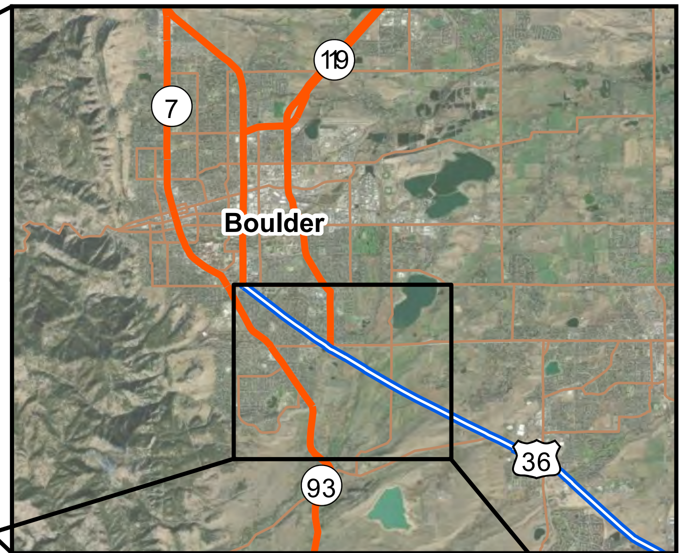
Note:
1. Licensed in states other than Colorado.

The City and MHFD team include the following personnel:

City Project Manager:	Brandon Coleman, P.E.
City Dam Safety Engineer:	Kevin Clark, P.E.
MHFD Watershed Manager:	Jim Watt, P.E.



PROJECT VICINITY MAP
(NOT TO SCALE)



PROJECT LOCATION MAP
(NOT TO SCALE)

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SITE LOCATION MAP
(NOT TO SCALE)

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CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	SITE VICINITY MAP
		PROJECT NO. 16134	July 2021 **Figure 1.1**

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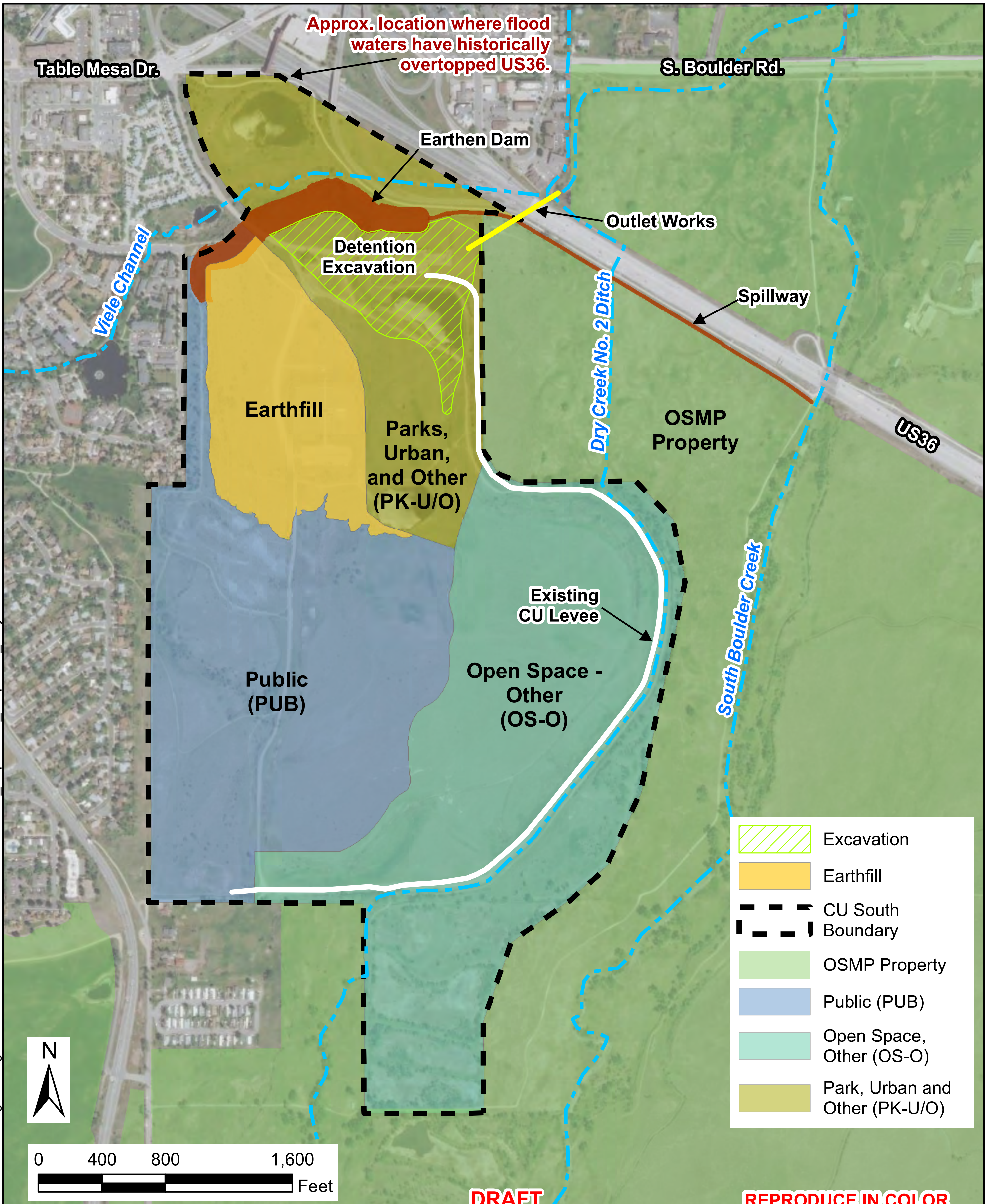

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NOTE: 1. NORTH IS UP ON THIS FIGURE. SUBSEQUENT PLAN FIGURES WITHIN THIS REPORT ARE ORIENTED WITH NORTH TO THE RIGHT.	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	PROPOSED PROJECT
		PROJECT NO. 16134	July 2021 **Figure 1.2**

SECTION 2 - SITE DESCRIPTION

2.1 General

The Project will be located south of US36, west of SBC, and east of several residential communities. The Study Area for the groundwater modeling includes the broad SBC alluvial valley that extends beyond the Project facilities. The Study Area is comprised primarily of undeveloped land, irrigated pasture, and residential developments. RJH has performed multiple site visits since 2017 to observe site conditions and perform data collection. A plan of the Study Area is provided on Figure 2.1.

2.2 Existing Study Area

2.2.1 University of Colorado Boulder South Campus

The CU Boulder South campus is a 308-acre property located south of US36, east of several residential communities, and west of OSMP property. The CU Boulder South campus currently includes a tennis complex, a maintenance building with an asphalt parking lot, and a series of pedestrian trails.

Gravel mining operations were performed on the CU Boulder South campus property before it was acquired by CU. The gravel mining created a large excavation that was about 10 to 15 feet below the original ground surface. Much of the mined area was subsequently backfilled. Mine excavations and incomplete backfilling of the property created several below-grade ponds that fill with groundwater. Water levels in these ponds fluctuate with groundwater levels.

Two surface water ditches are located within the previously mined areas. The locations of the ditches (CU Ditch East and CU Ditch West) are shown on Figure 2.1. The ditches collect groundwater and surface water, and convey flow northward until discharging to ponds on the CU Boulder South campus. During RJH's site visits we have observed that the ditches can be dry, have stagnant water, or be flooded with flowing water depending on the season, weather, and groundwater conditions.

2.2.2 Open Space and Mountain Parks Property

OSMP property is located on both sides of US36, west of SBC, and east of the CU Boulder South campus. OSMP property is generally undeveloped and consists of native grasses, irrigated pasture, and riparian areas, which generally include cottonwood trees and brush. OSMP property contains wetlands and federally listed threatened and endangered (T&E) species habitat for the Preble's meadow jumping mouse and Ute-ladies'-tresses orchid. The property is also used for cattle grazing.

Portions of OSMP property within the Study Area are irrigated for hay production. Numerous irrigation ditches and smaller lateral irrigation channels (laterals) exist to distribute water throughout irrigated areas. Based on information from OSMP and field observations by RJH, water is supplied to the OSMP fields using flood irrigation by placing check dams in irrigation ditches; the farmers control the location and timing of the flood irrigation and generally do not keep written records of this process. RJH has observed areas in OSMP fields that are submerged with 1 foot of water and then are dry in less than one week.

Eight existing wells are located on OSMP property near and immediately downstream of the Project site. We understand that these wells have been intermittently monitored by OSMP since the early 1990s. Five of the existing wells were field-located by OSMP and RJH staff, and three of the existing wells could not be field-located.

2.2.3 Developed Areas

Multiple residential communities exist within the Study Area. These include the Tantra Park neighborhood located immediately west of the CU Boulder South campus, the Keewayden neighborhood located north of S. Boulder Rd. and east of Foothills Parkway, and the Frasier Meadows neighborhood located north of US36 and west of Foothills Parkway. The residential communities primarily consist of single-family residences and condominiums.

Several commercial developments are located within the Study Area and include office buildings, gas stations, hotels, and retail centers. A Regional Transportation District hub is located at the intersection of US36 and Foothills Parkway.

2.3 Surface Water Features

2.3.1 South Boulder Creek

SBC is a major drainageway that extends from its headwaters in the mountains through Eldorado Canyon and subsequently southeast of the City before discharging to Boulder Creek. The SBC watershed encompasses approximately 136 square miles. Flow in SBC is from a combination of groundwater, precipitation runoff, releases from Gross Reservoir, and snowmelt.

SBC generally flows northward along the eastern side of the Study Area. Within the Study Area, SBC consists of a relatively straight, alluvial stream channel. The right overbank is significantly higher than the channel and is not expected to be overtopped during extreme flood events. The left overbank is shallower and is overtopped during both routine and extreme flood events.

2.3.2 Irrigation Ditches

Numerous irrigation ditches are located in and near the Study Area. Some irrigation ditches divert water from SBC toward the west and flow through the Study Area, and other irrigation ditches divert water from SBC toward the east and away from the Study Area. Anderson Ditch is the only irrigation ditch that conveys water into SBC. The three irrigation ditches used to irrigate fields within the Study Area are:

- S. Boulder and Bear Creek Ditch.
- Dry Creek No. 2 Ditch.
- Howard Ditch.

A plan of the irrigation ditches is presented on Figure 2.1.

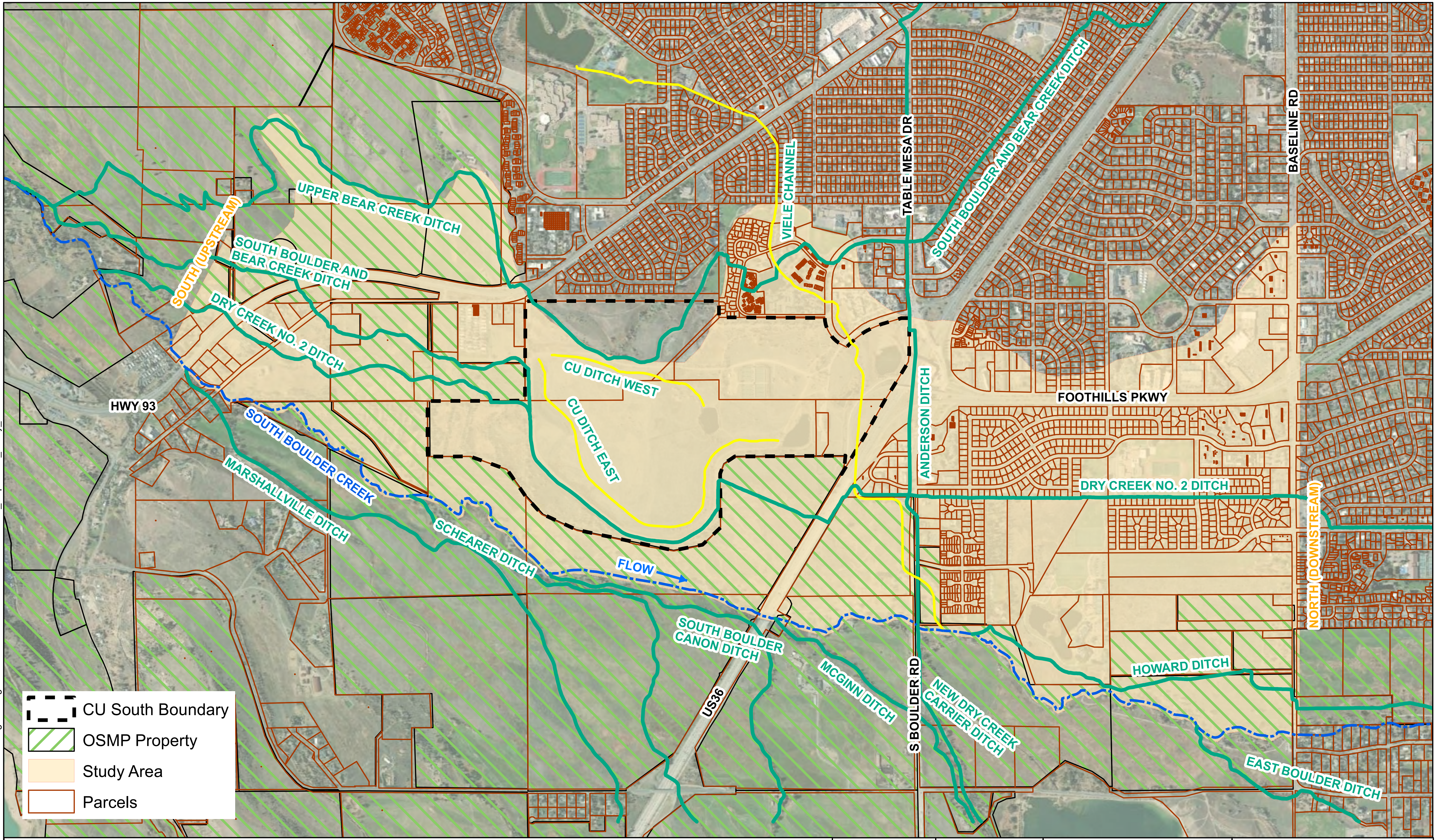
2.3.3 Viele Channel

Viele Channel generally flows across the Study Area from west to east as shown on Figure 2.1. This channel collects groundwater and surface water runoff, and flows into SBC. RJH has typically observed standing water in the channel near CU Boulder South campus and minor to moderate flow in the channel near the confluence with SBC. We also commonly do not observe surface water flow in Viele Channel where it crosses under Tantra Drive and US36.

2.4 South Boulder Creek Alluvial Valley

The SBC alluvial valley enters the upstream end of the Study Area as a relatively narrow mountain stream flowing from Eldorado Canyon. As SBC flows past the proposed Project facilities, the alluvial valley generally widens until it converges with the Boulder Creek alluvial valley downstream of Baseline Road. Much of the alluvial material has been mined from CU Boulder South campus and was replaced with fill; the natural alluvium appears to be constricted between the CU levee and SBC east of the CU Boulder South campus.

Based on data collected by RJH (Section 3), the SBC alluvial valley aquifer is an unconfined aquifer that extends throughout surficial soils (alluvium and fill) and is perched on the underlying low permeability bedrock. The alluvium generally decreases in thickness from upstream to downstream. The top of bedrock beneath the surficial soil appears to form a consistent broad surface that in some locations decreases in elevation to the west (away from SBC).



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NOTE:
1. IRRIGATION DITCH LOCATIONS DEFINED BY SHAPEFILES PROVIDED BY OSMP.

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SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	STUDY AREA
PROJECT NO. 16134	July 2021 — Figure 2.1

SECTION 3 - DATA COLLECTION

3.1 Topographic Data

Available ground surface topography data for the Study Area includes Light Detection and Ranging (LiDAR) data provided by the City and Boulder County, and aerial and field survey data provided by Flatirons, Inc. RJH combined the LiDAR and aerial survey data into a single surface that was used to develop the model ground surface. The vertical accuracy of the combined dataset is considered to be within 0.25 foot (BakerAECOM, LLC, 2012). The extent of the LiDAR and aerial survey data is shown on Figure 3.1.

3.2 Geotechnical, Geological, and Hydrogeological Data

3.2.1 Geotechnical Investigations

RJH collected geotechnical, geological, and hydrogeological information throughout the Study Area as part of field investigations performed in 2018 and 2019. The available data is summarized below and additional information is provided in the Phase I Geotechnical Report (RJH, 2019):

- Twenty-six borings were performed throughout the Study Area to collect geotechnical data. Twenty-four of these borings were completed as monitoring wells and instrumented with pressure transducers with integrated data loggers (data loggers) to measure groundwater levels, and the other two borings were backfilled with grout.
- Five data loggers were installed at five existing OSMP wells to measure groundwater levels.
- Three surface water stilling wells were installed in ponds on the CU Boulder South campus and were instrumented with data loggers to measure surface water levels.

Geotechnical information collected from CDOT and the CDSS database were used to supplement the Project-specific data collected by RJH. This information is summarized in the Phase I Geotechnical Report (RJH, 2019). A plan of geotechnical data locations used to develop the model structure is presented on Figure 3.2.

3.2.2 Geological Data and Interpretation

3.2.2.1 Geological Interpretation

Our interpretation of the Study Area geology is shown on Figure 3.3. The general subsurface profile at exploration locations consisted of fill or alluvium overlying bedrock of the Pierre Shale formation. Subsurface sections are presented in the Phase I Geotechnical Report (RJH, 2019). In general, fill overlied bedrock throughout mined portions of the CU Boulder South campus and alluvium overlied bedrock throughout the remainder of the Study Area.

A geological interpretation of the Study Area and material descriptions based on borings are presented in the Phase I Geotechnical Reports (RJH, 2019), and are summarized in the following sections.

3.2.2.2 Fill

Fill was encountered primarily in reclaimed mining areas of the CU Boulder South campus. The fill encountered in borings ranged from 2.0 to 22.8 feet thick, with the thicker fill deposits being encountered in the CU levee and other existing on-site embankments. Fill consisted of a variety of soil types that mostly ranged from poorly graded gravel with clay and sand to fat clay, and was commonly clayey sand.

3.2.2.3 Alluvium (Qal)

Alluvium encountered in borings ranged from 6.0 to 20.8 feet thick and samples recovered during drilling primarily classified as poorly graded sand with clay and gravel, poorly graded sand with silt and gravel, poorly graded gravel with clay and sand, and poorly graded gravel with silt and sand. In several of the borings, cobbles and/or boulders were encountered at or near the ground surface or while drilling.

Based on the recovered samples and observed drilling conditions, the alluvium appears to be a deposit of heterogeneous particles (sand, gravel, cobbles, and boulders) with minor amounts of silt or clay. Coarser or finer layers, either vertically or laterally, were not identified. The composition of collected samples was limited by the drilling and sampling techniques and, in our opinion, likely underestimate the abundance of gravel, cobbles, and boulders.

3.2.2.4 Fox Hills Sandstone (Kfh)

The Fox Hills Sandstone, which overlies the Pierre Shale east of SBC, was not encountered during geotechnical investigations and is not interpreted to be present beneath the SBC alluvial aquifer. Based on published mapping (Spencer, 1961), the contact between the Pierre Shale and the Fox Hills Sandstone near the Study Area is approximately 0.2 to 1.5 miles east of SBC, is higher in elevation than SBC, and the Fox Hills Sandstone dips downward to the southeast (away from the SBC alluvial valley).

3.2.2.5 Pierre Shale (Kp)

Bedrock of the Pierre Shale formation was encountered in each boring at depths that ranged from 3.7 to 22.8 feet below the ground surface. Borings ranged from 9.5 to 65.3 feet deep and terminated in the Pierre Shale. Pierre Shale is generally a low-permeability clayey shale composed mostly of low to medium plasticity fines. Bedrock is generally horizontally bedded and is predominantly unfractured. Bedrock ranged from fresh to intensely weathered and was mostly slightly weathered. Recovered samples of Pierre Shale were mostly dry to moist.

3.2.3 Stilling Well Data

Data loggers installed in the stilling wells provide long-term monitoring of the pond surface water. The data loggers collect surface water levels twice per day and the data is downloaded approximately every month. Data is available from approximately October 2018 to present. Water level trends measured by the data loggers are summarized in Section 3.2.4.

3.2.4 Monitoring Well Data

OSMP provided RJH with water level measurements collected from 1991 to 1998 for the existing wells on OSMP property. The historical data provided by OSMP is presented in the Phase I Geotechnical Report (RJH, 2019). Based on historical data, groundwater levels in the wells fluctuated about 2 to 6 feet seasonally from 1991 to 1998. Throughout this period of record, groundwater levels were highest generally in April through July and were lowest in September through November.

RJH installed data loggers in 36 monitoring wells drilled by RJH and five OSMP wells to provide long-term monitoring of groundwater. Wells are screened in either surficial soil units (fill or alluvium as described in Section 3.2.2) or bedrock. The data loggers collect groundwater levels twice per day and the data is downloaded approximately every month. Groundwater levels from the data loggers are generally available from October 2018 to present and manual groundwater measurements in some wells are available as early as February 2018.

Available groundwater and pond surface water levels measured from February 2018 to April 2020 are presented in the Water Level Data Collection Update Memorandum (RJH, 2020). Groundwater and surface water levels were generally relatively consistent and lowest from October 2018 to March 2019. From March through July 2019, water levels began to increase and become more variable, fluctuating about 1 to 4 feet in less than one week. Water levels generally declined from August through September 2019. The most significant fluctuations are observed in wells in alluvium in OSMP fields adjacent to US36; the seasonal fluctuations show generally similar trends to historical OSMP data for the same area. The general water level trends observed during fall 2018 through fall 2019 appear to be consistent with observations for fall 2019 to present.

3.3 Climate and Water Cycle Data

Climate data for the Study Area are available online through the National Oceanic and Atmospheric Administration's (NOAA) NWS website (NWS, 2020). The NWS website reports climate data for the Denver-Boulder Forecast Office (NOAA Earth System Research Laboratory, Physical Sciences Laboratory), which is located approximately 2 miles northeast of the proposed Project facilities. Available monthly summarized data that is representative of climate conditions are: precipitation, snowfall, maximum temperature, minimum temperature, and average temperature. Precipitation represents rainfall, snowfall, and hail either by direct measurement or using a snow-to-water equivalent (NOAA, 2020). Historical climate data from 1991 to present is provided in Appendix A. This period of data was collected by RJH because it corresponds to the largest time period of available monitoring well data (i.e., historical OSMP monitoring well data and Project monitoring well data presented in Section 3.2.4).

Water cycle data consists of background groundwater recharge caused by precipitation infiltration (background recharge) and evapotranspiration. Jasechko et al. (2014) reported that background recharge is typically about 16 percent of the annual precipitation, and the background recharge in arid and temperate climates is greater in the winter than in the summer months.

Evapotranspiration rates vary spatially depending on vegetative cover, crop type, and water availability, and vary seasonally with precipitation, weather, and vegetation growth patterns. The primary vegetation in the Study Area consists of native grasses, irrigated grasses, and riparian/phreatophytes, which is generally represented by cottonwood trees. Typical monthly evapotranspiration for irrigated grass in the Study Area ranges from 1.6 to 6.3 inches (Northern Water, 2020). Typical evapotranspiration rates for cottonwoods range from 3 feet per year to over 7 feet per year (Kimbrough, 1995; Robinson, 1958). RJH could not identify published typical evapotranspiration rates for native grass in the Study Area; however, it is our opinion that evapotranspiration rates for native grass would generally follow the same seasonal pattern as irrigated grass, except with lower evapotranspiration rates because of lack of water availability and how native grasses have adapted to the arid climate. Additional information about evapotranspiration data is provided in Appendix A.

3.4 South Boulder Creek Data

3.4.1 Stream Gauges

MHFD operates three gauging stations on SBC within the Study Area as shown on Figure 3.4. Characteristics of the three gauging stations are:

- Sans Souci: Data is available from 2011 to present. The Sans Souci gauging station is a flood alert gauge and is generally accurate for higher creek flows that identify flooding; however, the range of flows over which this station has been calibrated is unknown.
- S. Boulder Canon: Data is available from 2011 to 2013. The S. Boulder Canon gauging station is no longer operational because it was destroyed in the September 2013 flood event and has been removed.
- S. Boulder Rd.: Data is available from 2011 to present. The City reports that they are calibrating rating curves for this gauging station, which are considered accurate below about 15 cubic feet per second (cfs).

Flow and/or stage data for the three SBC gauging stations are available in real-time on the MHFD website (MHFD, 2020). The gauging stations often have multiple records per day. Records starting in 2011 typically have either flow or stage data whereas records starting in 2013 for the Sans Souci gauging station and in 2018 for the S. Boulder Rd. gauging station have both flow and stage data. Data for the Sans Souci and S. Boulder Rd. gauges are provided in Appendix B. Data for the S. Boulder Canon gauge was not evaluated by RJH because of the short period of available data.

3.4.2 Field Measurements

The City recorded streamflow and stage levels at five locations on March 10, 2020 to document general stream conditions along SBC during a typical non-irrigation month. The locations of field measurements are shown on Figure 3.4 and results are summarized in Table 3.1.

TABLE 3.1
SOUTH BOULDER CREEK MANUAL FIELD STREAM MEASUREMENTS

Location No.	Location Description	Streamflow Reading (cfs)	Stage Reading (ft)
1	Sans Souci Gauging Station	1.66	0.57
2	S. Boulder Rd. Gauging Station	1.79	0.67
3	Between New Dry Creek Carrier Ditch & Viele Channel	0.17	0.49
4	E. Boulder Ditch Flume	(1)	0.13
5	Baseline Rd.	0.2	0.95(2)

Notes:
1. Streamflow reading was not obtained.
2. No staff gauge is present at this location. Stage reading was estimated using flow measurement probe.

New Dry Creek Carrier Ditch diverts water from SBC between measurement locations 2 and 3 (Figure 3.4). During the fieldwork, the New Dry Creek Carrier Ditch gate was observed to be leaking water into the ditch from SBC at a visually-estimated rate of approximately 1 to 2 cfs. The observed leakage into New Dry Creek Carrier Ditch is generally similar to the difference in measured streamflow between locations 2 and 3.

By comparing the streamflow measurements between locations 1 and 2 and between locations 3 and 5, it appears that the flowrate in SBC was generally consistent to very slightly gaining on March 10, 2020 (i.e. groundwater flows into SBC and SBC flowrate increases slightly in the downstream direction). However, the relative differences between adjacent measurement locations are within the expected accuracy of the measurements and suggest that there is not significant interaction between this reach of SBC and the aquifer during the non-irrigation season.

3.5 Irrigation Ditch Data

3.5.1 Recorded Data

OSMP provided RJH with GIS shapefiles that represent the spatial extent of irrigated fields, the typical crop produced on each field, the associated irrigation ditch used to irrigate each field, and the locations of irrigation ditches and laterals. Many of the shapefiles provided by OSMP appear to have been last updated in October 2019 based on the file attribute information. The irrigated fields and main irrigation ditches based on shapefiles provided by OSMP are shown on Figure 3.5. The laterals are not shown on Figure 3.5.

The irrigation ditches within the Study Area have gauging stations that record the amount of water diverted from SBC. The locations of irrigation ditch diversion gauging stations based on records from the CDSS database (CDSS, 2020) are shown on Figure 3.5. Anderson Ditch has a gauging station west of the Study Area, which measures flow toward SBC; there is no gauging station at the confluence of Anderson Ditch with SBC. The S. Boulder and Bear Creek Ditch splits from Upper Bear Creek Ditch downstream of the diversion gauging station, and S. Boulder and Bear Creek Ditch flows into Dry Creek No. 2 Ditch in the Study Area. These junctions are not gauged and it is unknown what portion of the diverted water ultimately flows into Dry Creek No. 2 Ditch. There are no monitoring devices further downstream than the point of diversion from SBC on the irrigation ditches or on the laterals. Therefore, it is unknown how much water is applied to the irrigated fields on OSMP versus how much water continues downstream past the Study Area.

Ditch diversion data from the gauging stations is provided in Appendix C. Ditch diversion records are reported as total monthly diversion amounts and are available online through the CDSS database (CDSS, 2020) approximately one year after the irrigation year. An irrigation year is from November through the following October and is identified based on the calendar year starting in January (e.g., the 2019 irrigation year is from November 2018 through October 2019). Available ditch data is generally from as early as 1950 to October 2019; however, not all irrigation years are available for each ditch. Based on records from the CDSS database, flows in the irrigation ditches generally occur seasonally from the spring to late summer or early fall.

3.5.2 Field Observations

RJH observed general irrigation conditions during fieldwork activities since 2018. We also reviewed historical aerial imagery using Google Earth Pro (Google, Inc., 2020).

During geotechnical investigations, access routes to borings on OSMP property were designed to avoid T&E species and soft or wet areas from irrigation. RJH observed that areas inundated from flood irrigation would change location and the areas of wet or soft soils would change within one week. In other portions of the OSMP fields, vegetation was dry and sparse with cactus present, which implies a probable lack of irrigation in these areas.

When RJH was on-site approximately monthly to download data from monitoring well data loggers, soft soils or inundated areas were often encountered when traveling between borings on OSMP property by foot. The locations of the soft soils or inundation generally changed each month.

RJH performed site visits on June 16 through 18, 2020 to observe and characterize the irrigation activity on the OSMP property within the Study Area. The following were observed during the site visit and are presented from upstream to downstream:

- Laterals in the OSMP fields south and north of US36 were observed to have flow that overtopped the banks, followed topography, and joined as overland flow into other laterals. The connection of flow between laterals is not apparent on the shapefiles provided by OSMP.
- From the CU Boulder South campus downstream to the confluence with SBC, Viele Channel had standing water with little to no flow. Upstream of CU Boulder South campus, Viele Channel was dry.
- Based on flow measurements in Dry Creek No. 2 Ditch, there is an approximately 84 percent loss of available ditch flow over the OSMP fields south and north of US36. The loss of ditch flow is likely attributed to flood irrigation being applied to these fields.
- Anderson Ditch had standing water with no flow and the confluence with SBC was blocked with flashboards, preventing water in the ditch from entering SBC.
- Dry Creek No. 2 Ditch was passing approximately 0.5 cfs of flow downstream of the Study Area.

- OSMP fields immediately south of Baseline Road appeared generally dry with no flood irrigation occurring.
- Howard Ditch was passing approximately 3.2 cfs of flow downstream of the Study Area.

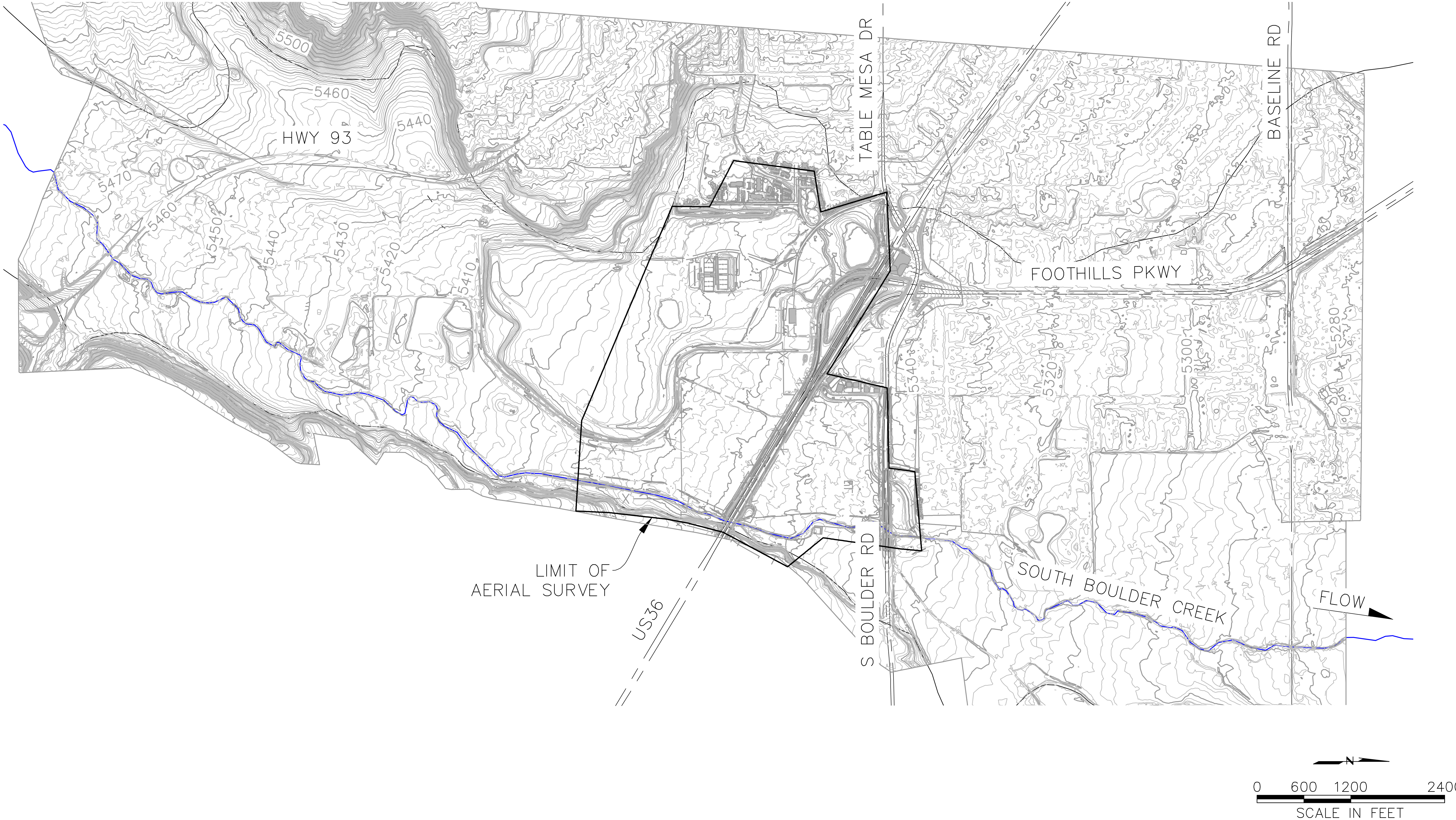
Vegetation changes based on color were observed in aerial imagery using Google Earth Pro (Google, Inc., 2020) and demonstrate general irrigation information. During months with little to no irrigation (e.g., March and September), ditches and some laterals throughout the OSMP fields are obvious and vegetation cover is typically brown. During months with irrigation (e.g., May), the ditches and laterals become less obvious as vegetation becomes greener throughout the irrigated fields. The amount of green vegetation varies in as little as one week. Even during irrigation months, it appears that there are local areas that receive less irrigation based on the brown color vegetation compared to nearby green vegetation.

Irrigation activity occurs by flood irrigation using ditches and laterals to provide water to multiple fields. However, there is only volumetric water data for the ditches where water is diverted from SBC. No flow or volumetric water data is available for the ditches downstream of the diversion or on any laterals. Once water is diverted from SBC, it can flow between laterals from overland flow. Because there are no written records of the flood irrigation location and timing within the OSMP fields, the amount and timing of water applied to the different OSMP fields is unknown.

Based on field observations, the irrigation on OSMP property appears highly variable in both spatial extent and temporal application.

3.6 Other Surface Water Data

Monitoring devices are not installed on Viele Channel or the CU Boulder South campus drainage ditches. We were unable to identify any existing surface water data for these facilities.



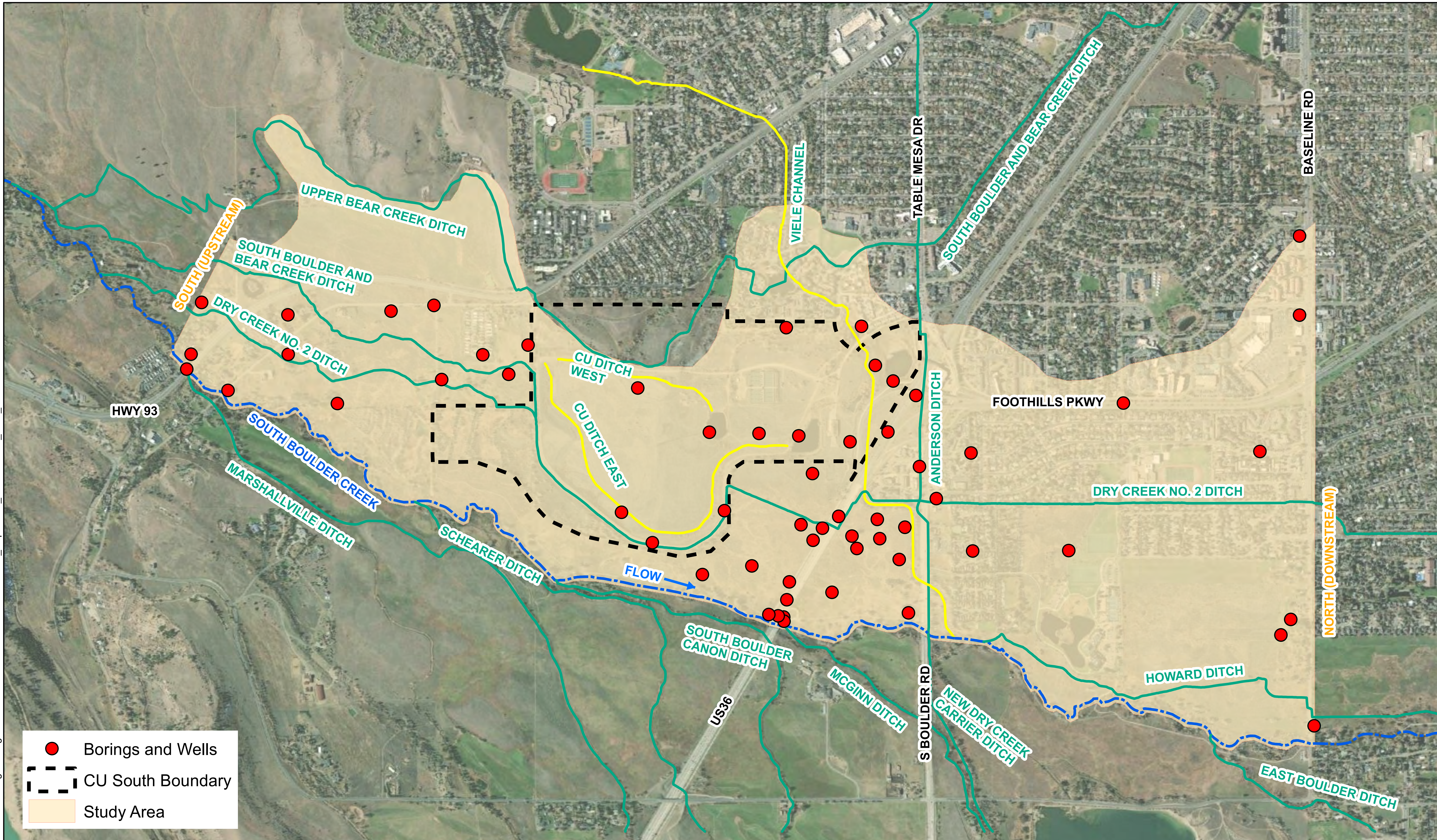
REPRODUCE IN COLOR

NOTE:

1. TOPOGRAPHY WAS DEVELOPED FROM LIDAR DATA PROVIDED BY THE CITY AND COUNTY OF BOULDER AND AERIAL SURVEY DATA PROVIDED BY FLATIRONS SURVEYING, INC.

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	STUDY AREA TOPOGRAPHY
		PROJECT NO. 16134	July 2021 **Figure 3.1**

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\BASELINE_REPORT\FIGURE 3.1 – STUDY AREA TOPOGRAPHY.DWG 7/8/2021 2:12 PM



NOTE:
1. POINTS SHOWN ARE GEOTECHNICAL LOCATIONS FROM CDOT, CDSS, OSMP, AND RJH.

0 600 1,200 2,400 Feet

REPRODUCE IN COLOR

N

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

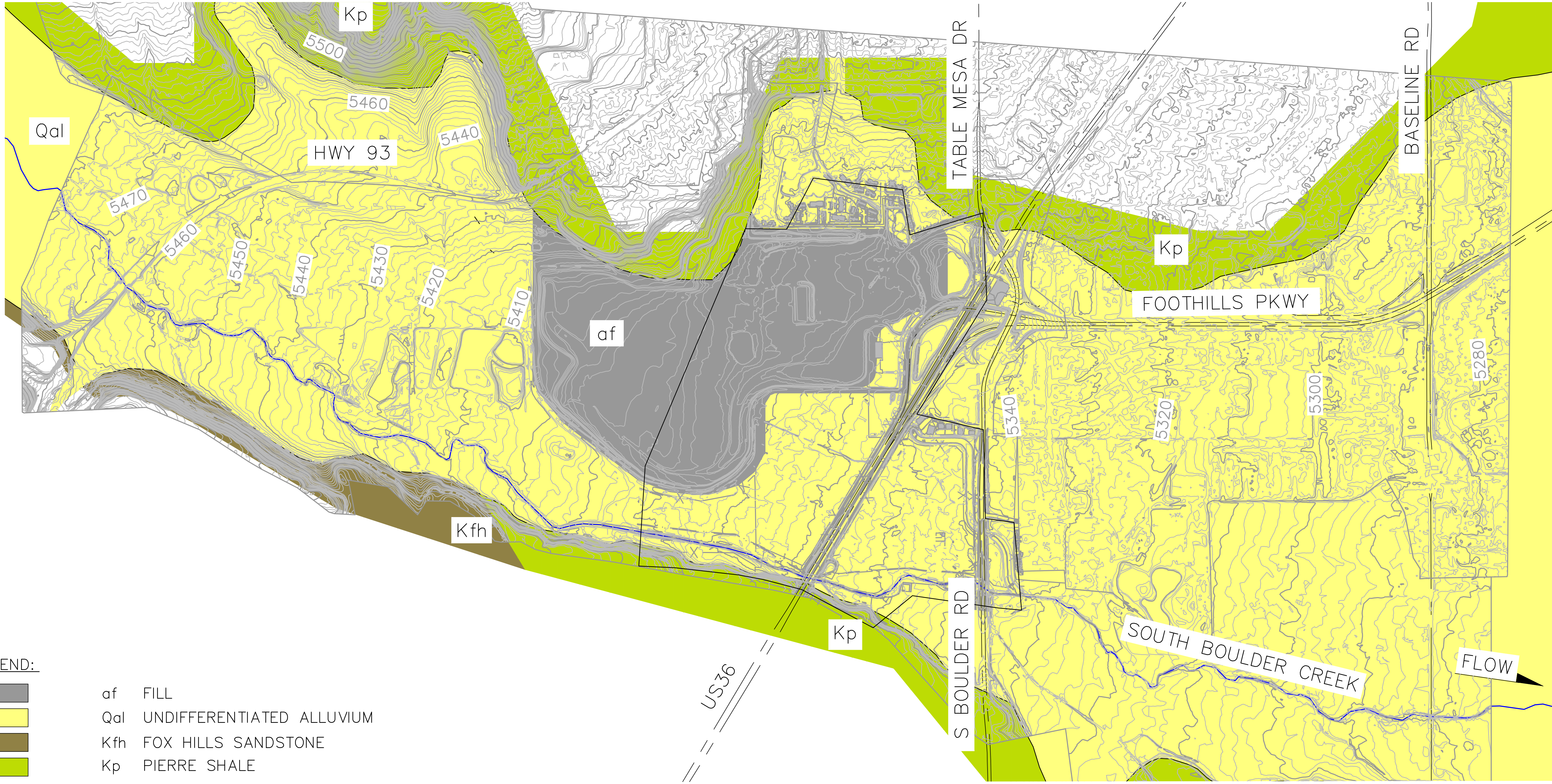
GEOTECHNICAL DATA LOCATIONS

PROJECT NO. 16134

July 2021

Figure 3.2

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline_Report\3.2_Geotechnical_Data_Locations.mxd



LEGEND:

	af	FILL
	Qal	UNDIFFERENTIATED ALLUVIUM
	Kfh	FOX HILLS SANDSTONE
	Kp	PIERRE SHALE

N

0 600 1200 2400

SCALE IN FEET

REPRODUCE IN COLOR

NOTES:

1. SURFICIAL DEPOSITS ARE MAPPED WHERE THEY ARE ANTICIPATED TO BE MORE THAN APPROXIMATELY 5 FEET THICK.
2. MAPPED UNITS ARE APPROXIMATE AND BASED ON INFORMATION FROM PUBLISHED U.S. GEOLOGICAL SURVEY MAPS (MALDE, 1995; SPENCER, 1961; TRIMBLE, 1975; WRUCKE AND WILSON 1967), DATA OBTAINED FROM THE NATURAL RESOURCES CONSERVATION SERVICE SOIL SURVEY, AND FIELD OBSERVATIONS BY RJH.

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

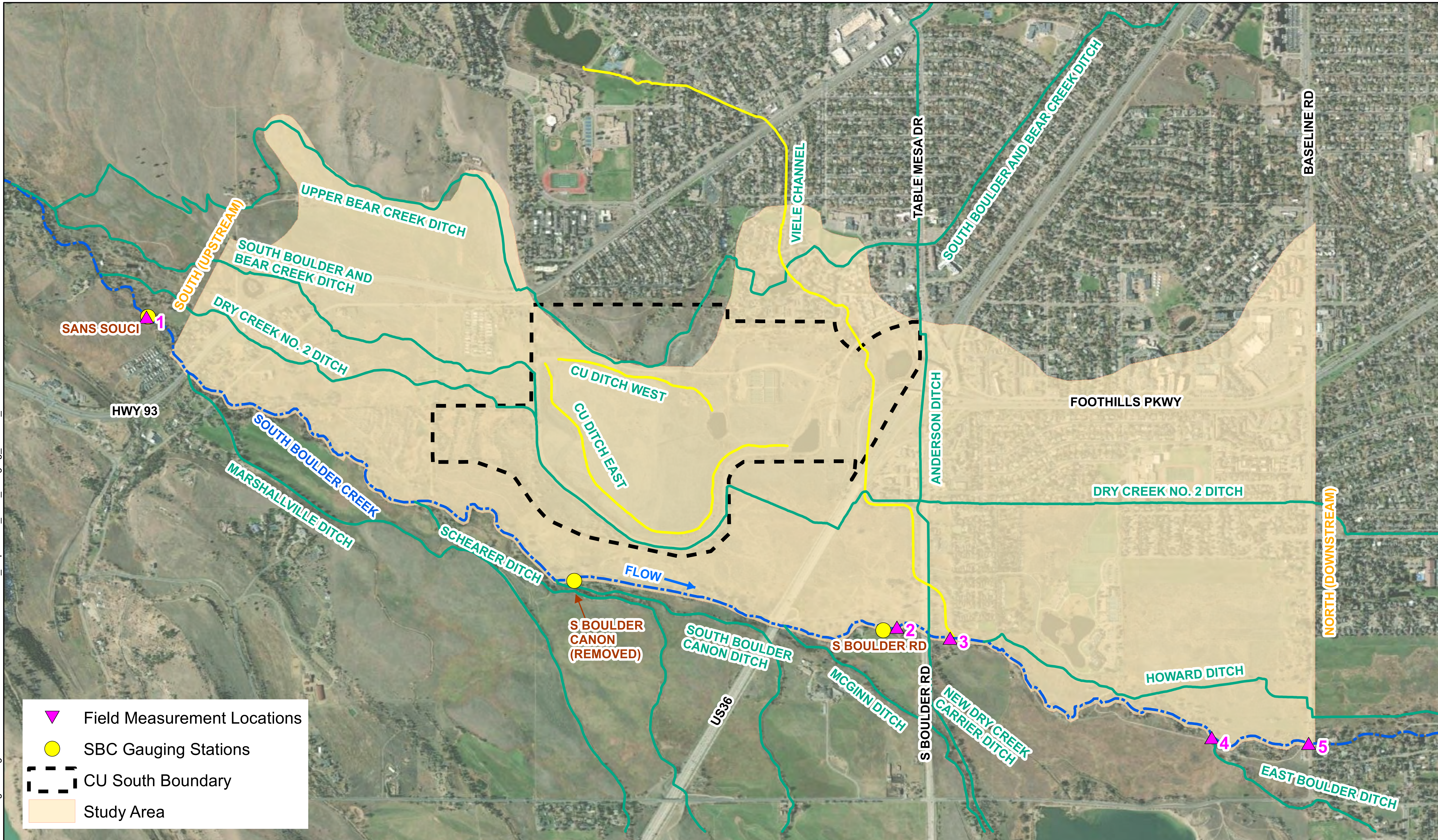
PROJECT NO. 16134

STUDY AREA GEOLOGY

July 2021

Figure 3.3

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\BASELINE_REPORT\FIGURE 3.3 – STUDY AREA GEOLOGY.DWG 7/8/2021 2:21 PM



NOTE:
1. FIELD MEASUREMENTS TAKEN ON MARCH 10, 2020 BY THE CITY OF BOULDER USING A HANDHELD FLOW METER.

0 600 1,200 2,400 Feet

REPRODUCE IN COLOR

N

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

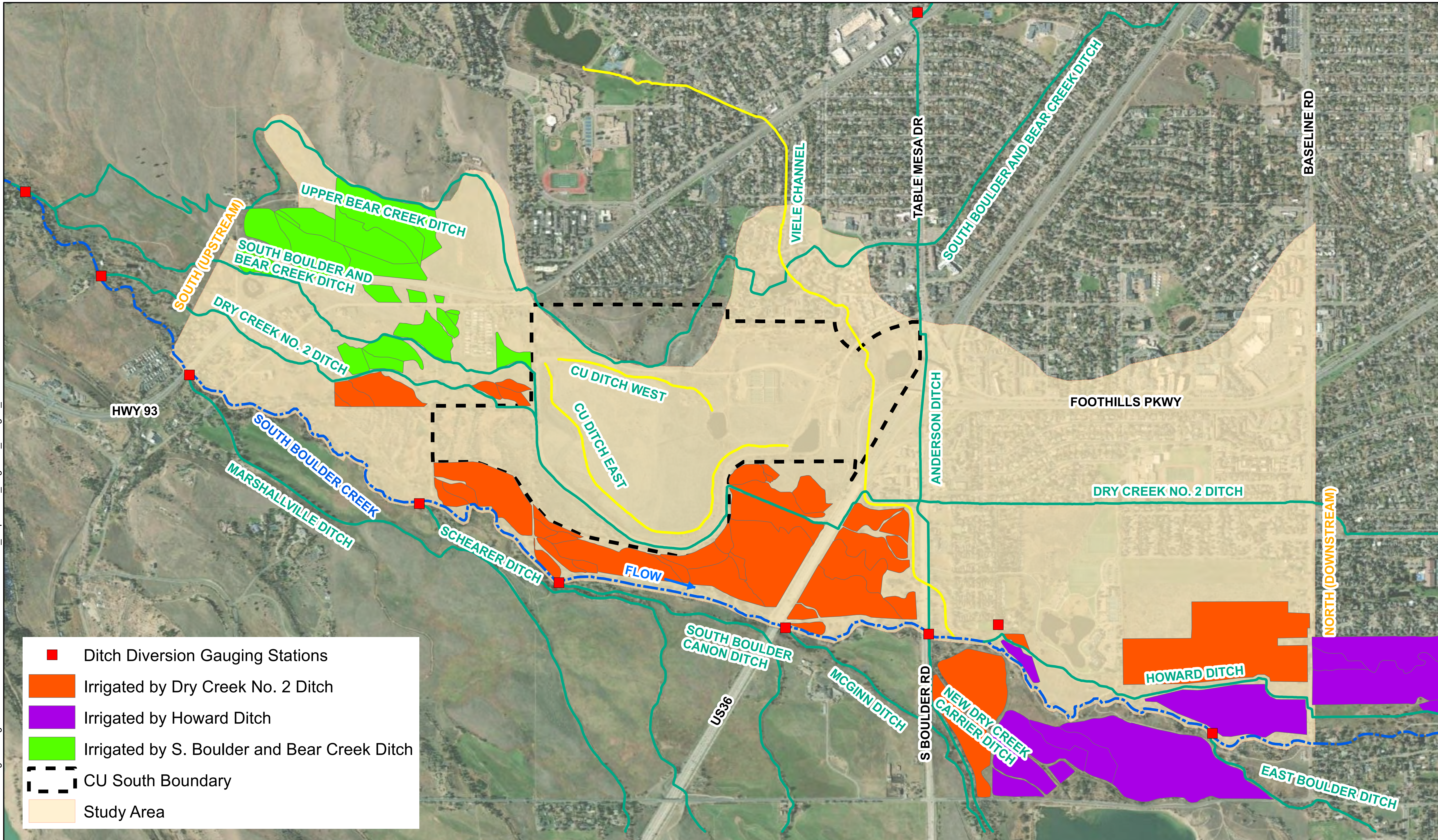
PROJECT NO. 16134

SOUTH BOULDER CREEK GAUGING STATIONS AND FIELD MEASUREMENTS

July 2021

Figure 3.4

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline_Report\3.4_SBC_Gauging_Stream_Measurements.mxd



P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\GroundwaterBaseline_Report\3.5_Irrigation_Gauges_Fields.mxd

NOTE:
1. IRRIGATION DITCH LOCATIONS AND IRRIGATED FIELDS DEFINED BY SHAPEFILES PROVIDED BY OSMP.

REPRODUCE IN COLOR

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

IRRIGATION GAUGING STATIONS,DITCHES, AND FIELDS

PROJECT NO. 16134

July 2021

Figure 3.5

SECTION 4 - HYDROGEOLOGIC CONCEPTUAL MODEL

4.1 General

The goal of a hydrogeologic conceptual model is to simplify the field conditions as much as possible while still retaining sufficient complexity to adequately simulate actual conditions (Anderson et al., 2015). The Hydrogeologic Conceptual Model is used to generate the Baseline Model, and identifies the general conditions to be input into the numerical model (i.e., the model extent, stratigraphy, hydraulic properties, and boundary conditions) and variables that are used to define the period of transient simulations (i.e., precipitation, applied irrigation, and evapotranspiration from natural vegetation and crops). Characteristics of the Hydrogeologic Conceptual Model are summarized in the following sections.

4.2 Model Extent

The approximate extent of the modeled area is represented by the Study Area shown on Figure 2.1. The model extent was about 3 miles long (north-south) and varied laterally (east-west) from about 0.3 miles near the southern boundary to 1.3 miles near the northern boundary. This area was bounded on the east by SBC, which generally flows from the south toward the north. The western model extent was bounded by a geologic contact between the Pierre Shale and surficial soil (alluvium and fill as shown on Figure 3.3), which represented our interpreted edge of the alluvial aquifer. The south and north ends of the model extent were bounded by artificial boundaries and were placed near borings at the upstream and downstream limits, respectively, of the Phase I geotechnical investigation. The selected upstream and downstream limits of the modeled area were also practical based on the following geomorphic reasons:

- Downstream of the modeled extent, the SBC alluvial valley widens and converges with the Boulder Creek alluvial valley.
- Upstream of the modeled extent, the SBC alluvial valley becomes a relatively narrow mountain stream.

Project facilities will generally be constructed near the middle of the model extent as shown on Figure 1.2. The alluvial aquifer ranged from about 3.5 to 22.0 feet thick and the maximum additional hydraulic head that will be impounded by the proposed detention facility is about 23 feet. The aquifer thickness and hydraulic head were small relative to the model extents, and in our opinion the model extents are sufficiently far away to reduce boundary effects to acceptable levels for the Baseline Model and to support evaluation and design of Project facilities.

4.3 Hydrologic System

As described in the Phase I Geotechnical Report (RJH, 2019), the SBC alluvial valley enters the upstream end of the Study Area as a relatively narrow mountain stream flowing from Eldorado Canyon. As SBC flows past the proposed Project facilities, the alluvial valley generally widens until it converges with the Boulder Creek alluvial valley downstream of Baseline Road. Much of the alluvial material has been mined from CU Boulder South campus and was replaced with fill; the natural alluvium appears to be constricted between the CU levee and SBC east of the CU Boulder South campus (Figure 3.3).

The SBC alluvial valley aquifer is interpreted to be an unconfined aquifer that extends throughout surficial soils (alluvium and fill) and is perched on the underlying Pierre Shale bedrock, which is a regional aquitard. At the locations of RJH's borings, the alluvium generally decreases in thickness from upstream to downstream. Based on the available data, the top of bedrock beneath the surficial soil appears to form a consistent broad surface that in some locations decreases in elevation to the west (away from SBC).

Pierre Shale bedrock is not anticipated to transmit significant groundwater; however, some bedrock was included in the model so subsequent design models could evaluate seepage beneath the proposed Project facilities. SBC and the associated alluvial aquifer continue upstream (south) and downstream (north) beyond our model extents.

Inflow or outflow to the modeled extent of the aquifer primarily included the following sources:

1. Regional groundwater flow into and out of the modeled aquifer along the upgradient and downgradient boundaries, respectively.
2. Interaction between groundwater and surface water along SBC and at ponds within the Study Area.
3. Groundwater discharge to drainage ditches (Viele Channel, CU Ditch West, and CU Ditch East) or other topographic low points such as empty irrigation ditches. The drainage ditches and irrigation ditches are shown on Figure 3.5.
4. Background recharge and evapotranspiration.
5. Recharge from irrigation activities. Irrigation ditches and the approximate extents of irrigated fields are shown on Figure 3.5.

Conceptualized model stratigraphy, range of material properties, and inflow and outflow sources are presented in the following sections.

4.4 Stratigraphy

The geologic units described in Section 3.2 were used to define the stratigraphy in the model. The Fox Hills Sandstone was not included because it is outside the model extent. In general, the subsurface profile in the model extent consists of surficial units (alluvium and fill) overlying the Pierre Shale bedrock. The areal extent of surficial soil units are shown on Figure 5.1. There are some areas of open water bodies within the Study Area that are also shown on Figure 5.1.

The alluvium unit was divided into three zones to simulate areas that have different material properties (i.e., hydraulic conductivity) based on in-situ test results performed during the Phase I geotechnical investigation and model calibration. One alluvium zone was used throughout most of the model extent and two smaller alluvium zones were used in the OSMP field north of US36. Material properties for the overall alluvium unit are presented in Section 4.5.

The Pierre Shale unit was divided into two zones to simulate areas of moderately weathered bedrock (i.e., weathered) and fresh to slightly weathered (i.e., unweathered) bedrock based on observations of bedrock samples recovered from borings performed during the geotechnical investigations. The weathered bedrock zone was considered to be the upper 12 feet of bedrock near the eastern model extending from approximately 1,500 feet upstream of US36 to the downstream model extent. The unweathered bedrock zone was considered to be the remainder of the model extent. A typical section showing the distribution of the Pierre Shale zones is shown on Figure 5.3.

4.5 Material Properties

4.5.1 General

The following material properties were developed for the geologic units presented in Section 4.4:

- Horizontal hydraulic conductivity (Kh).
- Anisotropy ratio (horizontal to vertical hydraulic conductivity, Kh/Kv).
- Specific storage (Ss).

- Specific yield (Sy).

Steady-state and transient models require horizontal hydraulic conductivities and anisotropy ratios. A transient analysis of an unconfined aquifer also requires specific storage and specific yield. The material properties presented herein are based on physical properties of the material and do not vary throughout the simulation period.

4.5.2 Hydraulic Conductivity and Anisotropy Ratio

Ranges of hydraulic conductivity were based on in-situ test results obtained during the Phase I geotechnical investigation (RJH, 2019) that we interpret to predominantly measure horizontal hydraulic conductivity. The in-situ tests consisted of rising head slug tests, falling head slug tests, single-well constant head tests within fill and alluvium units, and Packer tests within Pierre Shale bedrock. Five in-situ tests were performed in five borings within fill. Thirty-five in-situ tests were performed in 24 borings within alluvium. In some borings, multiple in-situ tests were repeated over the same test interval. Data from nine Packer tests in three borings within Pierre Shale were included in our evaluations. Each Packer test performed in Pierre Shale was conducted over a unique test interval within the borings such that there was no overlap of testing. Three Packer test results obtained from B-109(P) were not included in our evaluation because difficulties seating the Packer (i.e., sealing the inflatable Packer against the borehole walls) were experienced in this boring and in our opinion the Packer test results were not reliable. Additional information about the hydraulic conductivity testing is provided in the Phase I Geotechnical Report (RJH, 2019).

The range of hydraulic conductivity test results for each hydrogeologic unit are summarized in Table 4.1. The calculated hydraulic conductivities presented in this Report are rounded to two significant digits for presentation purposes; however, the primary importance is the order of magnitude of the results. The ranges of measured test results are generally within reasonable ranges for each of the tested hydrogeologic units.

Anticipated ranges for the anisotropy ratio of each hydrogeologic unit are summarized in Table 4.1. These values were selected based on engineering judgement and the following (Appendix E):

- An anisotropy ratio between 4 and 10 was identified for fill based on U.S. Bureau of Reclamation (Reclamation) recommendations for compacted clayey sand (Reclamation, 2014).

- An anisotropy ratio between 10 and 100 was identified for alluvium based on Reclamation recommendations for stratified water-deposited natural soils (Reclamation, 2014).
- An anisotropy ratio between 1 and 10 was identified for Pierre Shale based on Reclamation recommendations for rock and stratified deposits (Reclamation, 2014).

TABLE 4.1
SUMMARY OF IN-SITU HORIZONTAL HYDRAULIC CONDUCTIVITY TEST RESULTS AND RANGE OF PUBLISHED ANISOTROPY VALUES

Unit	Minimum Hydraulic Conductivity Test Result (cm/s)	Geometric Mean of Hydraulic Conductivity Test Results (cm/s)	Maximum Hydraulic Conductivity Test Result (cm/s)	Selected Range of Published Anisotropy Ratio (K_h/K_v)
Fill	9.7×10^{-6}	3.6×10^{-5}	3.6×10^{-4}	4 to 10
Alluvium	5.6×10^{-5}	5.8×10^{-4}	3.1×10^{-2}	10 to 100
Pierre Shale	1.0×10^{-7}	2.1×10^{-6}	3.2×10^{-4}	1 to 10

4.5.3 Specific Storage and Specific Yield

Ranges of specific storage and specific yield values were developed for each hydrogeologic unit based on published data (Appendix E) and are summarized in Table 4.2. Specific storage for each unit was based on values presented by Anderson et al. (2015) for similar materials. Specific yield for alluvium was based on estimates for fine sand and coarse materials with some fines content by Morris and Johnson (1967). The specific yield of the fill unit was based on estimates for silt by Morris and Johnson (1967). Specific yield of Pierre Shale was estimated from ranges for clay presented by Morris and Johnson (1967) and generalized values presented by Zheng and Bennett (1995).

TABLE 4.2
SUMMARY OF PUBLISHED SPECIFIC STORAGE AND SPECIFIC YIELD VALUES

Unit	Specific Storage (Ss) (ft^{-1})	Specific Yield (Sy) (%)
Fill	4.0×10^{-5} to 6.1×10^{-5}	1 to 39
Alluvium	1.5×10^{-5} to 3.0×10^{-5}	1 to 46
Pierre Shale	1.0×10^{-6} (1)	1 to 17

Note:
1. Range of values not provided.

4.6 Model Geometry Boundary Conditions

4.6.1 Upstream and Downstream Boundary Conditions

Inflow and outflow of groundwater along the upstream and downstream model extents were simulated using specified head boundary conditions. A specified head boundary condition allows water to enter or exit the model as needed to maintain a user-specified head (i.e., groundwater level). Groundwater data from monitoring wells near these areas were used to select appropriate specified head elevations; data from B-102(P) was used to define the upstream boundary condition and data from B-106(P) was used to define the downstream boundary condition. The specified head values at the boundary conditions varied monthly throughout the modeled time period and were based on the average groundwater levels recorded in the respective wells each month. The locations of the specified head boundary conditions are shown on Figure 5.1, and the locations of B-102(P) and B-106(P) are shown on Figure 6.1.

At the downstream end of the model, the groundwater elevation is anticipated to decrease from west to east when the SBC alluvial aquifer converges with the Boulder Creek alluvial aquifer. Therefore, the downstream boundary condition was varied along its length to simulate the expected variation in groundwater level.

The methods used to develop the upstream and downstream boundary conditions are provided in Section 5.

4.6.2 South Boulder Creek Boundary Condition

SBC is considered a hydrologic boundary and represented the eastern boundary of the groundwater model. Boundary condition options for modeling creeks within MODFLOW-USG include specified head, drain, river, and the SFR package. We modeled SBC using the SFR package because the SFR package is based on flow rates that can change over time and space, and therefore river gauging station data and ditch diversion data can be readily incorporated into the boundary condition.

Data from the Sans Souci gauging station (Section 3.4) were selected to establish the flow input at the upstream end of the SFR boundary condition because the Sans Souci gauging station is located near the upstream model extent.

Ditch diversions from SBC were incorporated into the SFR boundary condition by subtracting the diversion amount from the SFR inflow at the upstream end of the corresponding boundary condition segment. Anderson Ditch is the only monitored ditch in the Study Area that conveys water into SBC. Flow from this ditch was not added to the SFR boundary condition primarily for two reasons:

- All other irrigation ditch diversions within the Study Area are monitored near SBC and the data are considered reliable for estimating the change in flow rate within the creek; however, Anderson Ditch is monitored approximately 1.6 miles west of the confluence with SBC and therefore there is less reliability that the diversion records accurately reflect the amount of water that gets added to SBC (Figure 3.5), and
- RJH has observed flashboards placed in the Anderson Ditch such that water in the ditch was prevented from entering SBC.

The methods used to develop the SFR boundary condition are provided in Section 5.

4.6.3 West Model Extent and Bottom of Model

The western edge and bottom of the model were considered to be Specific Flux - No Flow boundaries. This type of boundary does not allow any water to enter or exit the model. The western edge and bottom of the model exist within Pierre Shale bedrock, which is not anticipated to contribute much flow to the conceptualized groundwater system.

4.7 Internal Boundary Conditions

4.7.1 Drain Boundary Conditions

Drainage ditches and irrigation ditches within the model extent were simulated using drain boundary conditions. Drain boundary conditions let water exit the model if the groundwater elevation is higher than the drain but do not allow water to enter the model. This type of boundary condition is appropriate to use in topographically low areas to allow for groundwater seepage out of the subsurface. Drain boundary conditions were assigned to the two drainage ditches on CU Boulder South campus, Viele Channel, and irrigation ditches as shown on Figure 3.5.

4.7.2 Recharge and Evapotranspiration

Two types of recharge were applied to the model: 1) background recharge caused by precipitation infiltration, and 2) irrigation recharge from flood irrigation activities. Background recharge was apportioned month by month based on precipitation data from the Denver-Boulder Forecast Office (NWS, 2020). Irrigation recharge was based on a portion of the available water diverted through irrigation ditches and was applied over irrigated fields during months when diversions were occurring. Losses from evapotranspiration were applied based on general vegetation type, crop type, and development. The input values selected for recharge were also adjusted during model calibration. The methods used to apply recharge and evapotranspiration are provided in Section 5. Model calibration is presented in Section 6.

4.8 Simulation Period

4.8.1 General

There are two general categories of groundwater models: steady-state models and transient models. Steady-state models are used to simulate groundwater conditions that reach dynamic equilibrium (i.e., recharge to the aquifer is balanced by discharge from the aquifer) (Fetter, 2001). Transient models are used to simulate conditions that do not reach equilibrium because repeated changing conditions affect groundwater flow before dynamic equilibrium can be reached.

Our Baseline Model consists of a steady-state component during non-irrigation conditions (Baseline Steady-State Model) and a transient component representing data for a period of one year (one irrigation season) (Baseline Transient Model).

The Baseline Steady-State Model was developed to simulate non-irrigation steady-state conditions to provide initial input values for the Baseline Transient Model. The Baseline Steady-State Model uses a portion of the non-irrigation season to represent typical conditions because groundwater levels during the non-irrigation season are relatively stable and appear to reach steady-state behavior.

The Baseline Transient Model was developed to simulate non-irrigation and irrigation transient conditions. One year of data was incorporated into the model and the sequence was repeated (i.e., one year of data was run twice in series) to reduce potential effects of the Baseline Steady-State Model component.

We also attempted to develop a steady-state model to simulate irrigation conditions. We identified that a very minor amount of irrigation needed to be applied on OSMP fields to produce the observed rises in monitoring well levels, which did not appear reasonable with respect to field observations. We concluded that a steady-state model was not appropriate for simulating the transient irrigation activities, and therefore we abandoned efforts at modeling irrigation activities as steady-state conditions.

4.8.2 Approach

Based on the data, annually there appear to be two distinct hydrogeologic seasons in the Study Area: a non-irrigation season and an irrigation season. The 2019 irrigation year (i.e., November 2018 through October 2019) was chosen as the transient simulation time period for the Baseline Transient Model because groundwater data was available from RJH's Phase I monitoring wells that could be used for model calibration throughout this time period. November 2018 was chosen as the simulation period for the Baseline Steady-State Model because it represents the first month of the 2019 irrigation year and typical groundwater conditions during the non-irrigation season.

In general, 2019 is considered to be a representative time period and appears to generally correspond to typical weather conditions observed from 1991 through 2019. Climate data comparing 2019 to the historical average from 1991 through 2019 is provided in Appendix A and we identified the following trends:

- 2019 follows the general pattern of precipitation for average historical data from January through July. Precipitation in August and September were considerably lower than the average; however, October and November were higher than average.
- The 2018/2019 winter season generally followed the average snowfall pattern. Higher than average and then lower than average snowfall amounts occurred in November and December, respectively.
- 2019 closely follows the average historical data for maximum temperature, minimum temperature, and average temperature.

SECTION 5 - NUMERICAL MODEL

5.1 Model Implementation and Settings

The MODFLOW suite of numerical programs is an international standard for simulating and predicting groundwater conditions and groundwater/surface water interactions (USGS, 2020). Numerical modeling was completed using MODFLOW-USG based on recommendations by the groundwater modeling team members and code selection considerations documented in ASTM D6170 (ASTM, 2017). MODFLOW-USG is an unstructured grid version of MODFLOW that was developed by the USGS and is a three-dimensional control volume finite difference model (Panday et al., 2013). The GUI software program Visual MODFLOW Flex, Version 6.1, Build 7088.31257 by Waterloo Hydrogeologic (Waterloo Hydrogeologic, 2019a) was used to develop the model ground surface and stratigraphy surfaces. The GUI software program Groundwater Vistas, Version 7.24, Build 128 by ESI (ESI, 2020) was used to generate input files, run MODFLOW-USG simulations, and view model results.

The modeled area was divided into discrete cells based on a numerical grid with a node at the center of each cell. Calculations are performed at the node of each cell, and model inputs and outputs are based on the average value within each cell being applied at the node. We used the *Interpolation of Target and Observation Well Data* technique within Groundwater Vistas to identify the modeled head level at the location of each well location. This technique identifies the modeled head at a well location by interpolating between the head values in the adjacent cells. This technique is the default setting within Groundwater Vistas and is used to account for calibration locations (wells) that are not located at the center of the cell.

The numerical process and governing principles of MODFLOW-USG are documented in Panday et al. (2013) and Fetter (2001), and are provided in Appendix J. Key settings for the numerical model are provided in Appendix J.

Data from November 2018 through October 2019 were used to develop a transient simulation that used 25 30-day stress periods. Initial heads were developed during the first stress period by running a steady-state simulation of the November 2018 conditions (Baseline Steady-State Model). These initial heads were used as inputs into the second stress period. Stress Periods 2 through 13 simulated monthly stress periods from November 2018 through October 2019, which corresponds with the monthly data for one irrigation year. Stress Periods 14 through 25 were a repeated sequence of the November

2018 through October 2019 inputs. Data for only one irrigation year were available and the repeated simulation of the irrigation year was intended to decrease any effects of the first steady-state stress period. One-day time steps were used, resulting in 30 time steps per stress period. In our opinion this level of temporal discretization is reasonable for simulating existing transient behavior of the hydrogeologic system and natural (i.e., non-flooding) post-Project behavior. Finer temporal discretization may be required to simulate post-Project flood loads.

5.2 Model Inputs

5.2.1 General

In general, the model inputs included topography, model grid, stratigraphy, material properties, and boundary conditions. Inputs that varied spatially such as material properties, recharge, and evapotranspiration were applied over different areal extents in the model. The areal extents are referred to as property zones. Property zones can overlap from one type of input to another and are based on the specific parameter being modeled. The development and selection of model inputs are described in the following sections.

5.2.2 Ground Surface and Finite Difference Grid

Points representing the combined LiDAR and aerial survey ground surface were used to develop the ground surface in the model. The extents of the LiDAR and aerial survey are shown on Figure 3.1. Contours of the points were imported into Groundwater Vistas and a surface applied to the discretized grid.

The finite difference grid was oriented north/south and east/west. The grid was refined with more discretization near the SBC boundary condition and limits of Project facilities. Local grid refinement was performed using the quadtree grid type provided by MODFLOW-USG and supported by Groundwater Vistas. In our opinion the degree of spatial discretization described below is reasonable for simulating both existing and post-Project groundwater conditions near proposed facilities. Planimetric cell sizes for each area in the model are generally located as follows:

- Far-field upstream and downstream areas: 80 feet by 80 feet.
- Along SBC boundary condition: 20 feet by 20 feet.
- Project facilities on CU Boulder South campus and along US36: 5 feet by 5 feet.

The transition between general cell sizes was accomplished automatically in Groundwater Vistas such that neighboring cell sizes were within a 50 percent difference (e.g., 20-foot cells were next to 10-foot cells).

Seven layers were used to define the vertical discretization: the surficial soil units were divided into three layers, the upper 12 feet of bedrock were divided into three layers, and the remaining bedrock was modeled as one layer. The vertical refinement was developed to effectively evaluate vertical gradient changes associated with the future use of the model to support preliminary design.

The total number of cells was approximately 1 million and is considered appropriate for the model size and model execution time. Model execution time is approximately 150 minutes. A plan of the numerical grid is shown on Figure 5.1.

5.2.3 Stratigraphy

Visual MODFLOW Flex was used to create the top of bedrock surface by interpolating unit contacts between the locations of available subsurface data from the CDOT, CDSS, and RJH Phase I borings (RJH, 2019). Interpolation was performed using the kriging method. Kriging is a geostatistical interpolation method that is appropriate to use when there is smooth spatial variability (Waterloo Hydrogeologic, 2019b). Smooth spatial variability was expected for the bedrock surface in the Study Area. Contacts were extrapolated to the edges of the model extent based on mapping data, contact trends, and geologic judgement. Additional control points were developed to constrain the model stratigraphy along mapped geologic contacts, in areas where available data was lacking, or where discrepancies were observed between the stratigraphic surface and the ground surface (e.g., the contoured bedrock surface extended above the ground surface across ditches).

The top of bedrock surface from Visual MODFLOW Flex was imported into Groundwater Vistas. The surface was subsequently modified using Groundwater Vistas to incorporate recently acquired subsurface data from the Phase II geotechnical investigation. Additional information about the development of the top of bedrock surface is provided in Appendix D. A bedrock contour map is shown on Figure 5.2. A total thickness of 30 feet of Pierre Shale was included throughout the model and is based on the deepest boring from the Phase I geotechnical investigation.

The model extent between the ground surface and the top of bedrock surface was divided into three layers of surficial soil units based on the geologic map shown on Figure 3.3. Existing fill within the US36 roadway embankment was modeled as alluvium, which in our opinion is a reasonable simplification that is not anticipated to significantly affect model results. Based on available data, the roadway fill is underlain by alluvium near the elevation of the natural ground surface and the groundwater table is located in alluvium below the bottom of the fill. Fill that might exist in developed areas elsewhere throughout the model extents was also modeled as alluvium.

A plan map and typical cross section showing the overall model stratigraphy are on Figures 5.1 and 5.3, respectively. Additional subsurface sections are presented in the Phase I Geotechnical Data Report (RJH, 2019).

5.2.4 Material Properties

5.2.4.1 General

Selected inputs for material properties and property zones applied in the numerical model are presented in the following sections. Development of the material properties and ranges of parameter values for the Hydrogeologic Conceptual Model are presented in Section 4.

5.2.4.2 Hydraulic Conductivity and Anisotropy Ratio

Simulated hydraulic conductivity for each hydrogeologic unit were adjusted based on model calibration and are summarized in Table 5.1. The areal extent of hydraulic conductivity property zones for the surficial soil units are shown on Figure 5.1 and a typical section showing the distribution of the Pierre Shale hydraulic conductivity property zones is shown on Figure 5.3.

TABLE 5.1
SUMMARY OF SIMULATED HORIZONTAL HYDRAULIC CONDUCTIVITY AND ANISOTROPY VALUES

Unit	Horizontal Hydraulic Conductivity (cm/s)	Anisotropy Ratio (K_h/K_v)
Fill	3.7×10^{-5}	3.7
Alluvium Zone A	1.9×10^{-2}	10.0
Alluvium Zone B	3.5×10^{-4}	10.0
Alluvium Zone C	7.1×10^{-4}	10.0
Weathered Pierre Shale	1.4×10^{-4}	10.0
Unweathered Pierre Shale	2.5×10^{-5}	10.0
Ponds	1.8×10^{-1}	1.0

The range of available in-situ hydraulic conductivity test results for each geologic unit (from data in Table 4.1) is shown on Figure 5.4 and the points identified by a red circle represent the simulated values used in the numerical model for each unit. The simulated hydraulic conductivity value for fill is near the middle of the range of in-situ test results. The simulated hydraulic conductivity values for the three zones of alluvium are within the limits of the available in-situ test results. The hydraulic conductivity values assigned to soil units were selected predominantly through iterative model calibration. Model calibration is presented in Section 6 and model sensitivity to alluvium hydraulic conductivity is presented in Section 7.

The Pierre Shale unit was divided into weathered and unweathered property zones as described in Section 4. The simulated hydraulic conductivity for the weathered Pierre Shale was near the upper end of the Phase I Packer test results and was about two orders of magnitude greater than the geometric mean of 2.1×10^{-6} cm/s. The simulated hydraulic conductivity for weather Pierre Shale was primarily based on test results performed in weathered bedrock. The unweathered Pierre Shale was assigned about one order of magnitude lower hydraulic conductivity than the weathered Pierre Shale. Based on our experience with the Pierre Shale, we anticipate it will predominantly be a low-permeable unit, however there could be localized higher-permeable fractured zones. In our opinion it is conservative to apply the high hydraulic conductivity values shown on Figure 5.4 to bedrock throughout the model because the bulk hydraulic conductivity of this unit is not expected to exceed the measured data. Regionally the Pierre Shale is an aquitard and it would be highly unusual for this unit to convey significant flows.

High hydraulic conductivity values were assigned to ponds to represent areas of open water and are based on engineering judgement.

Simulated values for anisotropy ratios are summarized in Table 5.1. These values were selected based on model calibration, engineering judgement, and the following (Appendix E):

- An anisotropy ratio of 3.7 was selected for fill and is within the same order of magnitude as the range presented in Table 4.1; however, the selected value is slightly below the low range value of 4 presented in Table 4.1. This value was adjusted during iterative model calibration.
- An anisotropy ratio of 10.0 was selected for alluvium because apparent stratification was not identified in the samples recovered during geotechnical investigations.

- An anisotropy ratio of 10.0 was selected for Pierre Shale primarily due to the observed bedding of the material and is within the range presented in Table 4.1.
- An anisotropy ratio of 1.0 was selected for ponds based on the properties of water (i.e., water does not exhibit anisotropy).

Model sensitivity to the anisotropy ratio of alluvium is presented in Section 7.

5.2.4.3 Specific Storage and Specific Yield

The specific storage and specific yield values for each unit were based on published data (Appendix E). The specific yield values for fill, alluvium, and bedrock were adjusted iteratively during model calibration. Simulated values for specific storage and specific yield are summarized in Table 5.2.

TABLE 5.2
SUMMARY OF SIMULATED SPECIFIC STORAGE AND SPECIFIC YIELD VALUES

Unit	Specific Storage (Ss) (ft^{-1})	Specific Yield (Sy) (Percent)
Fill	$5.0x10^{-5}$	8
Alluvium Zone A	$2.3x10^{-5}$	10
Alluvium Zone B	$2.3x10^{-5}$	10
Alluvium Zone C	$2.3x10^{-5}$	10
Weathered Pierre Shale	$1.0x10^{-6}$	3
Unweathered Pierre Shale	$1.0x10^{-6}$	3
Ponds	$2.6x10^{-6}$	100

Note:
1. This table presents the values of Ss and Sy that were applied to each of the hydraulic conductivity property zones defined in Table 5.1. This table does not reflect the names of the Ss and Sy property zones that were actually input into Groundwater Vistas.

Specific storage for each unit was based on the average of the ranges shown in Table 4.2. Specific yield for alluvium was primarily based on estimates for coarse materials with some fines content by Morris and Johnson (1967), and was adjusted based on model calibration. Compared to the range of values presented in Table 4.2, relatively low specific yield values were required for alluvium during calibration to achieve appropriate observed drawdown behavior when irrigation ends. Model calibration is presented in Section 6. The specific yield of the fill unit was primarily based on estimates for sand materials with fines content by Morris and Johnson (1967) and estimated to be lower than that of alluvium because the fill has a higher fines content and lower average hydraulic conductivity, and therefore is anticipated to yield less water through gravity drainage (Fetter, 2001). Specific yield of Pierre Shale was estimated from generalized values presented by Zheng and Bennett (1995) and is within the range presented in Table 4.2. The specific storage and specific yield values for ponds were based on the properties of water (e.g., water compressibility for estimating specific storage).

Model sensitivity to the specific yield of alluvium is presented in Section 7.

5.2.5 Model Geometry Boundary Conditions

5.2.5.1 Upstream and Downstream Boundary Conditions

The upstream specified head boundary condition was based on the monthly average groundwater level recorded in B-102(P). We modeled the downstream boundary condition using seven segments that were approximately equal in length as shown on Figure 5.1. The eastern downstream segment was based on data from B-106(P). Each segment to the west was set to 1 foot higher than its nearest eastern segment such that the specified head boundary condition incrementally increased from east to west. As shown on Figure 5.1, approximately 805 feet at the western-most end of the downstream model extent did not have a boundary condition applied. The modeled bedrock surface in this area is higher than the assigned downstream boundary condition elevations and therefore the western portion of alluvium is anticipated to be unsaturated in this area.

A summary of the specified head elevations assigned to the upstream boundary condition and segments 1 and 7 of the downstream boundary condition for each stress period are shown on Figure 5.5. Model input values are provided in Appendix J.

5.2.5.2 South Boulder Creek Boundary Condition

SBC was simulated using the SFR package. The SFR input was developed as follows and additional information is provided in Appendix F:

- Divide the creek into 21 separate segments based on locations of irrigation ditch diversions, where significant changes in channel geometry were identified, and in areas proximal to the Project facilities.
- Develop representative 8-point cross sections for each segment.
- Assign upstream and downstream streambed elevations to each segment. The elevation profile along each segment is linearly interpolated between these defined points by MODFLOW-USG.

- Assign streambed hydraulic conductivity, thickness, and roughness to each segment based on RJH's field observations.
- Input a representative inflow rate at the most upstream segment.
- Subtract flow at the locations of irrigation ditch diversions based on diversion data.

Stage (i.e., elevation of surface water along the boundary condition) is automatically calculated for each segment based on the input parameters described above. Flux across the SFR boundary condition (i.e., flow interaction between the creek and adjacent aquifer) depends on the head difference between stream stage and the surrounding aquifer, and streambed conductance. Streambed conductance was automatically calculated based on input values of streambed hydraulic conductivity, thickness, and wetted area of the streambed, which are provided in Appendix F.

Twenty-one segments were developed to represent SBC and varied in length from approximately 190 to 3,020 feet. The extents of each segment are shown on Figure 5.1. The streambed elevation was generally set 2 feet below the ground surface along each segment. This technique is standard practice for groundwater modeling; it accounts for the possibility that the LiDAR survey does not identify the lowest positions within the creek bed because LiDAR does not penetrate the water surface and vegetation may inhibit LiDAR data collection. RJH defined SFR segments with strategically-placed endpoints to allow the modeled channel to conform to sudden changes in grade without producing values above the topographic ground surface.

Based on field observations, the streambed within SBC is predominantly composed of coarse material (gravels and cobbles) and there does not appear to be a layer of sediment along the streambed that would impede interaction between the creek water and the aquifer. We modeled streambed material with a Manning's roughness of n = 0.045, thickness of 1 foot, and hydraulic conductivity of $7.3x10^{-2}$ cm/s. The hydraulic conductivity assigned to the streambed was developed based on model calibration and is higher than hydraulic conductivity values assigned to the alluvium zones (Table 5.1). In our opinion this is appropriate because the streambed material was observed to be coarser grained than collected samples of alluvium, and assigning a high hydraulic conductivity to the streambed would not inhibit flow between the creek and aquifer.

The SFR segments are shown on Figure 5.1, and a summary of the flow inputs and diversions for the SFR segments for each stress period are shown in Appendix J. Additional information about development of the SFR boundary condition is presented in Appendices F and G.

5.2.5.3 West Model Extent and Bottom of Model

The western edge and bottom of the model were simulated as Specific Flux - No Flow boundaries. These boundary types are automatically applied in Groundwater Vistas at all model edges that do not have other boundary conditions assigned.

5.2.6 Internal Boundary Conditions

5.2.6.1 Drain Boundary Conditions

Drain boundary conditions were assigned to drainage ditches and irrigation ditches to allow water to exit the model as seepage in these locations. The invert elevations of the drain boundary conditions were assigned 2 to 4 feet below the model ground surface for the reason presented in Section 5.2.5.2. Drain conductance was automatically calculated based on drain bed hydraulic conductivity, thickness, and cell area input values. We simulated the drain bed material with a hydraulic conductivity of 5.8×10^{-6} cm/s and thickness of either 0.1 foot or 1.0 foot. The model results were generally insensitive to increasing the drain bed hydraulic conductivity to higher than the selected value.

5.2.6.2 Recharge and Evapotranspiration

5.2.6.2.1 Background Recharge

Background recharge was applied to the surface of the model throughout the entire model extent. The model was divided into four different property zones and each zone was assigned a separate background recharge rate based on ground surface conditions as follows:

- **Natural Background Recharge:** Natural background recharge was considered to occur in primarily undeveloped areas. The natural background recharge rate was selected based on typical published ranges (Jasechko et al., 2014) and was iteratively adjusted during model calibration. The simulated natural background recharge rate was 12 percent of the precipitation rate from April through October and 25 percent of the precipitation rate from November through March.
- **CU Fill Recharge:** The simulated natural recharge on the fill soils on CU Boulder South campus was 60 percent of the natural background recharge. The fill is finer-grained than alluvium; therefore, it is anticipated that recharge occurring on the fill would have a higher likelihood of being absorbed within the unsaturated zone and

returning to the atmosphere through evapotranspiration instead of infiltrating and recharging the groundwater.

- **Developed Area Recharge:** The simulated recharge in developed (i.e., urbanized) areas was 50 percent of the natural background recharge to account for increased runoff and decreased infiltration caused by structures and pavements. We considered that groundwater recharge would not be caused by landscape irrigation (i.e., sprinkler irrigation) occurring in developed areas.
- **Open Water Background Recharge:** Open water bodies including SBC and ponds throughout the model extent were assigned a recharge rate equal to the locally reported precipitation each month (NWS, 2020).

Precipitation data from the Denver-Boulder Forecast Office includes water contributions from snowmelt and hail. In the winter and spring, background recharge from snowmelt might occur in a different month than when the precipitation actually fell; however, this pattern is not recorded and was not considered when developing the background recharge rates.

The areal extents of background recharge property zones are shown on Figure 5.6. A summary of the background recharge rates applied to each zone for each month are shown on Figure 5.7 and model input values are provided in Appendix J. Additional information about development of the background recharge zones is presented in Appendix H.

5.2.6.2.2 Irrigation Recharge

Irrigation recharge was applied over irrigated fields shown on Figure 5.6. Irrigation recharge onto individual fields was applied only when water was available in the ditch that could irrigate a particular field, and the total amount of water applied each month did not exceed the available water diverted by the ditch in that month.

Water from South Boulder and Bear Creek Ditch can flow into Dry Creek No. 2 Ditch at an ungauged confluence; RJH has observed this redistribution of water occurring during our site visits. We considered that water from South Boulder and Bear Creek Ditch could be applied to fields that are irrigated by Dry Creek No. 2 Ditch in September and October, which improved model calibration.

Recharge rates for the eight irrigation zones shown on Figure 5.6 were iteratively adjusted during model calibration. The spatial and temporal patterns of irrigation included in the model were primarily based on calibration to seasonal changes in monitoring well levels. The amount of irrigation water applied each month ranged from about 1 percent to 74 percent of the total available monthly diversion data presented in Section 3.5. A relatively minor amount (less than 10 percent) of the monthly available water from Howard Ditch was applied to irrigated fields within the model; in our opinion this is appropriate because the majority of fields irrigated by Howard Ditch are located outside of the model extents.

The areal extents of irrigation recharge property zones are shown on Figure 5.6. A summary of the irrigation recharge rates applied to each zone for each month are shown on Figure 5.8 and model input values are provided in Appendix J.

Additional information about development of the irrigation recharge zones, irrigation recharge rates, and a summary of how the applied irrigation compares to the monthly ditch diversions are presented in Appendix I.

5.2.6.2.3 Evapotranspiration

Evapotranspiration was applied to the surface of the model throughout the entire model extent. The model was divided into five general property zones and each zone was assigned a separate evapotranspiration rate based on published data (Appendix A) for vegetative cover and ground surface conditions as follows:

- **Irrigated Grass:** The OSMP GIS files identified irrigated grass as being the crop type in irrigated fields. The irrigated grass evapotranspiration rate was based on published monthly values from Northern Water (Northern Water, 2020). During spring months when irrigation was not occurring, irrigated grass evapotranspiration was simulated using a rate that was intermediate between the published monthly values and the values selected for background/native grass (presented in the next bullet). This parameter was iteratively adjusted during model calibration.
- **Background/Native Grass**: Background/native grass evapotranspiration was considered to occur in primarily undeveloped and non-irrigated areas. The simulated background/native grass evapotranspiration rate ranged from 20 to 83 percent of the irrigated grass rate and generally follows the same seasonal pattern as irrigated grass. This parameter was iteratively adjusted during model calibration.
- **Riparian/Phreatophyte:** Riparian/phreatophyte evapotranspiration was considered to occur in areas with riparian vegetation consisting of mostly mature cottonwood trees based on observations from site visits, review of Google Earth

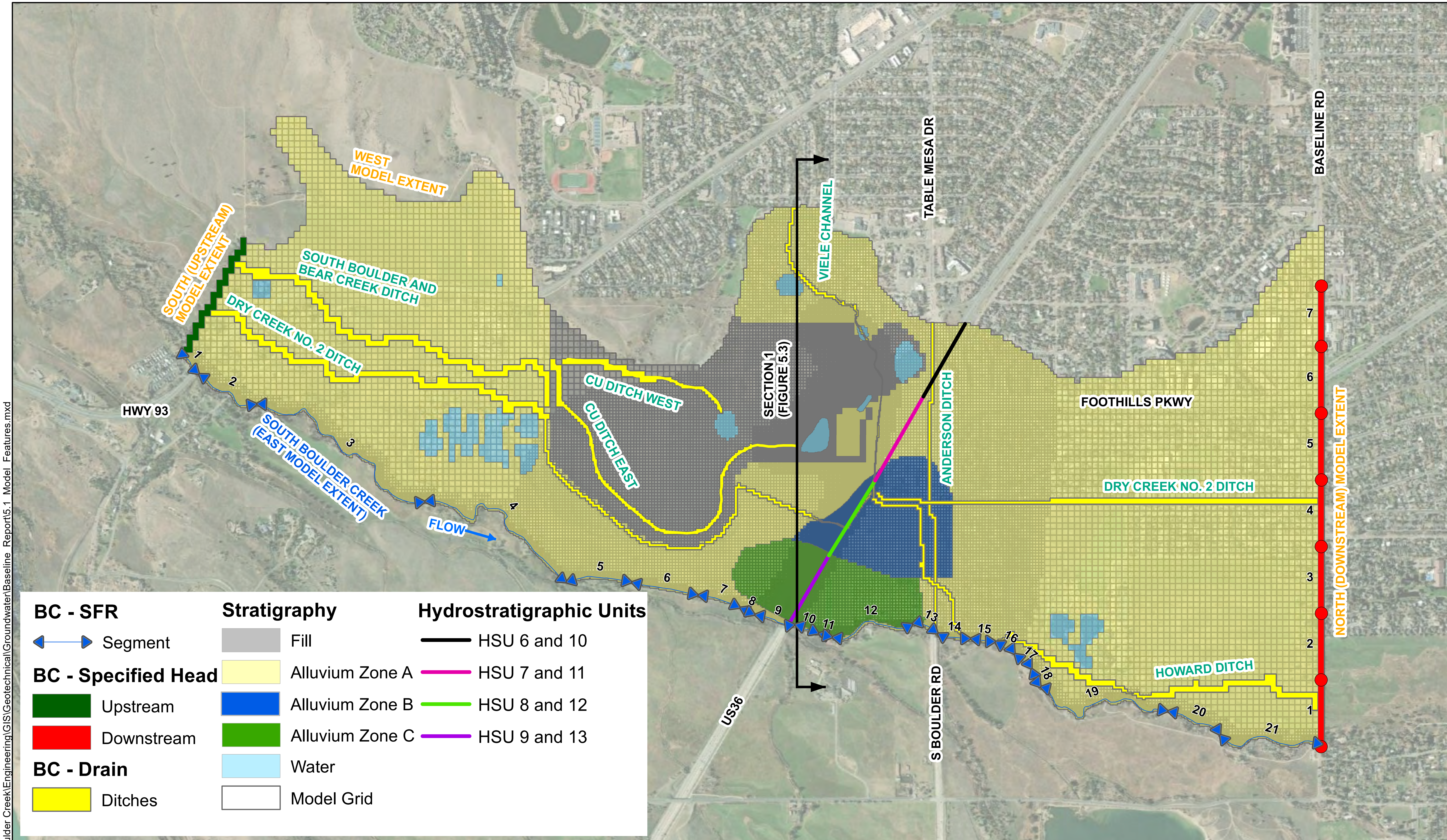
aerial imagery (Google, Inc., 2020), and information from Kimbrough (1995) and Norton (2017). The riparian/phreatophyte zone was also applied to ponds located at the south end of the CU Boulder South campus based on the presence of vegetation types within and near the ponds. The simulated riparian/phreatophyte evapotranspiration rate was based on published annual rates from Robinson (1958) and Kimbrough (1995). RJH converted the published annual rate to a monthly rate that generally varied following the same seasonal pattern as irrigated grass.

- **Open Water:** Open water bodies including SBC and ponds throughout the model extent were assigned a pan evaporation rate based on a pan coefficient equal to 0.8 (Northern Water, 2020).
- **Developed Areas:** The simulated evapotranspiration in developed (i.e., urbanized) areas was 50 percent of the background/native grass evapotranspiration to account for decreased vegetation due to the presence of structures and pavements.

The simulated extinction depths for irrigated grass, background/native grass, riparian/phreatophyte, and developed area zones were 6 feet to retain root depths mostly within surficial soil units. The parameter was adjusted during model calibration. The extinction depths for the open water zones were based on the approximate bottom of each pond.

Actual evapotranspiration rates can vary temporally and spatially throughout natural plant communities and can also vary for a specific plant species based on growing conditions. Reasonable values of evapotranspiration were approximated based on published values and adjusted to seasonal trends if needed; the model is not intended to simulate evapotranspiration rates with high accuracy.

The areal extents of evapotranspiration property zones are shown on Figure 5.9. A summary of the evapotranspiration rates applied to each zone for each month are shown on Figure 5.10 and model input values provided in Appendix J.



NOTE:
1. MODEL GRID CELL SIZE RANGES FROM 80X80 FT AT THE FAR-FIELD MODEL EXTENTS TO 5X5 FT NEAR THE PROPOSED PROJECT FACILITIES.
2. PROPOSED PROJECT FACILITIES ARE SHOWN ON FIGURE 1.2.

0 600 1,200 2,400 Feet

REPRODUCE IN COLOR

N

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SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

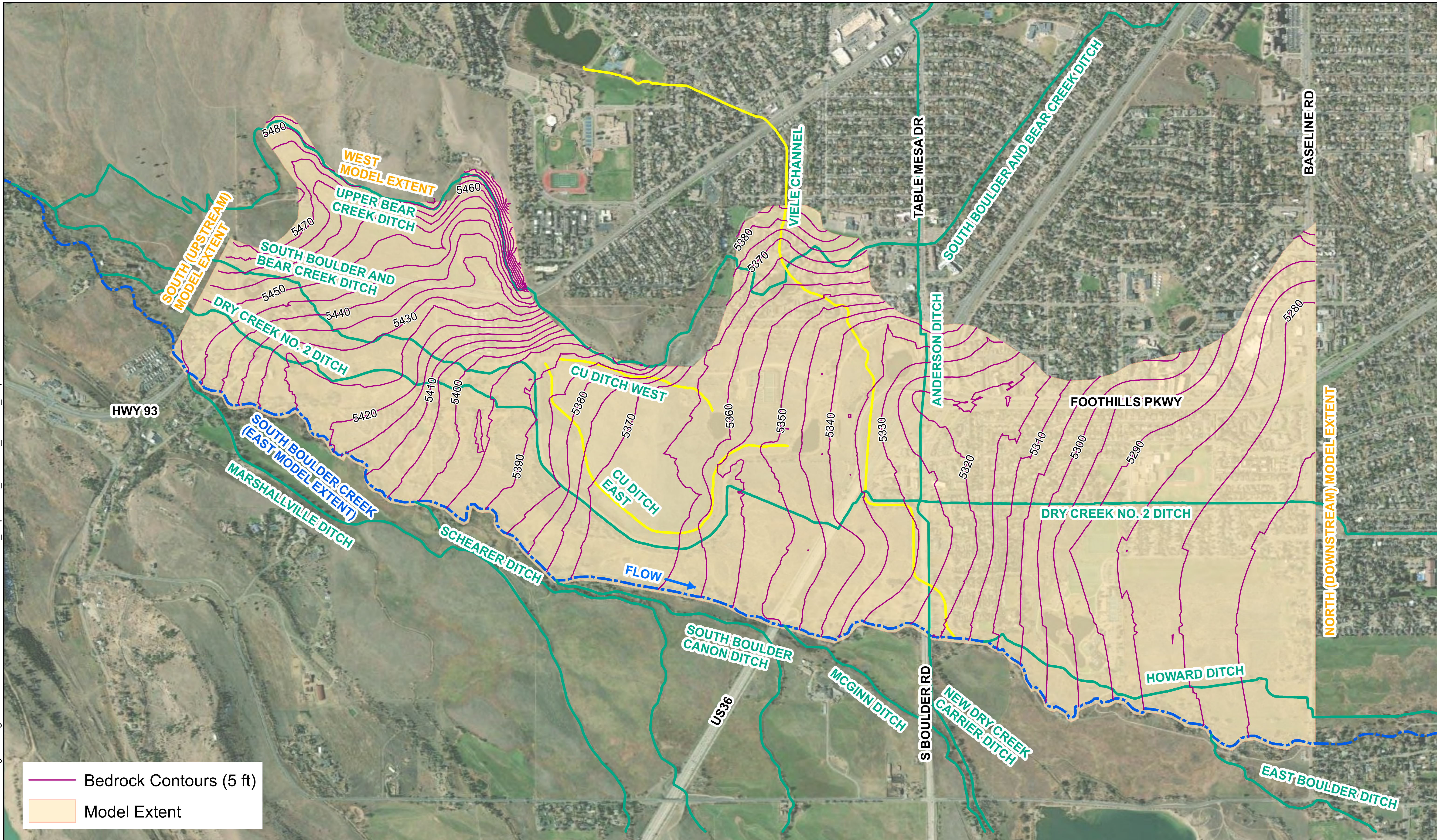
MODEL FEATURES

PROJECT NO. 16134

July 2021

Figure 5.1

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline Report\5.1 Model Features.mxd



NOTE:
1. CONTOURS ARE 5-FOOT INTERVALS.

0 600 1,200 2,400 Feet

REPRODUCE IN COLOR

N

DATUM: NAVD 88

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SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

BEDROCK CONTOUR MAP

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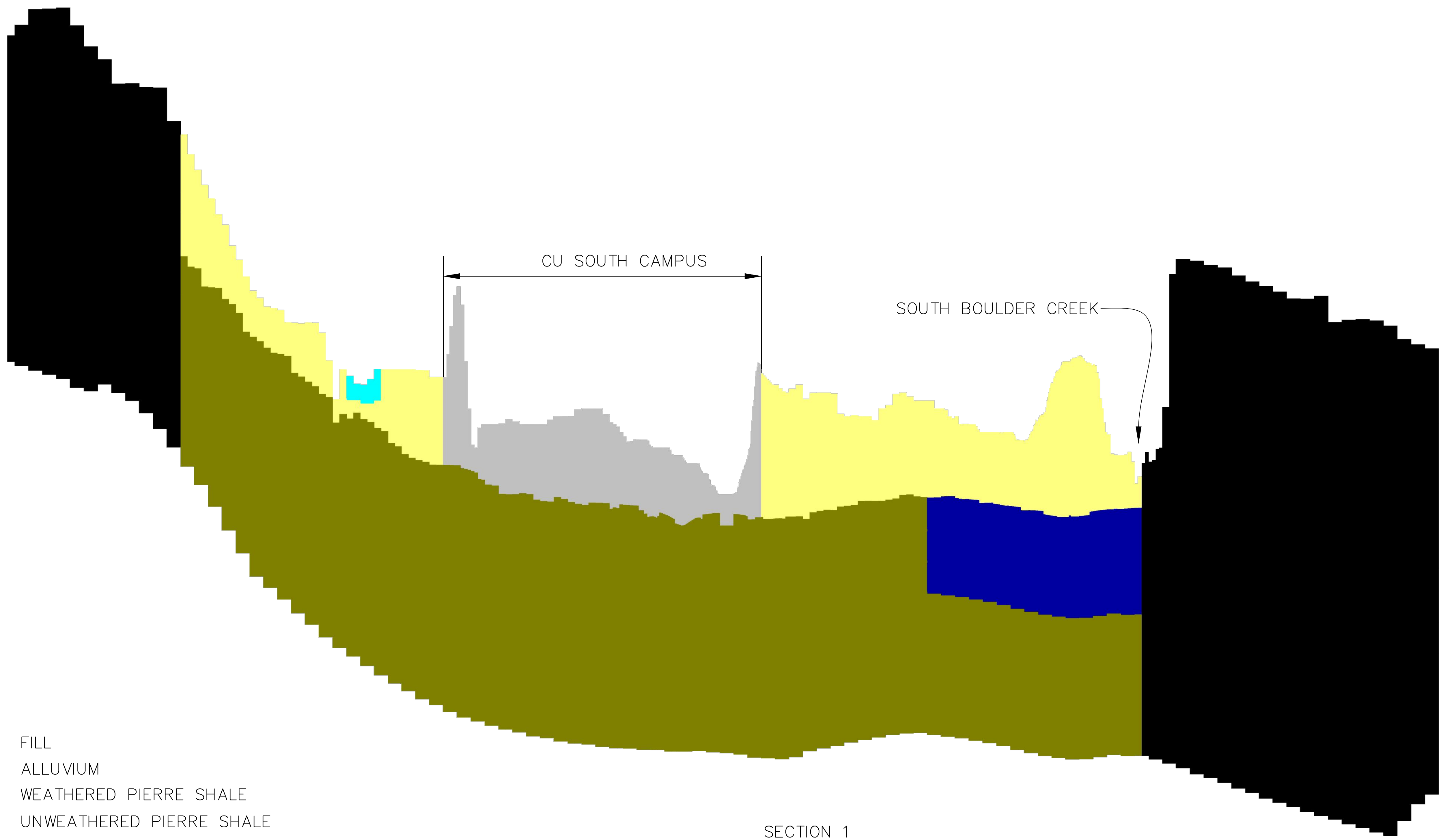
Figure 5.2

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline_Report\5.2_Bedrock_Contour_Map.mxd



LEGEND:

- FILL
- ALLUVIUM
- WEATHERED PIERRE SHALE
- UNWEATHERED PIERRE SHALE
- POND
- OUTSIDE MODEL EXTENT

SECTION 1

(NOT TO SCALE)

REPRODUCE IN COLOR

NOTES:

1. TYPICAL STRATIGRAPHIC SECTION THROUGH THE BASELINE MODEL. SECTION LOCATION IS SHOWN ON FIGURE 5.1. TAKEN FROM THE NUMERICAL MODEL GRAPHICAL OUTPUT.

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SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

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STRATIGRAPHY TYPICAL SECTION

July 2021

Figure 5.3

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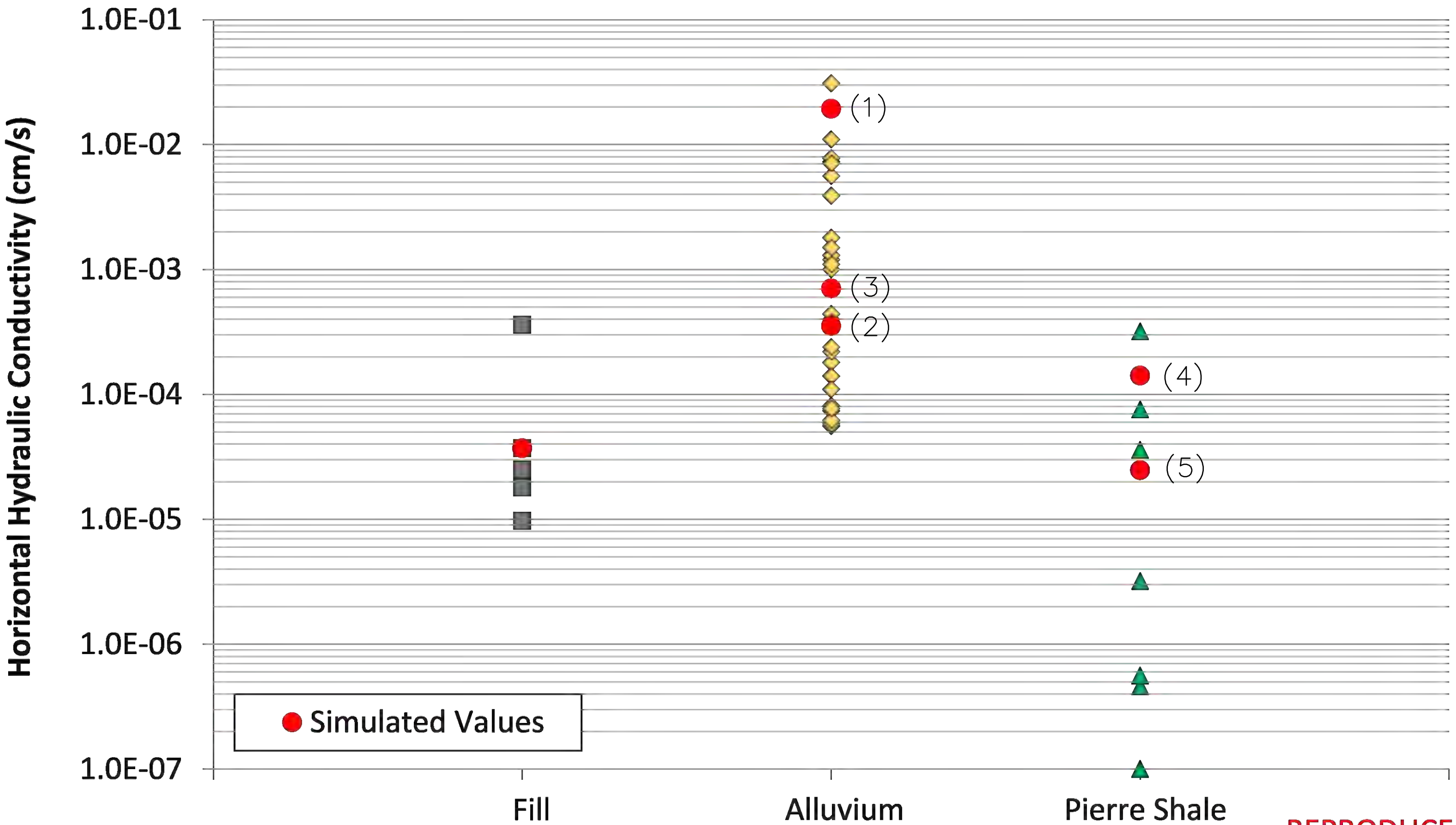

REPRODUCE IN COLOR

NOTES:

1. ALLUVIUM ZONE A
2. ALLUVIUM ZONE B
3. ALLUVIUM ZONE C
4. WEATHERED PIERRE SHALE
5. UNWEATHERED PIERRE SHALE
6. INDIVIDUAL DATA POINTS REPRESENT TEST RESULTS FROM IN SITU HYDRAULIC CONDUCTIVITY TESTS.

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	GEOLOGIC UNIT HYDRAULIC CONDUCTIVITY
	PROJECT NO. 16134	July 2021 **Figure 5.4**

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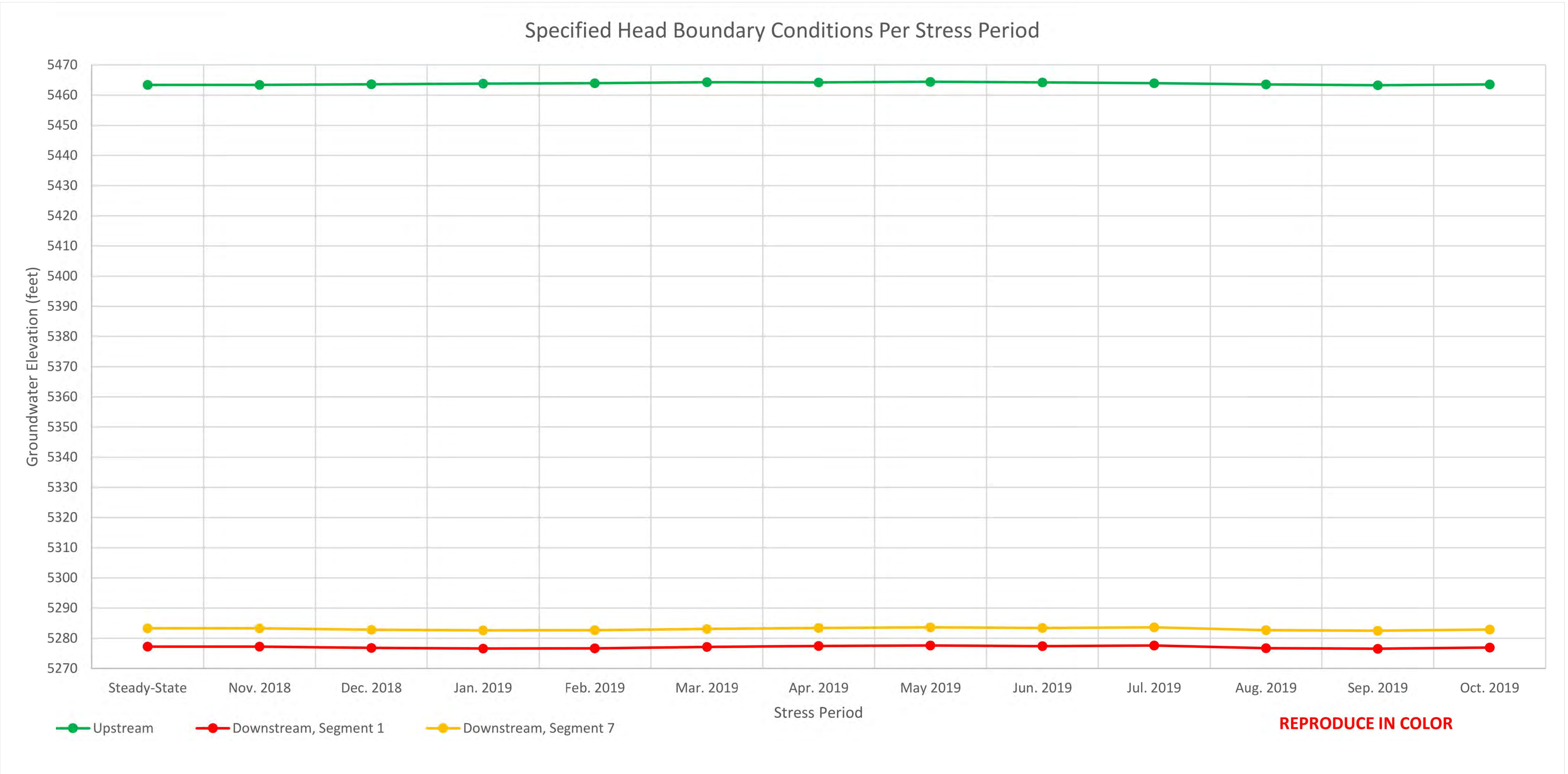


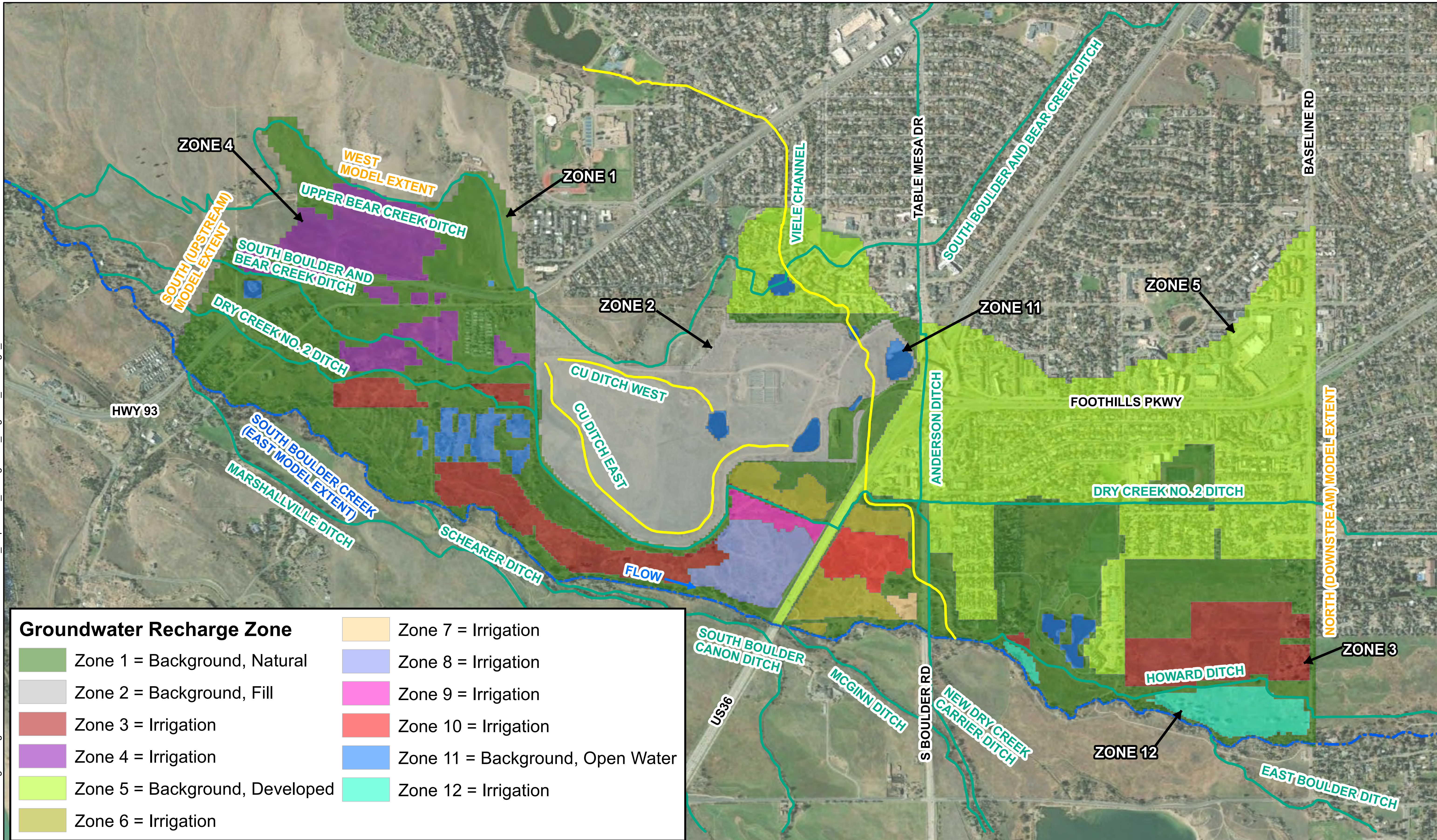
REPRODUCE IN COLOR

NOTES:

1. SPECIFIED HEAD BOUNDARY CONDITION LOCATIONS ARE SHOWN ON FIGURE 5.1
2. THE DOWNSTREAM BOUNDARY CONDITION CONSISTS OF SEVEN SEGMENTS THAT VARY AT 1-FOOT INCREMENTS BETWEEN THEM.

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	SIMULATED SPECIFIED HEAD BOUNDARY CONDITIONS PER STRESS PERIOD
		PROJECT NO. 16134	July 2021 **Figure 5.5**

P:\16134 - SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\BASELINE_REPORT\16134_3004_FIGURES_MODEL_INPUT_GRAPHS.DWG 7/8/2021 2:46 PM



NOTES:
1. IRRIGATION RECHARGE ZONES INCLUDE RECHARGE FROM IRRIGATION ACTIVITIES AND NATURAL BACKGROUND RECHARGE FROM PRECIPITATION.

REPRODUCE IN COLOR

CITY OF BOULDER

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SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

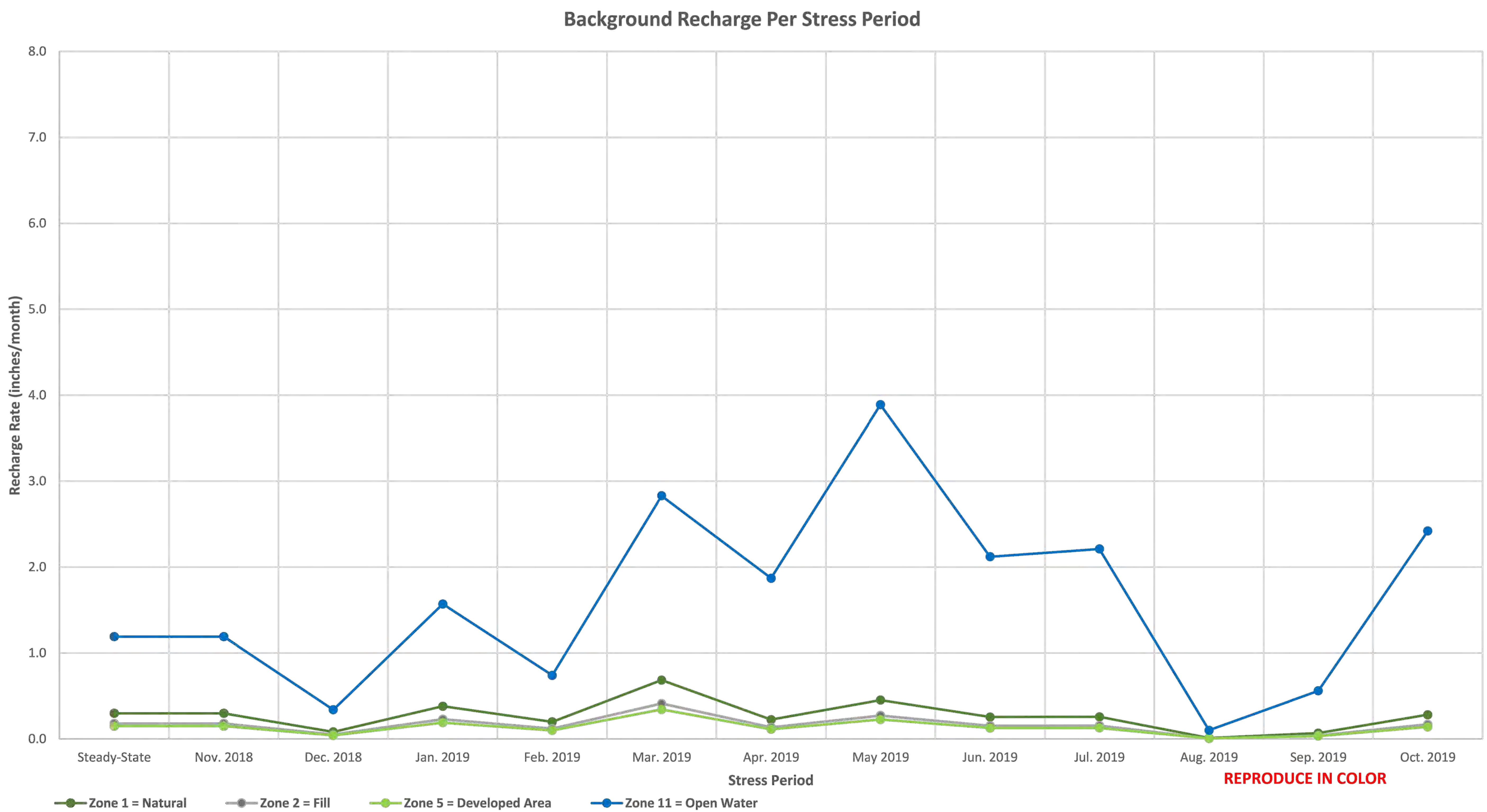
BACKGROUND AND IRRIGATION RECHARGE ZONES MAP

PROJECT NO. 16134

July 2021

Figure 5.6

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline_Report\5.6_Background_Irrigation_Recharge_Zones.mxd



REPRODUCE IN COLOR

NOTES:

1. BACKGROUND RECHARGE ZONES ARE SHOWN ON FIGURE 5.6.
2. OPEN WATER RECHARGE VALUES EQUAL MONTHLY PRECIPITATION.

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SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

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SIMULATED BACKGROUND RECHARGE PER ZONE PER STRESS PERIOD

July 2021

Figure 5.7

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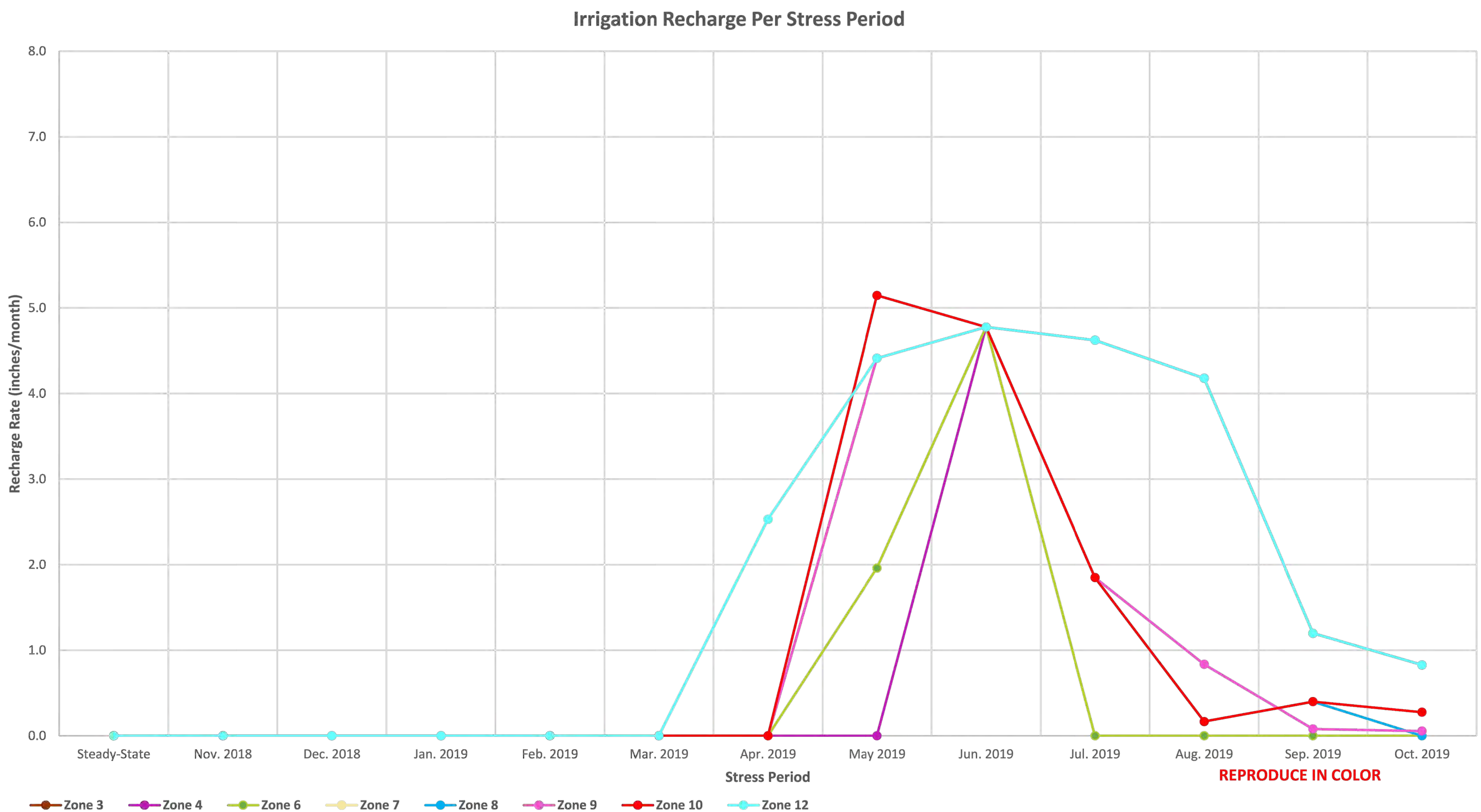

REPRODUCE IN COLOR

NOTES:

1. IRRIGATION RECHARGE ZONES ARE SHOWN ON FIGURE 5.6.
2. THE RECHARGE RATES INPUT INTO GROUNDWATER VISTAS FOR EACH ZONE CONSIST OF THE SUM OF THE IRRIGATION RECHARGE RATES SHOWN ON THIS FIGURE AND THE NATURAL BACKGROUND RECHARGE RATES SHOWN ON FIGURE 5.7.

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	SIMULATED IRRIGATION RECHARGE PER ZONE PER STRESS PERIOD
		PROJECT NO. 16134	July 2021 Figure 5.8

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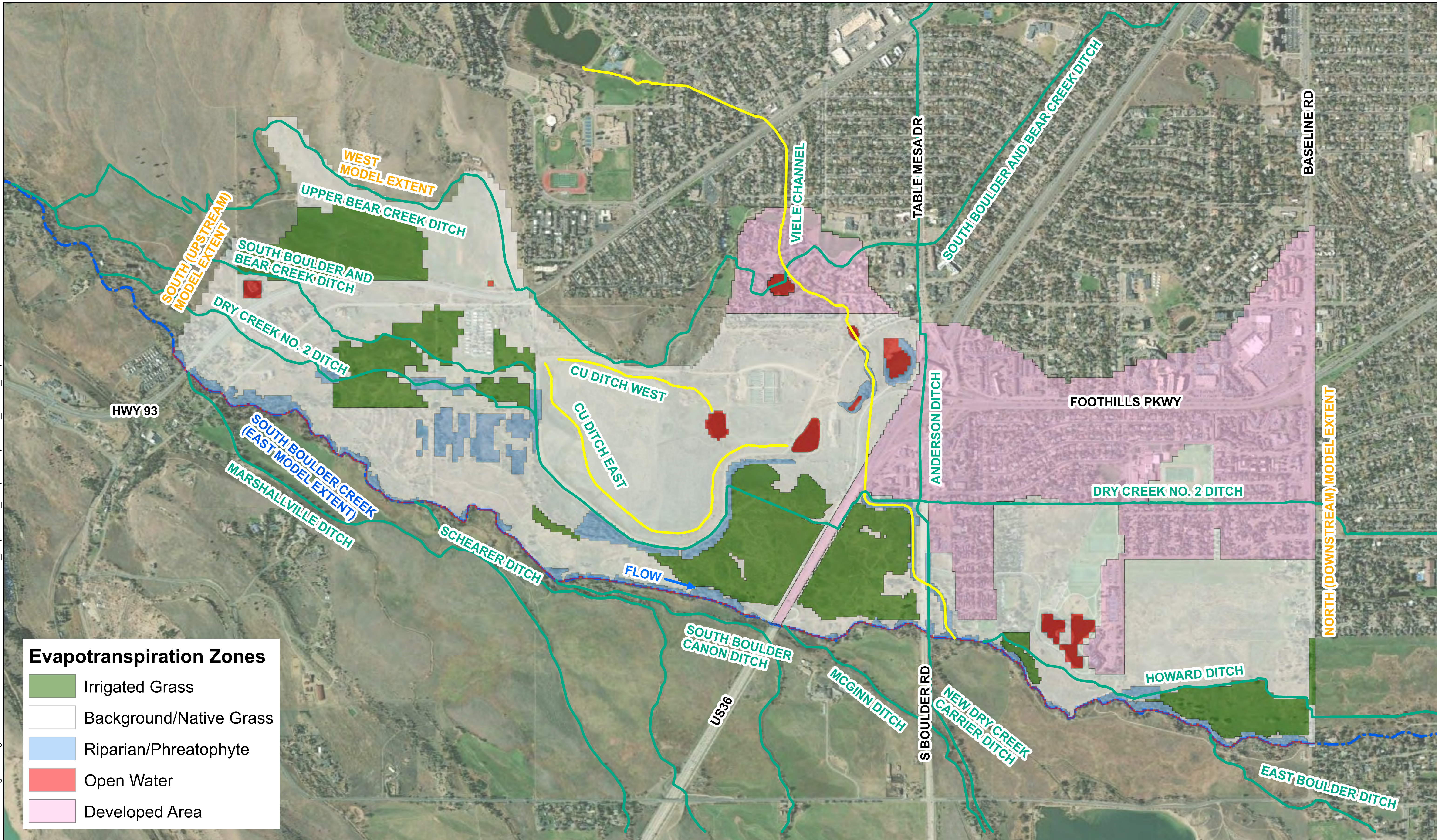

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CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

PROJECT NO. 16134

EVAPOTRANSPIRATION ZONES MAP

July 2021

Figure 5.9

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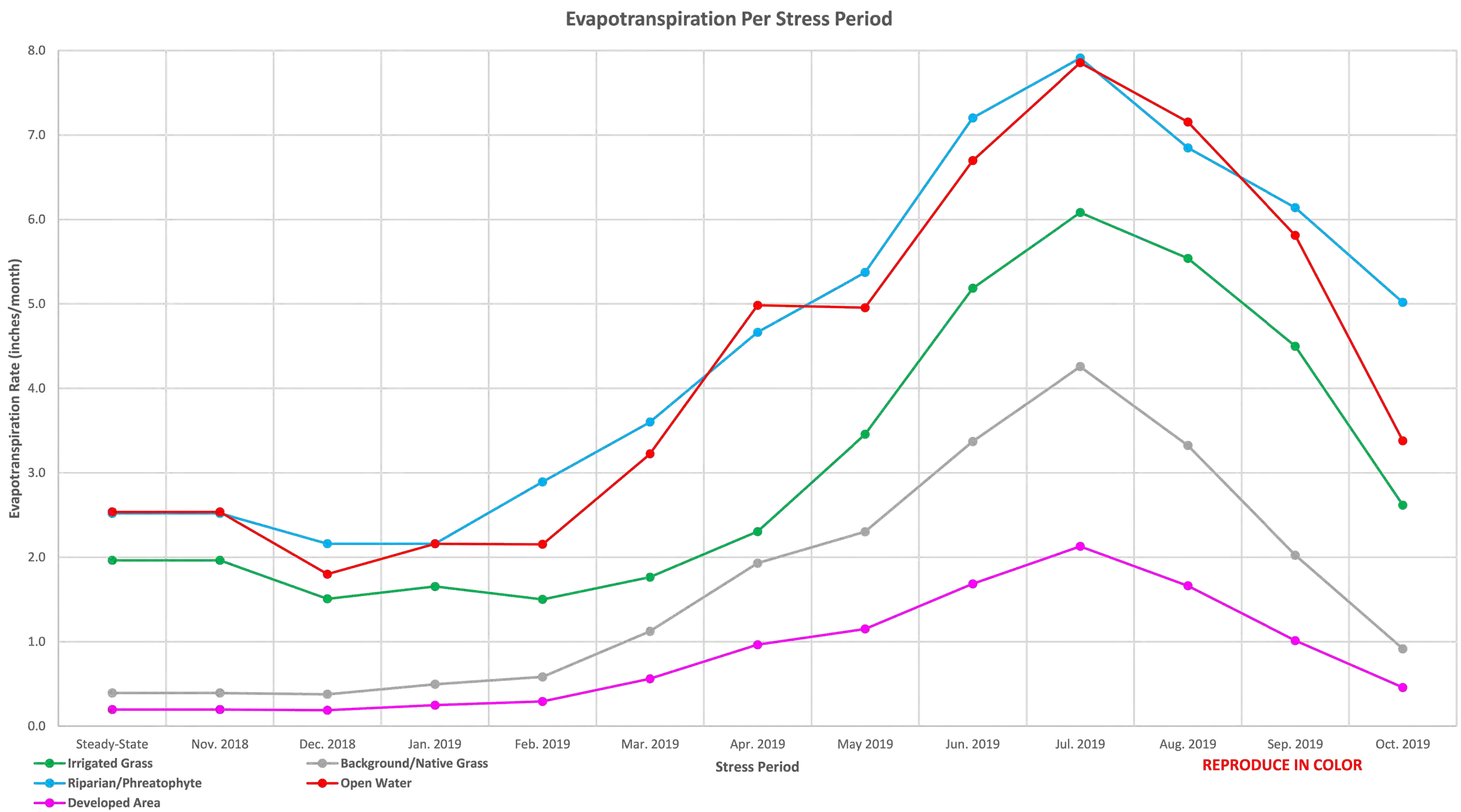

REPRODUCE IN COLOR

NOTES:

1. EVAPOTRANSPIRATION ZONES ARE SHOWN ON FIGURE 5.9.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	SIMULATED EVAPOTRANSPIRATION PER ZONE PER STRESS PERIOD	
PROJECT NO. 16134	July 2021	Figure 5.10

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SECTION 6 - RESULTS AND CALIBRATION

6.1 General Model Results and Calibration Approach

During the numerical modeling process, values for selected model inputs were varied within reasonable ranges to develop the calibrated Baseline Model. The input values summarized in Section 5 and the results presented in Section 6 correspond to those from the calibrated model; these Report sections do not present a comprehensive description of the process used to arrive at the calibrated model because parameter changes were iterative. Section 7 presents results from a systematic sensitivity analysis that was performed for input parameters that were anticipated to highly influence model results.

A variety of quantitative and qualitative techniques were used to evaluate model calibration including the magnitude and distribution of residuals based on head differences, the scaled RMS error, the drawdown behavior observed in the monitoring wells, and engineering judgement. Techniques for model calibration were based on the experience of the modeling team and general calibration considerations presented in ASTM D5490 (ASTM, 2014). The intent of the model calibration was to generally achieve similar drawdown behavior (i.e., mimic monthly groundwater level fluctuations) in addition to calibrating to the absolute head values observed in monitoring wells. The model was quantitatively calibrated to heads based on observed water levels in monitoring wells. The model was qualitatively calibrated to flow based on observed surface water conditions in ditches and measured flow patterns that showed SBC to not be significantly gaining or losing water near the Study Area. Head results and calibration are presented in Section 6.2, and flow results and calibration are presented in Section 6.3.

To achieve model solver convergence during numerical processing of the Baseline Model, each time step needed to satisfy both the 0.02-foot or less head change criterion for outer iterations (HCLOSE) and less than 250 maximum number of outer iterations (MXITER).

6.2 Head Results and Calibration

6.2.1 General and Calibration Values

Data from 32 wells equipped with data loggers (RJH, 2019) were used for head calibration. The locations of wells used for the model head calibration are shown on Figure 6.1.

Head calibration data from each well are shown on Figures 6.2 through 6.11. Groups of wells presented on these figures are based on hydrogeologic unit and spatial location within the model extent. On these figures, the lines represent the groundwater levels collected by the data loggers and the "X" symbols represent the monthly average water level that was selected as the calibration points from each well. Average monthly values were used to match the resolution of other input data. Some wells exhibit short-term groundwater level fluctuations that are not represented by the monthly average data.

The head calibration input values for each well for each month are provided in Appendix J. Calibration to observed heads generally consisted of comparing the predicted (i.e., model result) head at each well location to the observed water level (Appendix J) for each month. The difference between the predicted and observed water level is called a "residual." We used both unweighted and weighted residuals to statistically evaluate head calibration. For unweighted residuals, the residual value at each well location is treated equally. For weighted residuals, a weighting factor was applied to generally represent the importance of each well based on its location within the model extent. The unweighted (e.g., actual) residual value is multiplied by the weighting factor for the purposes of calculating weighted calibration statistics. The target weighting distribution is shown on Figure 6.1. The OSMP fields north and south of US36 were considered to be the most important for model calibration, and wells in these areas were assigned a weighting of 1. Locations near other Project facilities and near wetland areas upstream of CU Boulder South campus were considered moderately important, and wells in these areas were assigned a weighting of 0.5. Far-field locations and the CU Boulder South campus fill were considered to be less critical for model calibration and were assigned a weighting of 0.25.

6.2.2 Groundwater Contour Maps

Maps of the computed groundwater contours for November 2018 and July 2019 are shown on Figures 6.12 and 6.13, respectively. RJH selected November 2018 (Stress Period 1) of the Baseline Steady-State Model to represent the typical non-irrigation months because groundwater conditions were relatively stable and low from November 2018 through February 2019. RJH selected July 2019 (Stress Period 10) of the Baseline Transient Model to represent the typical irrigation months because many wells exhibited their highest groundwater levels in July.

In general, the computed groundwater contours for July 2019 range from about 2 to 4 feet higher in elevation than the contours for November 2018. This observation is expected based on the seasonal fluctuations recorded in the monitoring wells and is interpreted to be due to irrigation activity. In both figures, SBC appears to be slightly gaining water from the aquifer near the constriction of alluvium between the CU levee and SBC east of CU Boulder South campus, and slightly losing water to the aquifer in the area near the OSMP fields south and north of US36. This result is generally consistent with the field observations presented in Section 3.4 that SBC does not appear to be strongly gaining or losing water near the Study Area.

The distribution of unweighted residuals is also shown on Figures 6.12 and 6.13. Negative residuals represent model predictions that are higher (overpredicted) than the observed groundwater levels and positive residuals represent model predictions that are less (underpredicted) than the observed groundwater levels. Figures 6.12 and 6.13 show the following:

- The unweighted residuals throughout the model range from -4.5 to +4.8 feet in November 2018 and range from -4.3 to +4.4 feet in July 2019.
- Unweighted residuals in OSMP fields north and south of US36 range from -2.6 to +0.7 feet in November 2018 and range from -2.3 to +1.8 feet in July 2019. The unweighted residuals are mostly within +/-1.0 foot during both time periods.
- The magnitudes of residuals are generally highest in the far-field upstream area and along the western portion of the CU Boulder South campus. These areas are distant from sensitive areas (i.e., OSMP fields adjacent to US36) and are not anticipated to be significantly affected by the proposed facilities; therefore, achieving calibration within this area was considered to be less important than achieving calibration on OSMP fields adjacent to US36.

6.2.3 Calibration Plots and Statistics

Head calibration plots for the initial steady-state stress period (Stress Period 1) and the entire transient model are shown on Figures 6.14 and 6.15, respectively. Additional head calibration plots for March 2019 (Stress Period 6), July 2019 (Stress Period 10), and September 2019 (Stress Period 12) are also provided in Appendix K.1 to illustrate model calibration approximately quarterly throughout the 2019 irrigation year. Each of these calibration plots illustrate the performance of the model by comparing the observed head calibration data to the predicted values from the model. The diagonal line on each figure is a one-to-one (1:1) line that represents perfect agreement between the model results and the observed data. Distribution of points above the line demonstrates model overpredictions (negative residuals) whereas points below the line are model underpredictions (positive residuals). In a well-calibrated model, the distribution of points should be near the 1:1 line and should generally be about equally distributed on both sides of the line. On each figure, there is a calibration plot for the unweighted and weighted scheme. The upper plot on each figure shows the unweighted heads and the lower plot on each figure shows the weighted heads.

For the steady-state stress period (Figure 6.14) each point represents a calibration well (Figure 6.1 and Appendix J). For the transient model (Figure 6.15), there is a data point to represent each stress period of each well. On both Figure 6.14 and Figure 6.15, points are distributed near the 1:1 line and are about equally distributed on either side of the 1:1 line for both the unweighted and weighted schemes.

On each of the quarterly calibration plots (Appendix K.1), each point represents a calibration well within the respective month of the transient model. Points are generally near the 1:1 line and show that the model produces reasonable approximations of observed groundwater levels at various months throughout the transient simulation period.

Calibration statistics for the unweighted and weighted head residuals from the steady state model and transient model are presented in Table 6.1. The scaled RMS error is a statistical parameter that describes how well the predicted heads compare to the observed heads. Lower scaled RMS errors represent better calibration, and a scaled RMS error below about 5 percent is considered acceptable (MDBC, 2001). The scaled RMS error for the unweighted schemes of the steady-state and transient models was 1.2 and 1.1 percent, respectively, which are below the acceptable value of 5 percent.

TABLE 6.1
OVERALL MODEL HEAD RESIDUAL STATISTICS

Statistic(1)	Ideal Value	Baseline Steady-State Model		Baseline Transient Model	
		Unweighted Value	Weighted Value	Unweighted Value	Weighted Value
Overall Measures					
Range in Observations (ft)	--(2)	186.10	186.10	187.90	187.90
Number of Observations	Large	26	26	724	724
Number of Adjusted Parameters	--(2)	--(5)	--(5)	23(6)	23(6)
Measures of Model Bias					
Residual mean (ft)	0.00	-0.20	-0.03	0.41	0.28
Min Residual (ft)	0.00	-4.52	-2.58	-4.52	-2.70
Max Residual (ft)	0.00	4.76	2.38	5.53	3.95
Measures of Model Overall Fit (Unscaled) (All Values are Positive)					
Absolute Residual Mean (ft)	Small	1.63	0.82	1.56	0.94
Residual Standard Deviation (ft)	Small, 1.0(3)	2.20	1.08	2.01	1.20
RMS Error (ft)	Small, 1.0(3)	2.21	1.08	2.05	1.23

Statistic(1)	Ideal Value	Baseline Steady-State Model		Baseline Transient Model	
		Unweighted Value	Weighted Value	Unweighted Value	Weighted Value
Measures of Model Overall Fit Scaled by Range of Observations					
Absolute Residual Mean (ft/ft)	Small	0.009	--(7)	0.008	--(7)
RMS Error (ft/ft)	Small	0.012	--(7)	0.011	--(7)
Sum of squared residuals (ft^2)	Small(4)	127	30.3	3050	1100

Notes:

1. The units presented are for unweighted values. Weighted values are dimensionless.
2. An ideal value does not exist; this value will vary from model to model.
3. For the unscaled weighted values, a value of 1.0 suggests that the model fits consistently with the error inferred by the weighting imposed. Values less than 1.0 may suggest overfitting and less accurate simulated results.
4. Smaller is better for each particular model, however this value cannot be used to compare the fit between separate models.
5. The Baseline Steady-State Model is the initial steady-state stress period of the Baseline Transient Model. Parameters were not adjusted to calibrate the steady-state model independently of the transient model.
6. Twenty-three parameters were adjusted independently of each other during iterative model calibration: hydraulic conductivity of seven units listed in Table 5.1; anisotropy ratio of fill; specific yield of fill, alluvium units, and bedrock units; natural background recharge; irrigation recharge of eight irrigation zones; evapotranspiration rate of irrigated grass and background/native grass; and extinction depth. The specific yield parameters were only used during calibration of the transient model.
7. Scaled, weighted statistics are not presented. These values gain meaning based on the comparison between the unscaled weighted values and 1.0 as described in Note 3.

Plots of residual head values versus observed head values for the initial steady-state stress period (Stress Period 1) and the entire transient model are shown on Figures K.2.1 and K.2.2, respectively, in Appendix K.2. These figures show the same data from Figures 6.14 and 6.15 except with residual head values plotted on the vertical axis instead of model head values. Figures K.2.1 and K.2.2 show the spatial distribution of residuals throughout the model. We interpret the following from the data shown on Figures K.2.1 and K.2.2:

- There does not appear to be a consistent trend of residuals increasing or decreasing with observed values. This suggests that the overall hydraulic gradient through the model is generally appropriate.
- Residuals are generally positive in the upstream portion of the model (observed values of about El. 5380 to 5440), which means the model is slightly underpredicting groundwater levels in this area.
- The spread of residual values is relatively small at the far upstream and downstream ends of the model. In these areas, unweighted residuals are generally

less than +/- 1 foot for the transient simulation (the upper graph on Figure K.2.2). Small residuals are expected in these areas because calibration near the upstream and downstream ends of the model are strongly influenced by the upstream and downstream boundary conditions.

- The spread of residuals is relatively large about near the middle of the model (observed values of about El. 5330 to 5370). In this area, unweighted residuals are generally within +/- 4 feet for the transient simulation (the upper graph on Figure K.2.2). A wider range of residuals exist in this area because there are a large number of calibration points in this area, hydraulic stresses are relatively dynamic during the transient simulation, and the model cannot account for local variations in aquifer properties that may exist at or between closely spaced wells. Residuals are generally distributed between positive and negative values, which means the Baseline Model is simulating a condition that is about average of the observed heads. Despite the spread of residuals, the low scaled RMS error of about 1 percent (Table 6.1) means the Baseline Model is calibrated to heads within industry-acceptable limits.

The weighting of heads described in Section 6.2.1 and shown on Figure 6.1 can be interpreted as the inverse of the standard deviation of heads. Namely, weighting of 1.0 corresponds to a standard deviation of heads of 1 foot at these locations; weighting of 0.5 corresponds to a standard deviation of 2 feet; and weighting of 0.25 corresponds to a standard deviation of 4 feet. The standard deviation of weighted residuals (Table 6.2, Figure K.2.1, and Figure K.2.2) is close to 1.0. This shows an internal consistency between the model fit and the assigned weighting distribution, which is desirable.

6.2.4 Head and Drawdown Results by Well

The calibration statistics presented in Table 6.1 represent how well the model collectively matches the calibration head data from all wells and all transient stress periods. For a transient simulation it is also important for the model to reasonably approximate variability within each individual well over time.

Graphs that show comparisons over time between observed and predicted conditions within each well are shown on Figure 6.16, Figure 6.17, and in Appendix K.3. Figure 6.16 shows a comparison for a selected well in OSMP fields south of US36 (B-123[P]) and Figure 6.17 shows a comparison for a selected well in OSMP fields north of US36 (B-126[P]). These two wells illustrate typical calibration behavior in critical areas adjacent to proposed facilities. Similar comparisons for each of the other calibration wells are provided in Appendix K.3.

The calibrations comparisons on Figure 6.16 and Figure 6.17 consist of three plots per well:

1. The upper plot shows how the observed and calculated heads vary throughout each of the transient stress periods.
2. The lower plot shows drawdown of each well throughout each of the transient stress periods. “Drawdown” represents the difference between either the observed or predicted head at each stress period and the respective initial value from the end of the steady-state stress period (i.e., Stress Period 1).
3. The middle plot shows the simulated recharge at the well location for each stress period, and illustrates how the computed heads and drawdown are strongly influenced by the applied recharge. Additional information about the simulated recharge is presented in Section 5.2.6.2 and on Figures 5.6 through 5.8.

Calibration comparisons in Appendix K.3 consist of two plots that show head data and drawdown data similarly to Figures 6.16 and 6.17, however plots of recharge are not included in Appendix K.3.

The predicted heads shown for B-102(P) and B-106(P) in Appendix K.3 vary step-wise between each stress period, whereas the remaining wells generally vary smoothly from one stress period to the next. B-102(P) and B-106(P) are located near specified head boundary conditions at the upstream and downstream ends of the model, and the observed heads at these locations are influenced by boundary conditions that remained constant throughout each stress period.

In sensitive areas (i.e., OSMP fields north and south of US36) the model predictions generally follow similar drawdown patterns as the observed well levels. For wells in the far-field upstream alluvium and within the CU Boulder South campus, the predicted head and drawdown curves generally do not follow the observed patterns or amplitudes as closely.

In general, groundwater levels in many wells rise earlier in the spring than what is predicted by the model, and observed seasonal groundwater fluctuations are larger than what is predicted by the model. These phenomena are illustrated on Figures 6.16 and 6.17, and are likely caused by a source of water that is not currently represented by the model boundary conditions, which could include (a) infiltration from spring snowmelt,

(b) recharge of the aquifer from high spring flows in SBC, or (c) irrigation activities that initiate earlier than what is reported in the ditch diversion data. We applied irrigation recharge to irrigated fields as soon as the water became available based on ditch diversion records, however we were unable to apply irrigation early enough in the spring to simulate some of the observed groundwater rises. The calibrated model was more successful, however, at calibrating to the peak and falling limb of seasonal groundwater fluctuations as illustrated on Figures 6.16 and 6.17.

6.3 Flow Results and Calibration

6.3.1 Global Water Budget Components and Error

Water budget components for the baseline model are shown on Figure 6.18. Flows through the model vary seasonally by about a factor of 3 and range from approximately 350,000 cubic feet per day during the summer to about 115,000 cubic feet per day during the winter. The predominant components of the water budget are inflow from recharge, outflow from evapotranspiration, and interactions with surface water in SBC (labeled as "stream leakage" on Figure 6.18).

The water budget error (the difference between total predicted inflows and outflows within the model) for the Baseline Steady-State Model and Baseline Transient Model are presented in Table 6.2. Flow rates in Table 6.2 are presented as averages throughout each stress period. The model convergence and water budget errors for both models were within acceptable tolerances based on industry standards for groundwater modeling. As shown in Table 6.2, the percent discrepancies were generally similar for each respective month between the two years of simulation except for November. The percent discrepancy for November of Year 1 was significantly less than the discrepancy for November of Year 2, which is attributed to influences from the initial steady-state stress period and is expected.

TABLE 6.2
WATER BUDGET ERRORS FOR BASELINE MODEL[1]

Stress Period (Number)	Stress Period (Month)	Inflow[2] (ft^3/day)	Outflow[2] (ft^3/day)	Difference[3,4] (ft^3/day)	Percent Discrepancy[3,4]
1	Steady-State	123,360	123,363	-3	< 0.01
Year 1					
2	Nov. 2018	123,360	123,362	-2	< 0.01
3	Dec. 2018	117,716	117,043	673	0.57
4	Jan. 2019	138,479	138,255	224	0.16
5	Feb. 2019	124,832	125,039	-207	-0.17
6	Mar. 2019	184,676	185,425	-749	-0.41
7	Apr. 2019	177,793	178,265	-472	-0.27
8	May 2019	295,571	295,979	-408	-0.14
9	Jun. 2019	351,570	351,164	406	0.12
10	Jul. 2019	329,334	329,514	-180	-0.05
11	Aug. 2019	261,413	259,909	1,504	0.58
12	Sep. 2019	190,850	190,437	413	0.22
13	Oct. 2019	168,706	169,385	-679	-0.40
Year 2					
14	Nov. 2018	135,766	136,289	-523	-0.39
15	Dec. 2018	115,513	114,840	672	0.58
16	Jan. 2019	140,416	140,186	230	0.16
17	Feb. 2019	121,858	122,066	-208	-0.17
18	Mar. 2019	183,619	184,368	-749	-0.41
19	Apr. 2019	169,957	170,429	-472	-0.28
20	May 2019	290,155	290,557	-402	-0.14
21	Jun. 2019	345,296	344,890	406	0.12
22	Jul. 2019	325,689	325,869	-180	-0.06
23	Aug. 2019	259,589	258,085	1,504	0.58
24	Sep. 2019	190,026	189,613	413	0.22
25	Oct. 2019	168,530	169,209	-679	-0.40

Notes:
1. Water budget errors are presented incrementally for each individual stress period.
2. Inflow and Outflow represent the average flow rate throughout each stress period. Changes in storage are included in the Inflow and Outflow data. An increase in storage is included as Inflow and a decrease in storage is included as Outflow.
3. Positive differences and percent discrepancies mean inflow is greater than outflow.
4. Negative differences and percent discrepancies mean outflow is greater than inflow.

6.3.2 Flow Results Beneath US36

We used the Hydrostratigraphic Unit (HSU) package within Groundwater Vistas to calculate the amount flow through the model beneath US36. The HSU package allows for identifying the amount of flow that passes through a group of model cells.

Eight HSUs (HSU 6 through HSU 13) were evaluated to itemize the amount of flow through different locations of the model. The HSU locations are shown on Figure 5.1 and characteristics of each HSU are summarized in Table 6.3. HSUs 6 through 9 identify flows through soil and HSUs 10 through 13 identify flows through bedrock. The lateral extents of each HSU were selected to divide the model into four similarly sized reaches that also accounted for the distribution of alluvial zones (Figure 5.1) and the configurations of proposed facilities. The HSUs were aligned along US36 because this was a convenient feature near the proposed facilities that extends across the model and can be used during future modeling to evaluate the effects of design solutions.

The predicted flow through the Baseline Model in each of the HSUs is presented on Figure 6.19 and is summarized in Table 6.3. During the initial steady-state stress period (time = 0), the predicted total flow through alluvium (HSU 6 through 9) was about 5,650 ft^3/day and the total flow through bedrock (HSU 10 through 13) was about 260 ft^3/day. The results show that the majority of the flow is occurring through HSU 7, followed by HSU 6. This is expected because these two HSUs are located within Alluvium Zone A (Figure 5.1), which was simulated with a higher hydraulic conductivity than the other alluvial zones (Table 5.1). We used Darcy's Law (Q = kiA) to independently check the simulated flow through the alluvium (HSU 6 through 9) based on model input parameters and results. Our calculated flows were similar in magnitude and spatial trend to those output by the model, and therefore the flow outputs appear reasonable. The calculated flows are summarized in Table 6.3 and calculations are presented in Appendix K.4.

TABLE 6.3
SUMMARY OF FLOWS BENEATH US36

HSU Number(1)	Material	Approximate Length (feet)	Simulated Flow(2) (ft^3/day)	Calculated Flow(3) (ft^3/day)
6	Alluvium Zone A	1,130	850	860
7	Alluvium Zone A	1,300	4,280	3,460
8	Alluvium Zone B	1,180	200	90
9	Alluvium Zone C	1,080	320	90
10	Bedrock	1,130	50	(4)

HSU Number(1)	Material	Approximate Length (feet)	Simulated Flow(2) (ft^3/day)	Calculated Flow(3) (ft^3/day)
11	Bedrock	1,300	40	(4)
12	Bedrock	1,180	80	(4)
13	Bedrock	1,080	90	(4)

Notes:
1. HSU locations are shown on Figure 5.1.
2. Simulated flow is the flow predicted by the Baseline Model during the initial steady-state stress period. Additional information is presented on Figure 6.19.
3. Calculated flow is the flow during the initial steady-state stress period estimated by RJH using Darcy's Law. Calculations are presented in Appendix K.4.
4. RJH did not calculate flows through the bedrock because simulated flows through the bedrock were very minor compared to flows through alluvium.

The results on Figure 6.19 show that HSU 7 is predicted to generally have slightly increasing flow throughout the duration of the 2-year transient simulation. Much of the initial increase occurs from 210 to 270 days (June and July 2019), which corresponds to the peak and latter portion of the simulated irrigation season (Figure 5.8). The increase in flow over time is unexpected and is likely not representative of long-term system behavior. During the second year of the two-year transient simulation, the flow rate through HSU 7 appears to have more closely stabilized (i.e. the flow at 720 days returns to near the flow at 360 days). Flow rates through the other HSUs generally show more consistent seasonal trends and return to near their baseline levels at the end of each hydrologic season (at time 360 and 720 days).

The amount of water predicted to exit drain boundary conditions during the transient simulation is shown on Figure 6.20. We interpret the following from the data shown on Figure 6.20:

- The majority of water that is collected by drains is predicted to enter Dry Creek No. 2 Ditch. This ditch is predicted to collect 2,500 to 3,700 cubic feet per day. This exceeds half of the flow that is predicted to be conveyed through alluvium in HSU 7 (Figure 6.19). The high flows in Dry Creek No. 2 Ditch are likely caused by its long extent because this ditch exists throughout the length of the model extent (e.g., Figure 6.12). Despite the high amount of flow from this boundary condition, the groundwater head contours (Figure 6.12 and 6.13) do not appear to be strongly influenced by Dry Creek No. 2 Ditch.

- Both years of the two-year simulation produce similar flow results through the drains, however the transient flows generally decline from what is predicted by the initial steady state simulation.

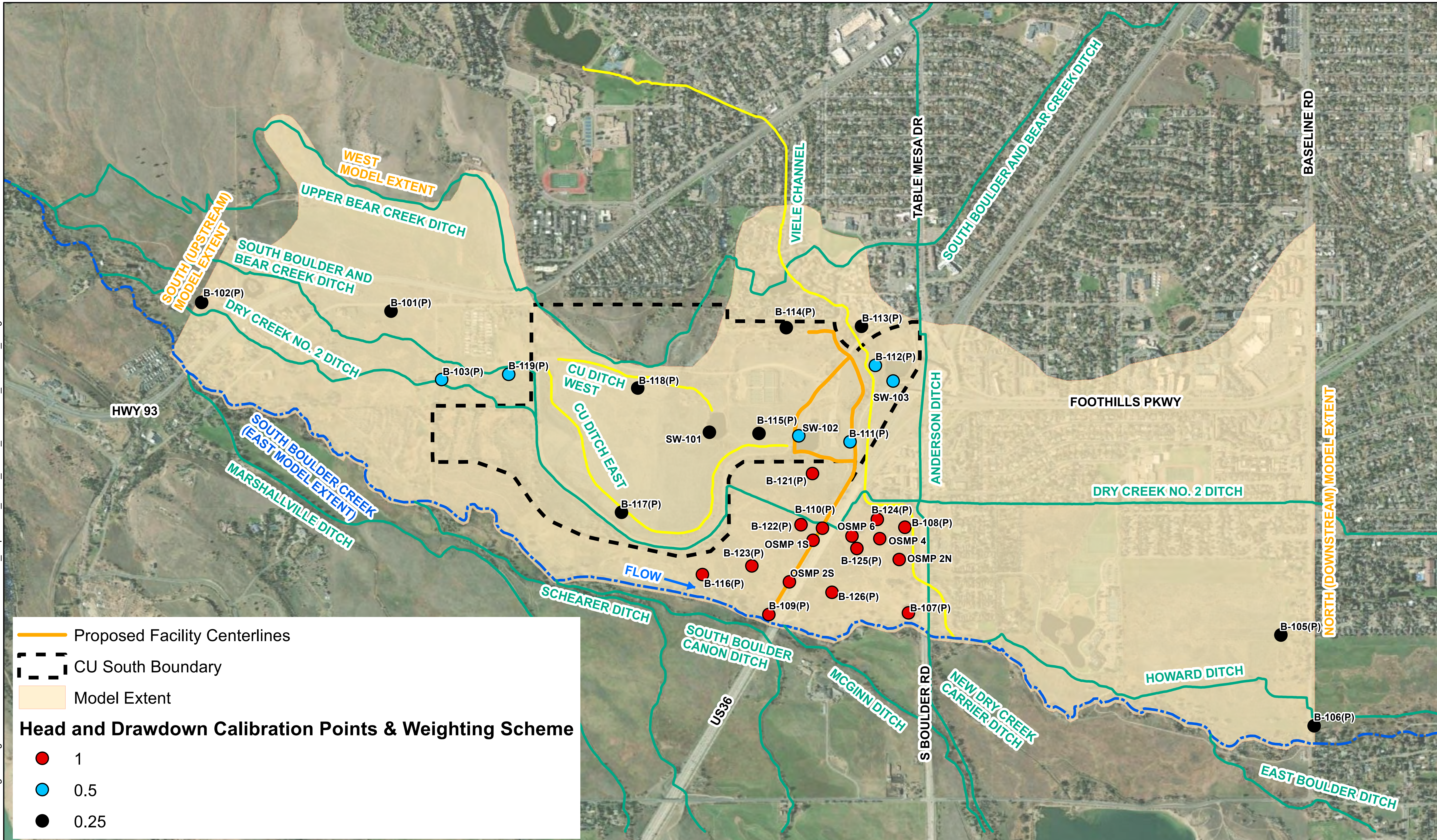
Although the actual flow rates beneath US36 and within ditches are not known, in our opinion the simulated flows obtained from the HSUs and drain boundary conditions provide a reasonable baseline that can be used for evaluating the relative effects of proposed facilities and design solutions.

6.3.3 Flow Calibration

Groundwater flow data is not readily available for the Study Area and therefore evaluations of flow calibration were qualitative. RJH offers the following observations and opinions about the flow calibration results:

- The SFR boundary condition incorporated available flow data. Flow rates reported by the San Souci gauge (Figure 3.4) were input at the upstream end of the boundary condition and monthly ditch diversions were applied at appropriate locations along SBC. In our opinion available published flow data has generally been incorporated into the model.
- Simulated groundwater contours (Figures 6.12 and 6.13) show that SBC is not strongly gaining or losing water within the Study Area. This generally agrees with field observations and measured values (Table 3.1).
- The SFR boundary condition predicts that there is still surface water flowing through SBC at the downstream end of the model throughout every stress period. The amount of flow in SBC exiting the model ranges from 18 to 107 cfs. This is consistent with field observations that, even during irrigation season, there is some flow in SBC continuing downstream past the Study Area. This flow rate is significantly higher than the measured flow rates presented in Table 3.1, however it is generally within the range of inflow rates defined for the upstream end of SFR Segment 1 (Appendix J).
- The amount of irrigation recharge applied to irrigated fields was less than the available water diverted each month. The irrigation rate generally ranged from about 1 to 74 percent of the water diverted each month, which is considered reasonable. Supporting calculations are provided in Appendix I.
- Drawdown curves (Appendix K.3) show that head levels predicted by the model decline similarly to observed heads and coincide with the end of the irrigation season.
- Hydraulic conductivity values are consistent with the ranges of available in-situ data for each hydrogeologic unit.

- The amount of water predicted to exit drain boundary conditions is generally reasonable with respect to field observations:
  - Negligible water (less than 150 cubic feet per day [less than approximately 1 gallon per minute]) is predicted to leave the model through drain boundary conditions assigned to Howard Ditch and Anderson Ditch. This is generally consistent with field observations of irrigation ditches being dry during months when water is not being diverted through the ditches.
  - Approximately 2,500 to 3,700 cubic feet per day (13 to 19 gallons per minute) is predicted to exit the model through Dry Creek No. 2 Ditch. This is a relatively minor amount of water considering the length of the ditch through the model (Figure 2.1), and might be caused from assigning the drain boundary condition lower than the ground surface topography.
  - The drain boundary conditions applied along the S. Boulder and Bear Creek Ditch, and the CU Ditch East and Viele Channel drainage ditches were each predicted to remove about 200 to 900 cubic feet per day (approximately 1 to 5 gallons per minute). Negligible water is predicted to leave the model through the CU Ditch West drain boundary condition. There is currently no quantitative flow data available in these locations to allow for calibration, however, the model results are generally similar to field observations. Viele Channel generally contained stagnant water with no observed flow. CU ditches ranged seasonally from being dry, having stagnant water, or flooded with flowing water. The model results are generally consistent with observed field conditions in CU Ditch East; however, the model does not replicate wet ground conditions that we have observed near CU Ditch West.



0 600 1,200 2,400 Feet

REPRODUCE IN COLOR

N

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

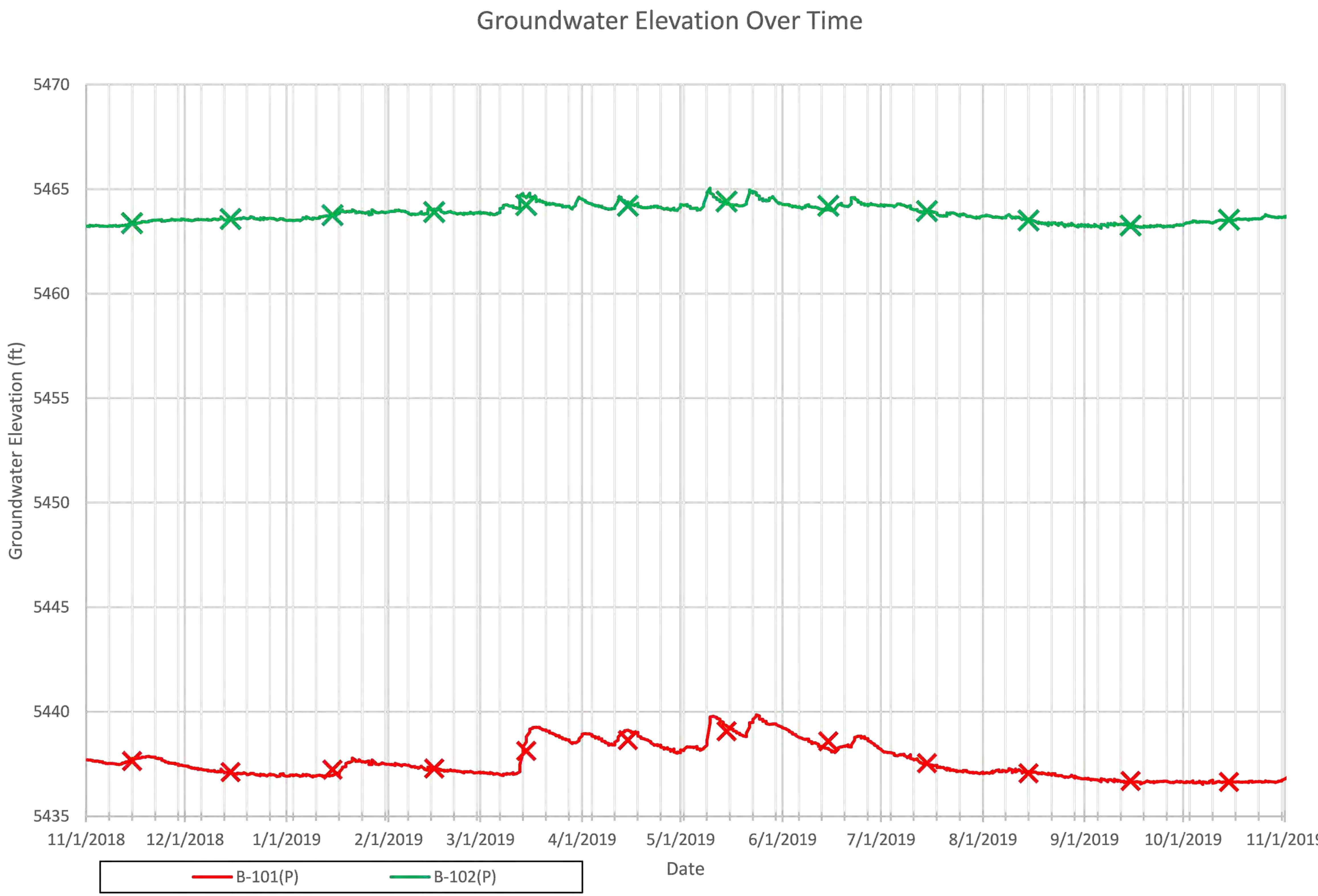
PROJECT NO. 16134

HEAD AND DRAWDOWN CALIBRATION POINTS AND WEIGHTING SCHEME

July 2021

Figure 6.1

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline_Report\6.1_Wells_Model_Calibration_Residual_Weight.mxd



REPRODUCE IN COLOR

NOTES:

1. LINES ARE DATA RECORDED TWICE DAILY BY DATA LOGGERS.
2. "X" IDENTIFIES THE MONTHLY AVERAGE WATER LEVELS USED AS THE CALIBRATION VALUE.

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

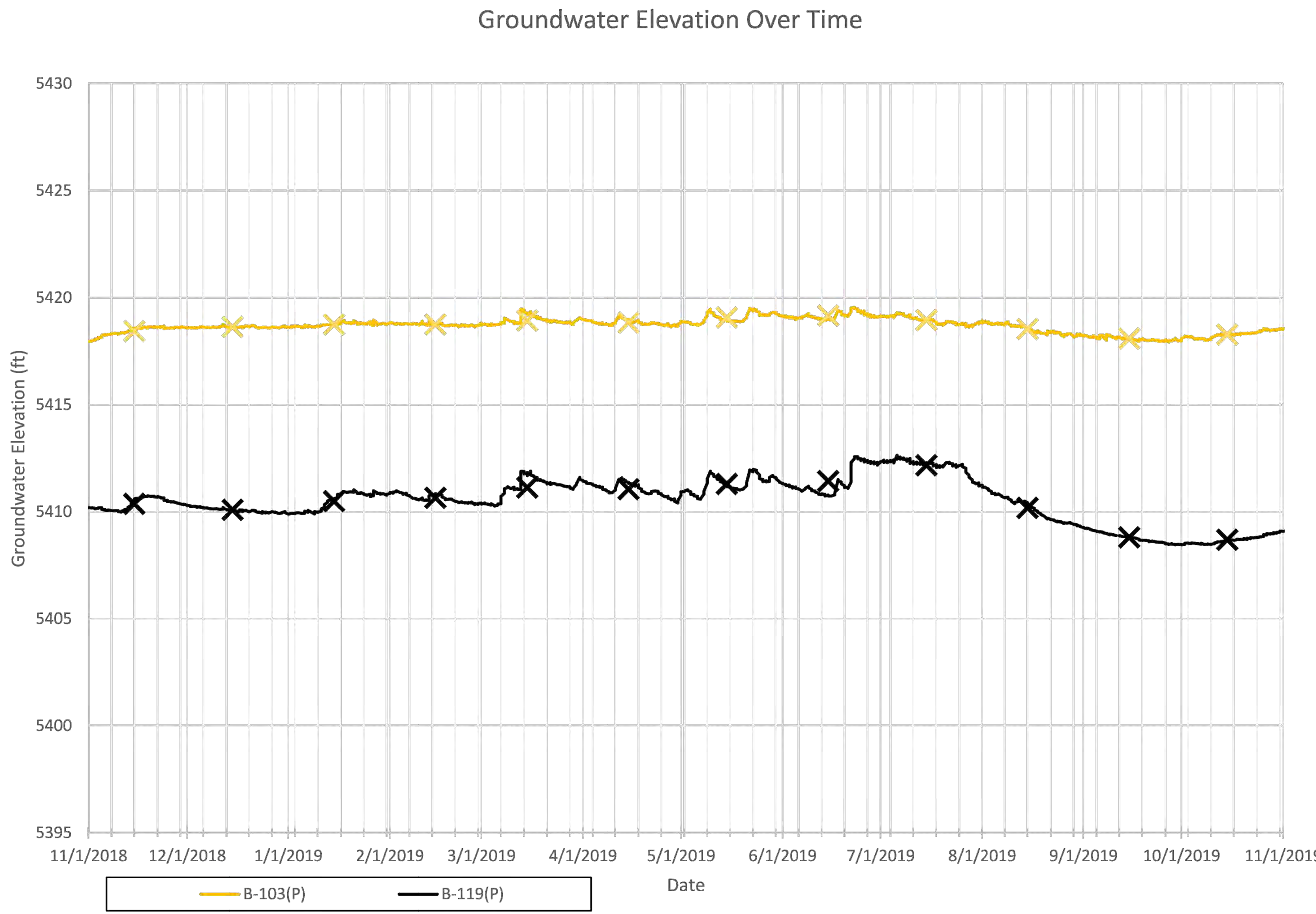
PROJECT NO. 16134

MONITORING WELL WATER LEVELS - ALLUVIUM UPSTREAM - GROUP A

July 2021

Figure 6.2

P:\16134 - SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\BASELINE_REPORT\16134_3004_FIGURES_MW_LEVELS.DWG 7/8/2021 3:00 PM



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REPRODUCE IN COLOR

NOTES:

1. LINES ARE DATA RECORDED TWICE DAILY BY DATA LOGGERS.
2. "X" IDENTIFIES THE MONTHLY AVERAGE WATER LEVELS USED AS THE CALIBRATION VALUE.

CITY OF BOULDER

RJH CONSULTANTS, INC.

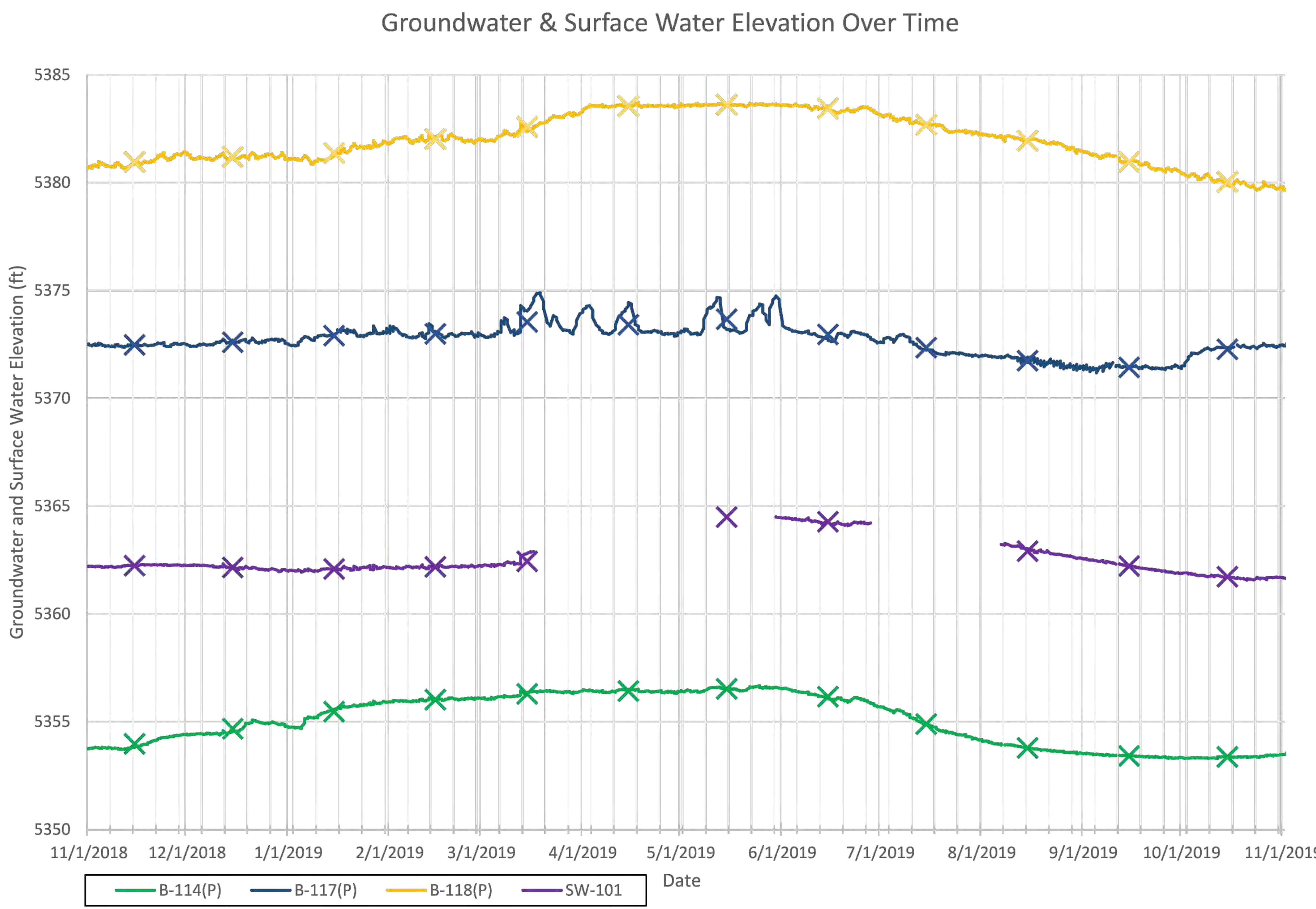
SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

PROJECT NO. 16134

MONITORING WELL WATER LEVELS - ALLUVIUM UPSTREAM - GROUP B

July 2021

Figure 6.3



REPRODUCE IN COLOR

NOTES:

1. LINES ARE DATA RECORDED TWICE DAILY BY DATA LOGGERS.
2. "X" IDENTIFIES THE MONTHLY AVERAGE WATER LEVELS USED AS THE CALIBRATION VALUE.

CITY OF BOULDER / RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	MONITORING WELL WATER LEVELS - FILL - GROUP A
	PROJECT NO. 16134	July 2021 **Figure 6.4**

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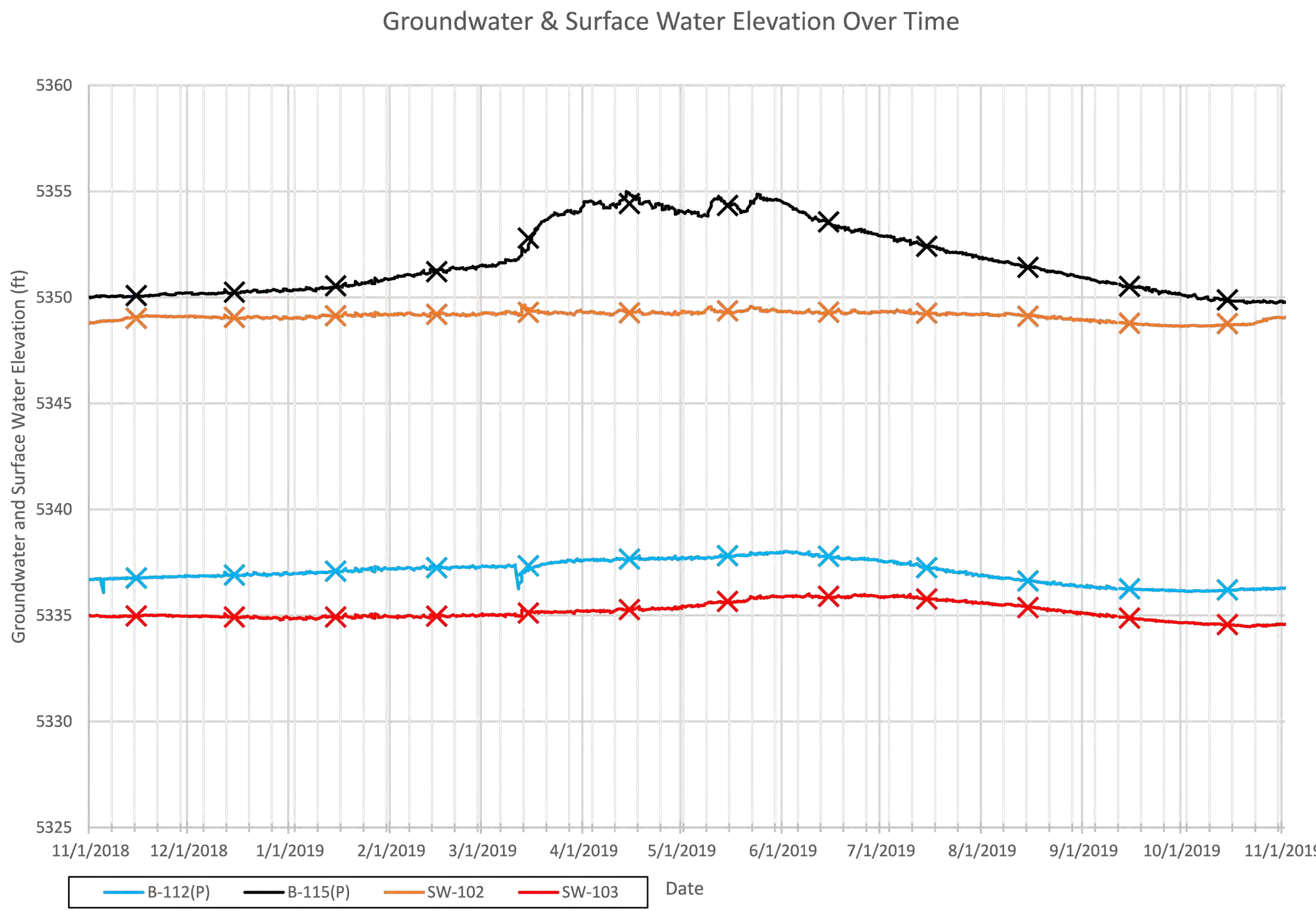

REPRODUCE IN COLOR

NOTES:

1. LINES ARE DATA RECORDED TWICE DAILY BY DATA LOGGERS.
2. "X" IDENTIFIES THE MONTHLY AVERAGE WATER LEVELS USED AS THE CALIBRATION VALUE.

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	MONITORING WELL WATER LEVELS - FILL - GROUP B
		PROJECT NO. 16134	July 2021 **Figure 6.5**

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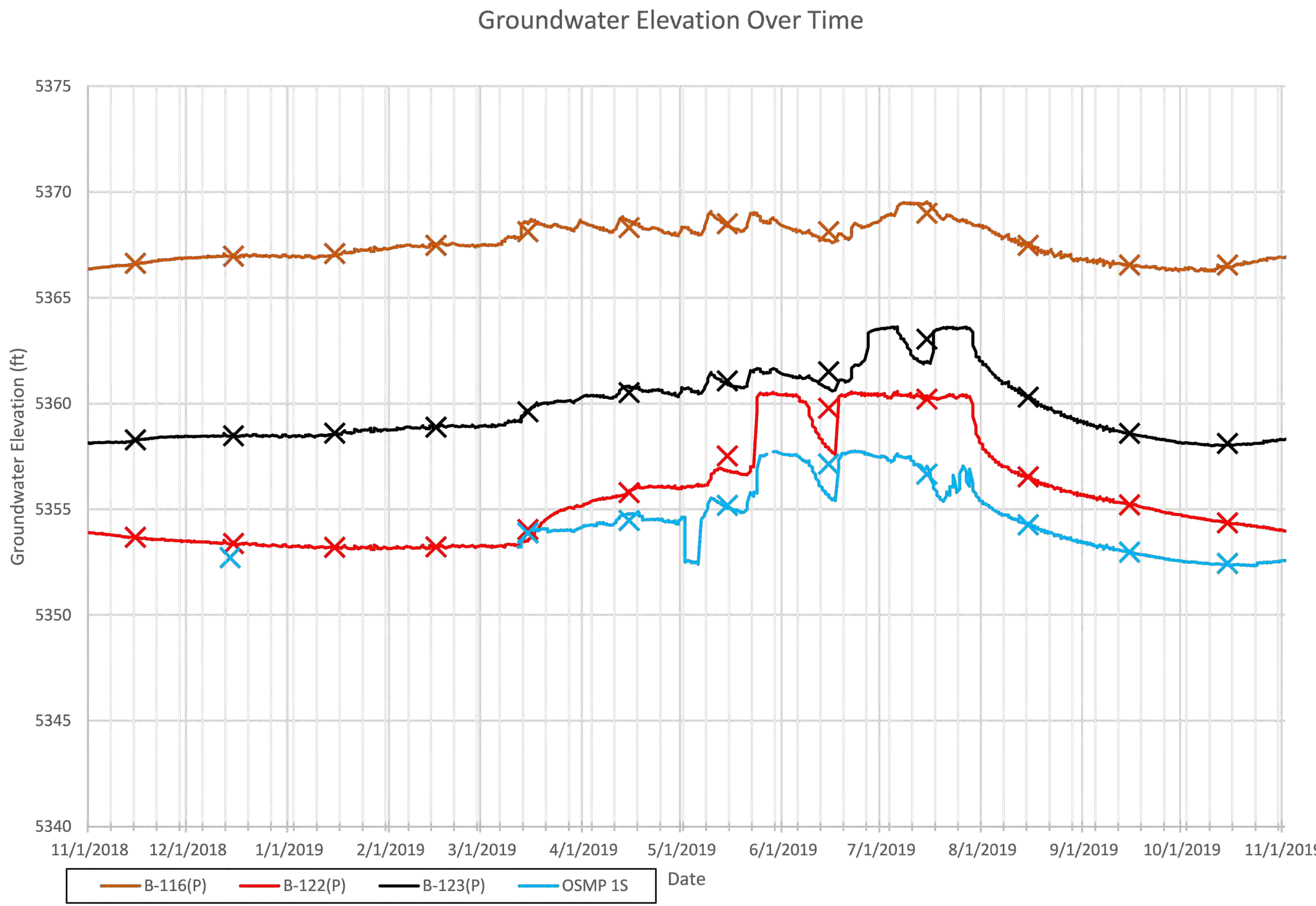


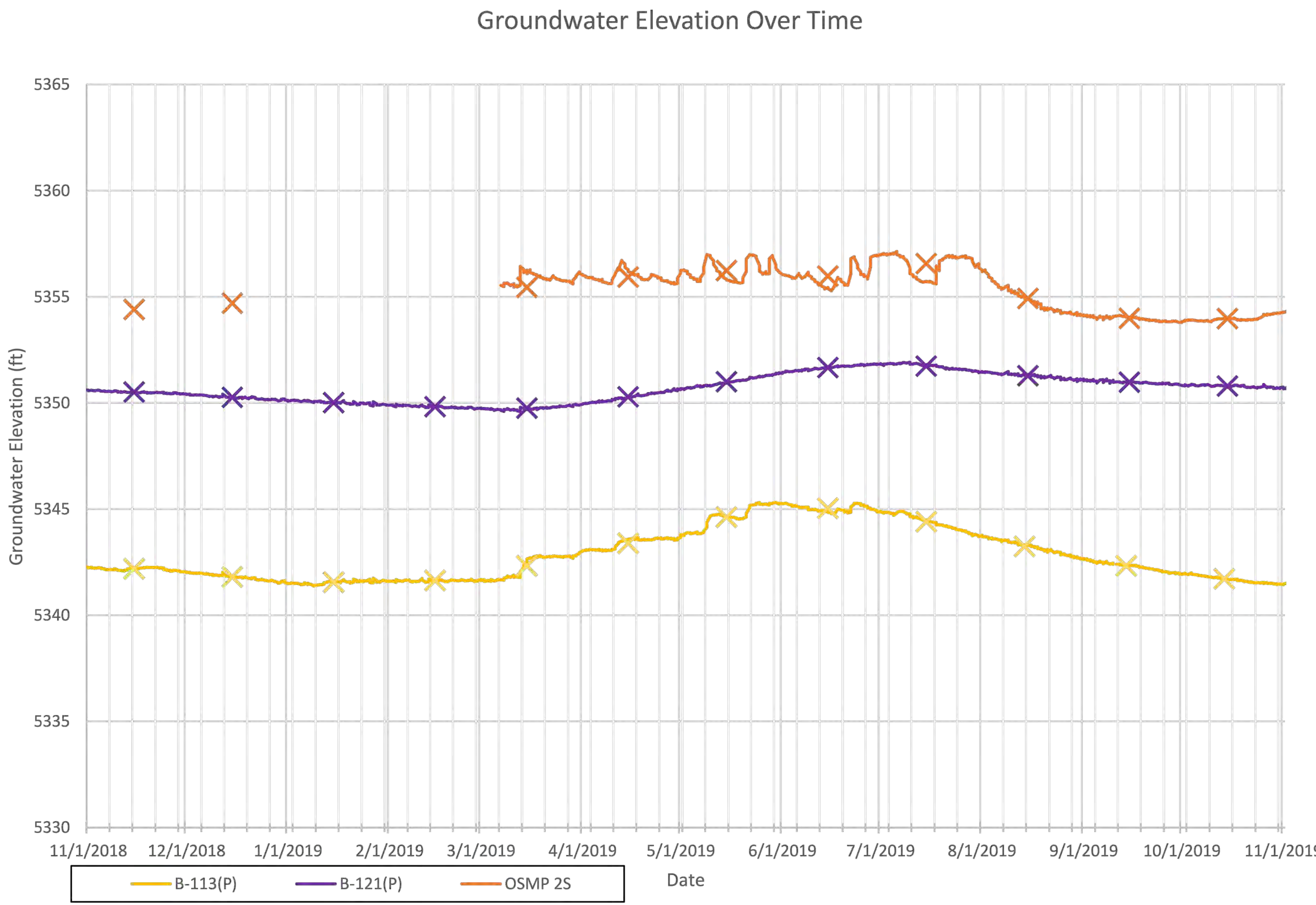
REPRODUCE IN COLOR

NOTES:

1. LINES ARE DATA RECORDED TWICE DAILY BY DATA LOGGERS.
2. "X" IDENTIFIES THE MONTHLY AVERAGE WATER LEVELS USED AS THE CALIBRATION VALUE.

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	MONITORING WELL WATER LEVELS - ALLUVIUM OSMP SOUTH - GROUP A
		PROJECT NO. 16134	July 2021 **Figure 6.6**

P:\16134 - SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\BASELINE_REPORT\16134_3004_FIGURES_MW_LEVELS.DWG 7/8/2021 3:07 PM



REPRODUCE IN COLOR

NOTES:

1. LINES ARE DATA RECORDED TWICE DAILY BY DATA LOGGERS.
2. "X" IDENTIFIES THE MONTHLY AVERAGE WATER LEVELS USED AS THE CALIBRATION VALUE.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	MONITORING WELL WATER LEVELS - ALLUVIUM OSMP SOUTH - GROUP B	
PROJECT NO. 16134	July 2021	**Figure 6.7**

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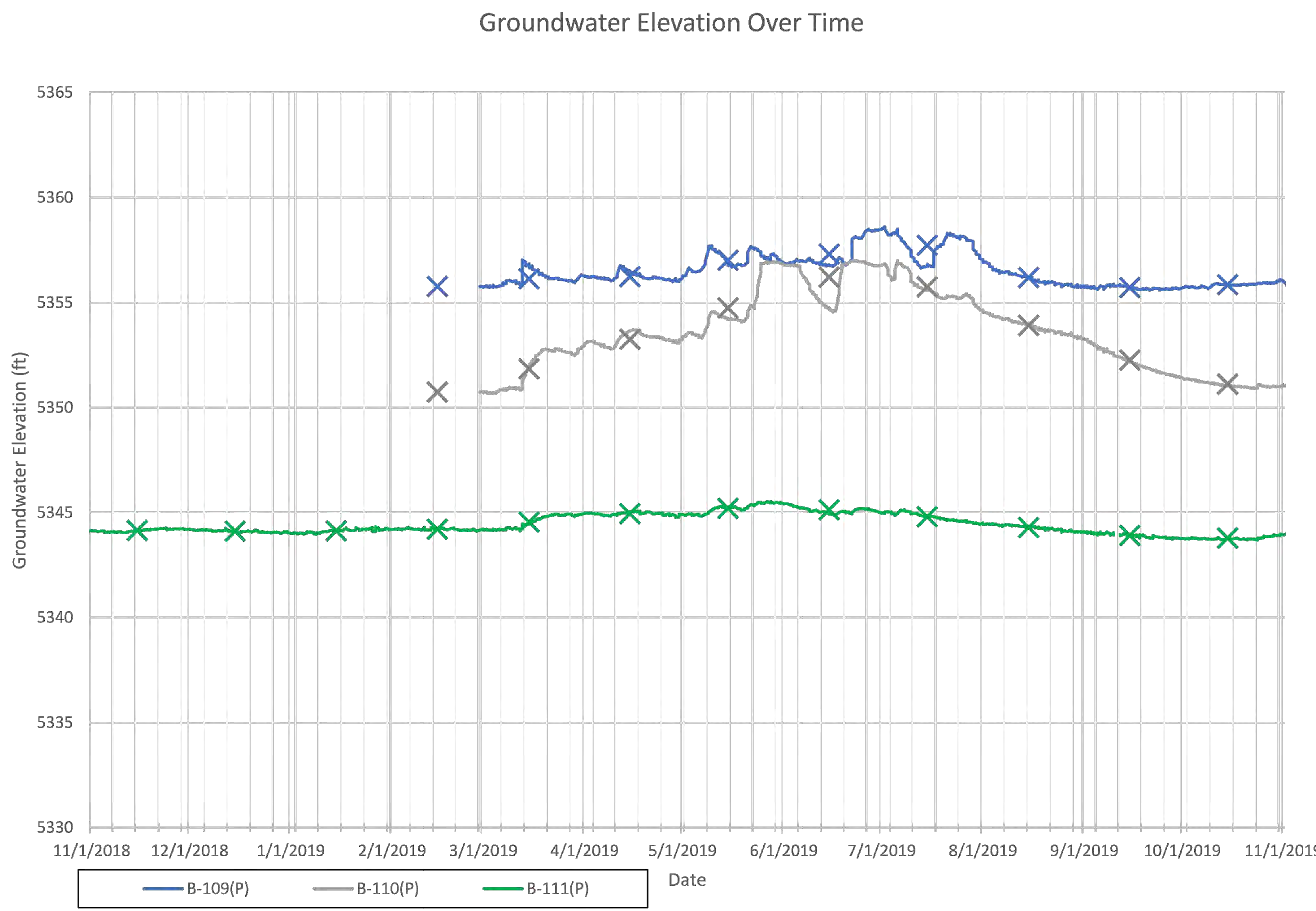

REPRODUCE IN COLOR

NOTES:

1. LINES ARE DATA RECORDED TWICE DAILY BY DATA LOGGERS.
2. "X" IDENTIFIES THE MONTHLY AVERAGE WATER LEVELS USED AS THE CALIBRATION VALUE.

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	MONITORING WELL WATER LEVELS - ALLUVIUM OSMP SOUTH - GROUP C
		PROJECT NO. 16134	July 2021 **Figure 6.8**

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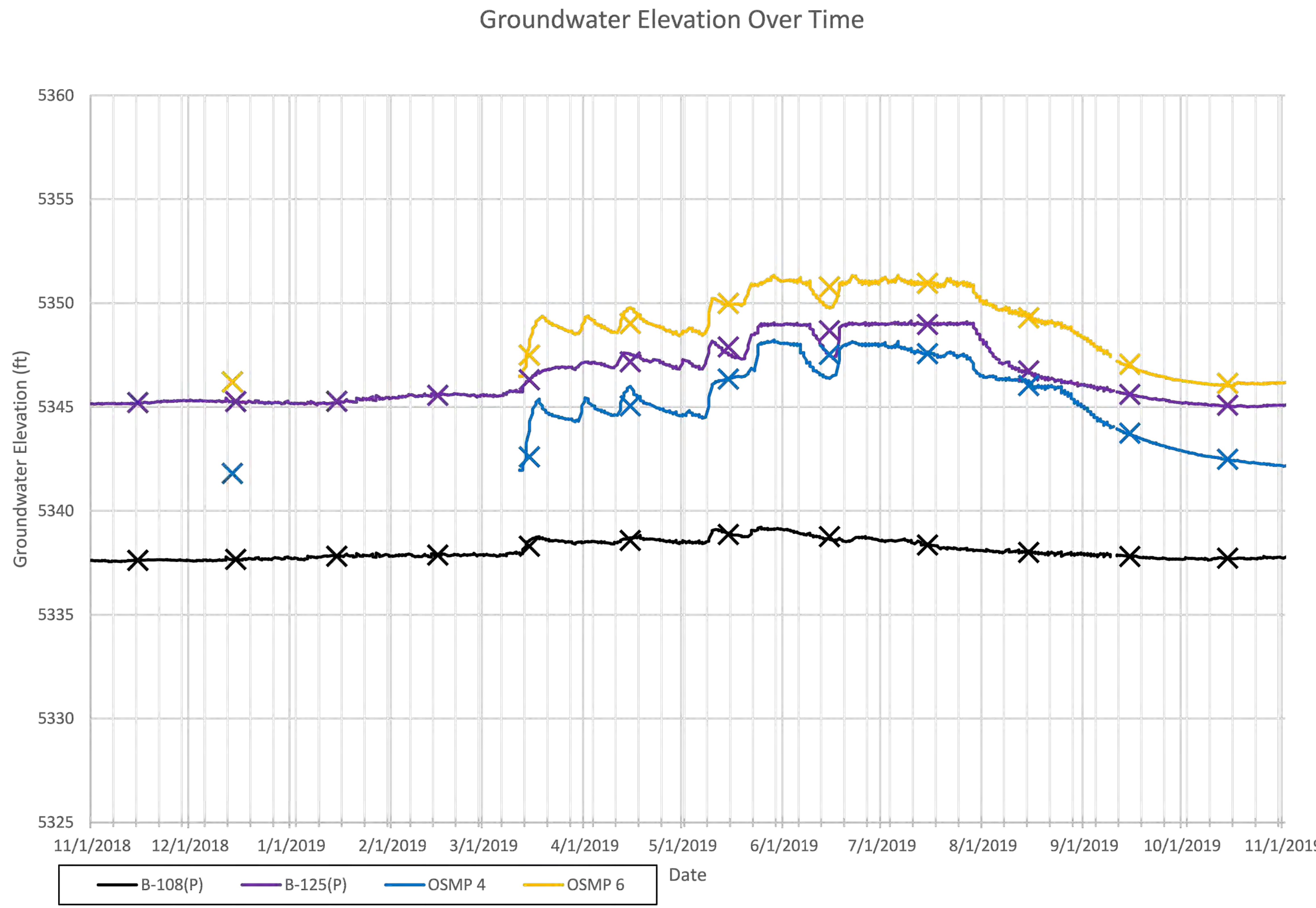

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NOTES:

1. LINES ARE DATA RECORDED TWICE DAILY BY DATA LOGGERS.
2. "X" IDENTIFIES THE MONTHLY AVERAGE WATER LEVELS USED AS THE CALIBRATION VALUE.

REPRODUCE IN COLOR

CITY OF BOULDER

RJH CONSULTANTS, INC.

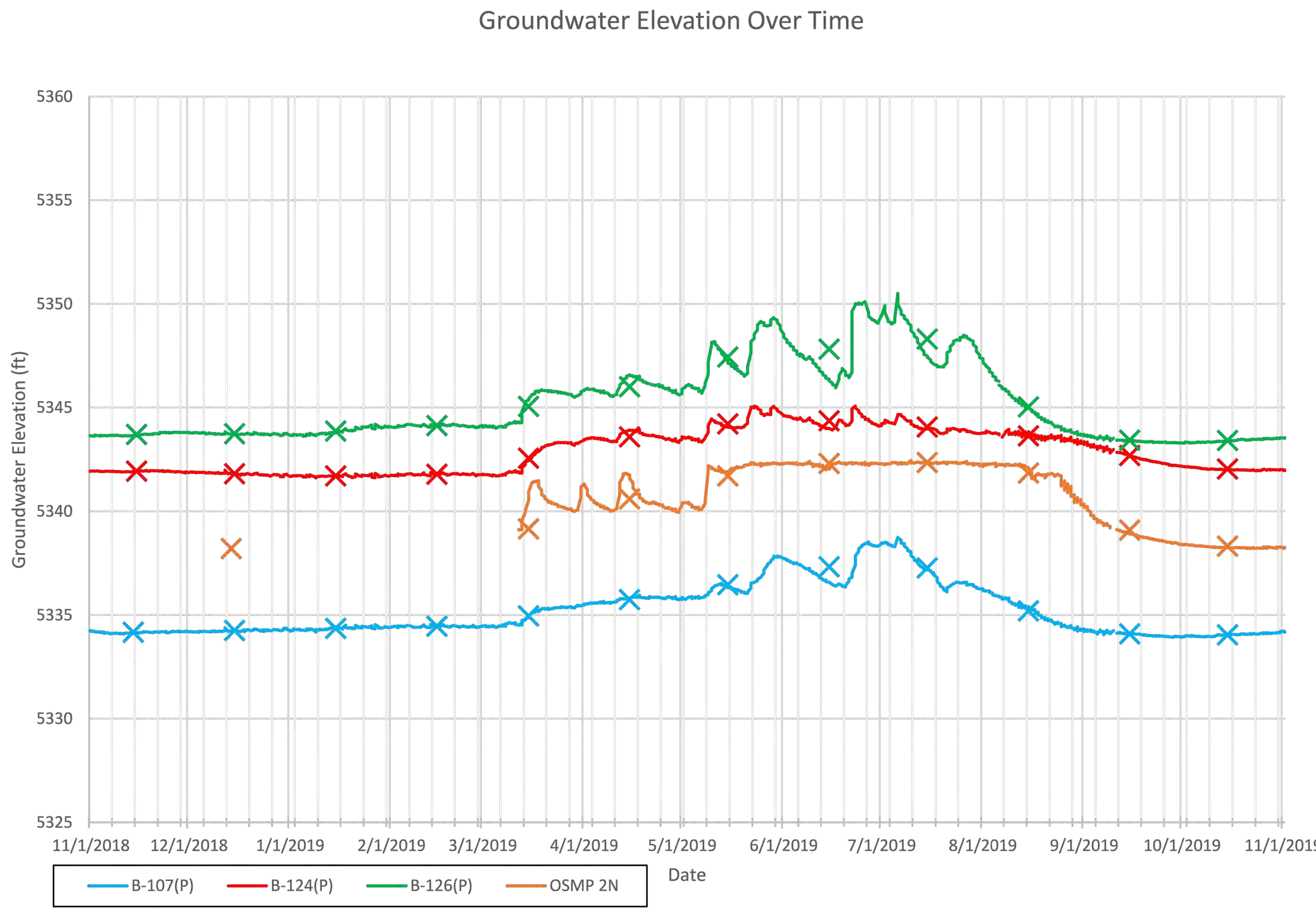
SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

PROJECT NO. 16134

MONITORING WELL WATER LEVELS - ALLUVIUM OSMP NORTH - GROUP A

July 2021

Figure 6.9



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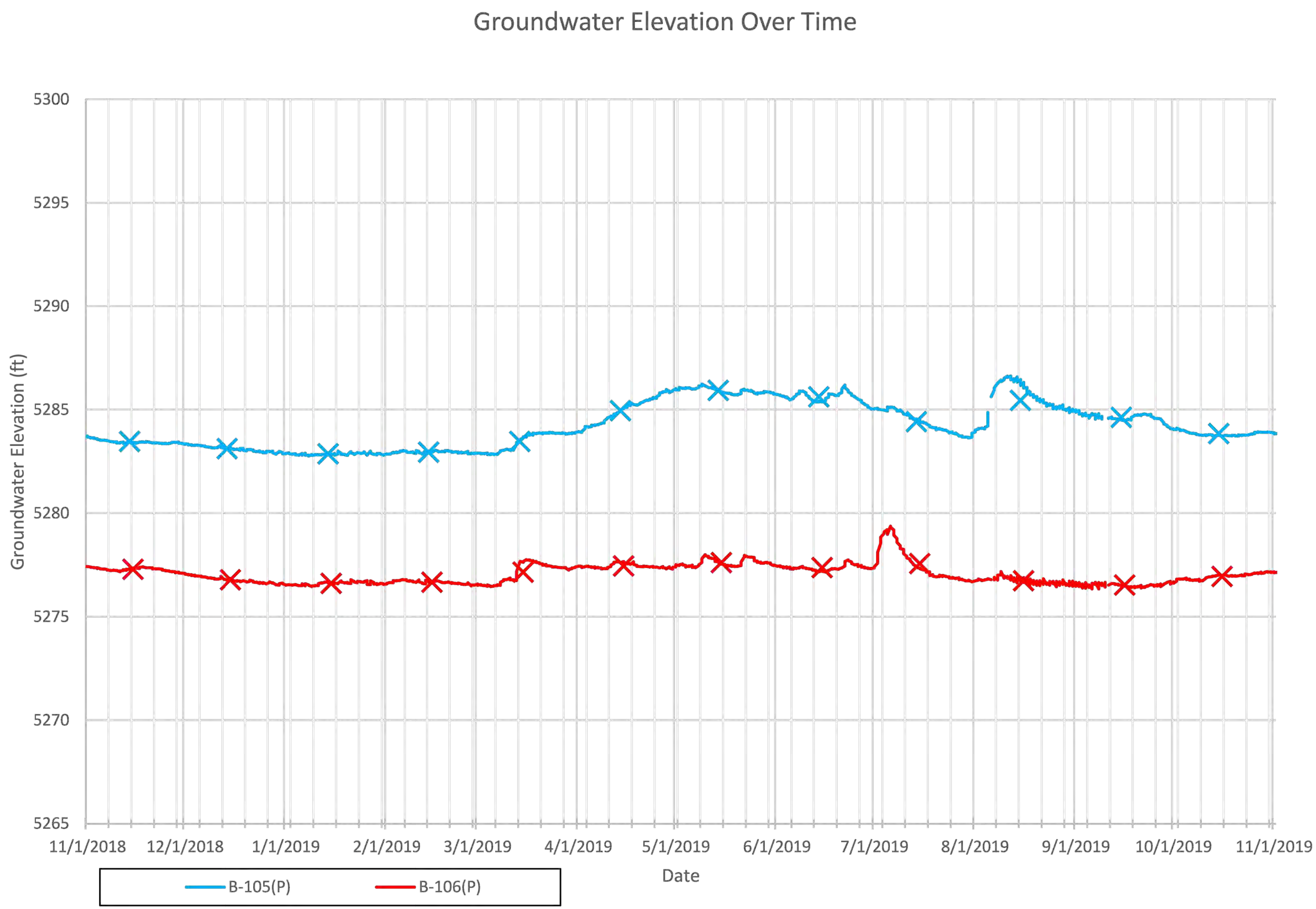
NOTES:

1. LINES ARE DATA RECORDED TWICE DAILY BY DATA LOGGERS.
2. "X" IDENTIFIES THE MONTHLY AVERAGE WATER LEVELS USED AS THE CALIBRATION VALUE.

REPRODUCE IN COLOR

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	MONITORING WELL WATER LEVELS - ALLUVIUM OSMP NORTH - GROUP B
		PROJECT NO. 16134	July 2021 **Figure 6.10**



REPRODUCE IN COLOR

NOTES:

1. LINES ARE DATA RECORDED TWICE DAILY BY DATA LOGGERS.
2. "X" IDENTIFIES THE MONTHLY AVERAGE WATER LEVELS USED AS THE CALIBRATION VALUE.

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	MONITORING WELL WATER LEVELS - ALLUVIUM DOWNSTREAM
		PROJECT NO. 16134	July 2021 **Figure 6.11**

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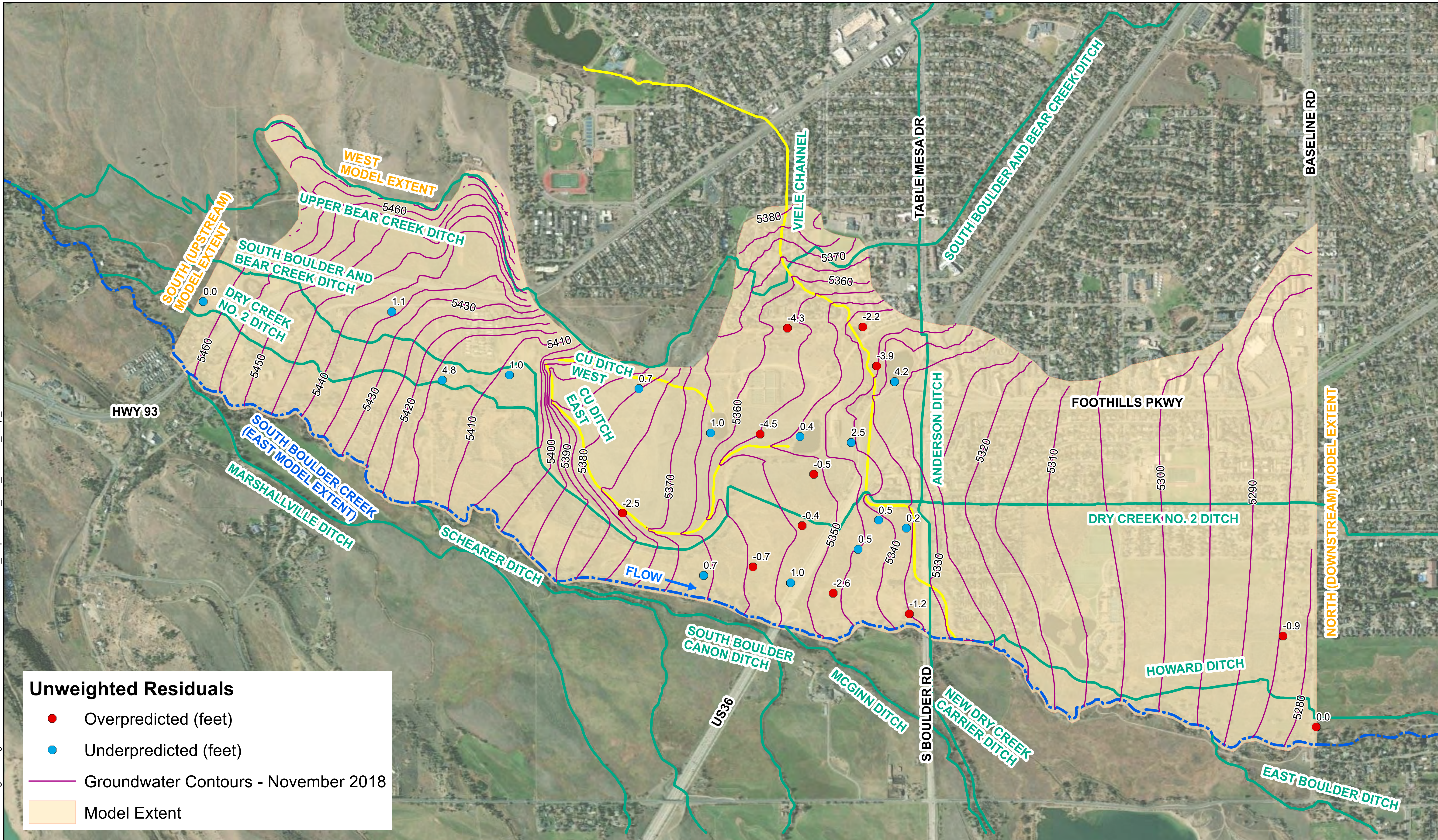


NOTE:
1. GROUNDWATER CONTOURS ARE 5-FOOT INTERVALS.

0 600 1,200 2,400 Feet

REPRODUCE IN COLOR

N

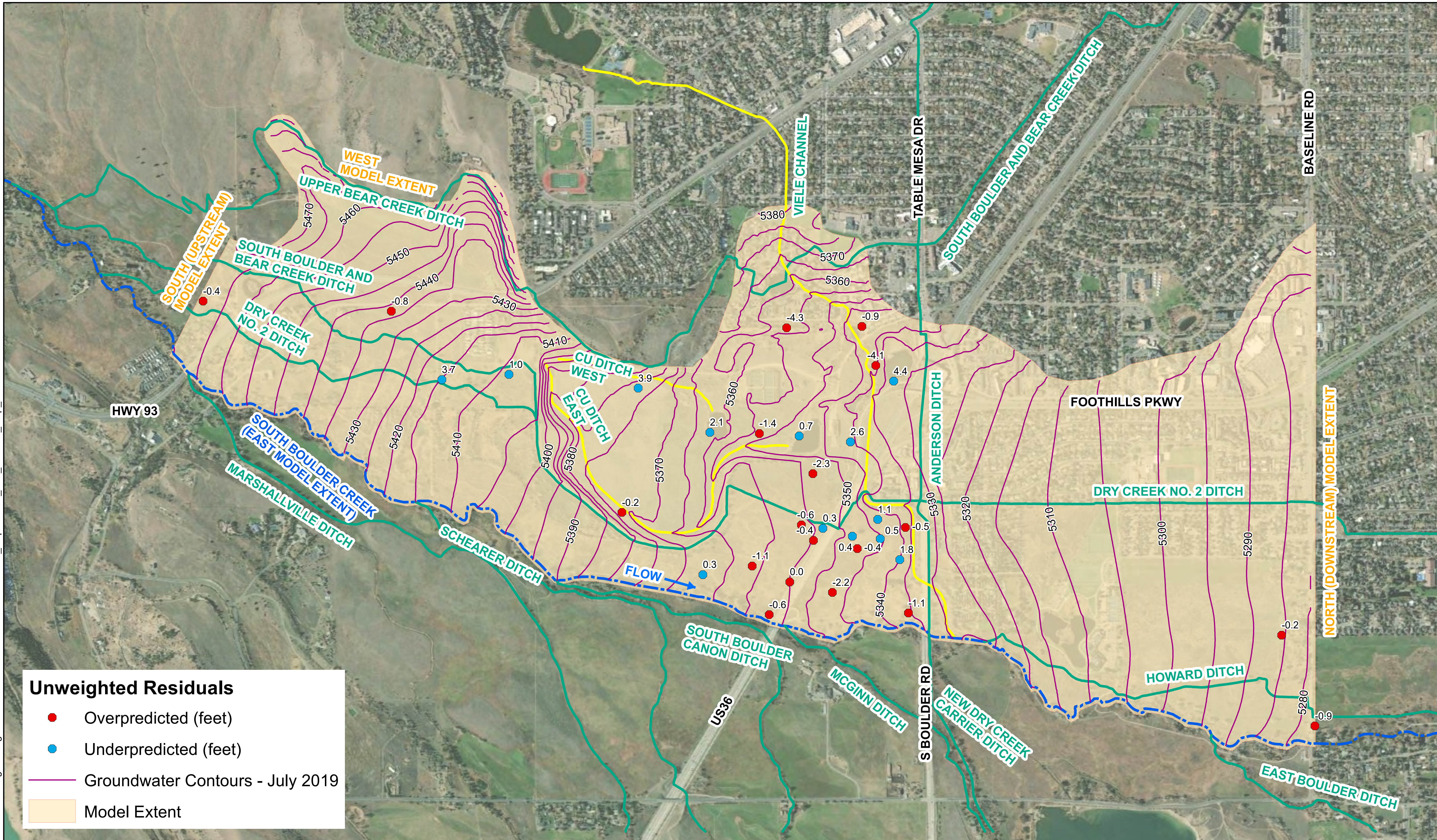
DATUM: NAVD 88

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	SIMULATED GROUNDWATER HEAD CONTOUR MAP - NOVEMBER 2018 (STRESS PERIOD 1)
PROJECT NO. 16134	July 2021 **Figure 6.12**

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\GroundwaterBaseline_Report\6.12_GW_Contour_Map_SSNov2018.mxd



P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\GroundwaterBaseline_Report\6.13_GW_Contour_Map_Jul2019.mxd

NOTE:
1. GROUNDWATER CONTOURS ARE 5-FOOT INTERVALS.

0 600 1,200 2,400 Feet

REPRODUCE IN COLOR

N

DATUM: NAVD 88

CITY OF BOULDER

RJH CONSULTANTS, INC.

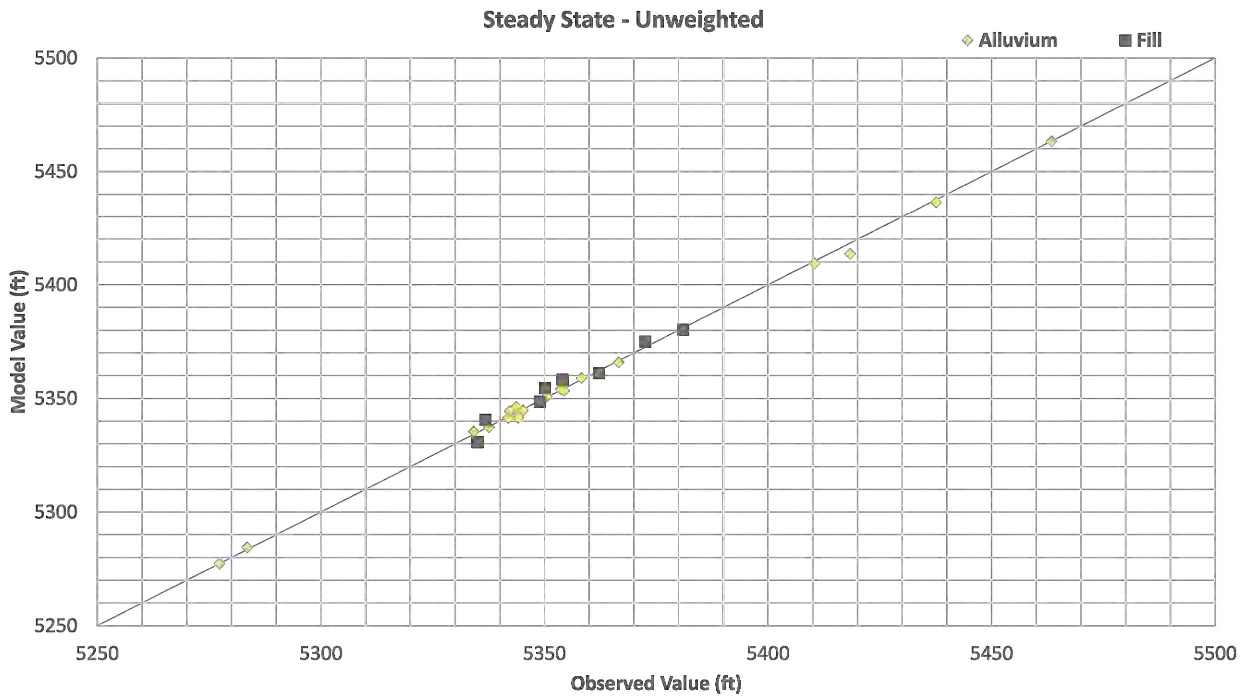
SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

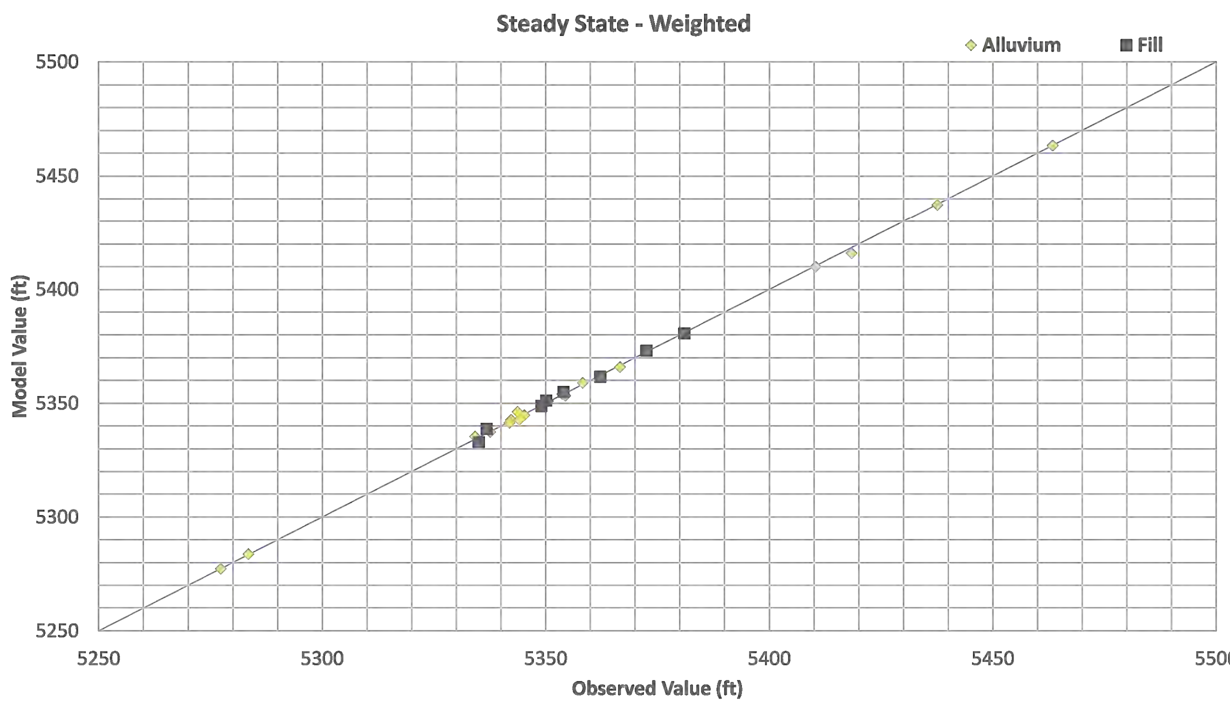
PROJECT NO. 16134

SIMULATED GROUNDWATER HEAD CONTOUR MAP - JULY 2019 (STRESS PERIOD 10)

July 2021

Figure 6.13





NOTES:

1. MODEL VALUES AND OBSERVED VALUES ARE GROUNDWATER HEAD IN FEET.
2. EACH DATA POINT REPRESENTS AN INDIVIDUAL WELL. WELL LOCATIONS ARE SHOWN ON FIGURE 6.1.

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

PROJECT NO. 16134

HEAD CALIBRATION PLOTS - BASELINE STEADY-STATE MODEL

July 2021

Figure 6.14

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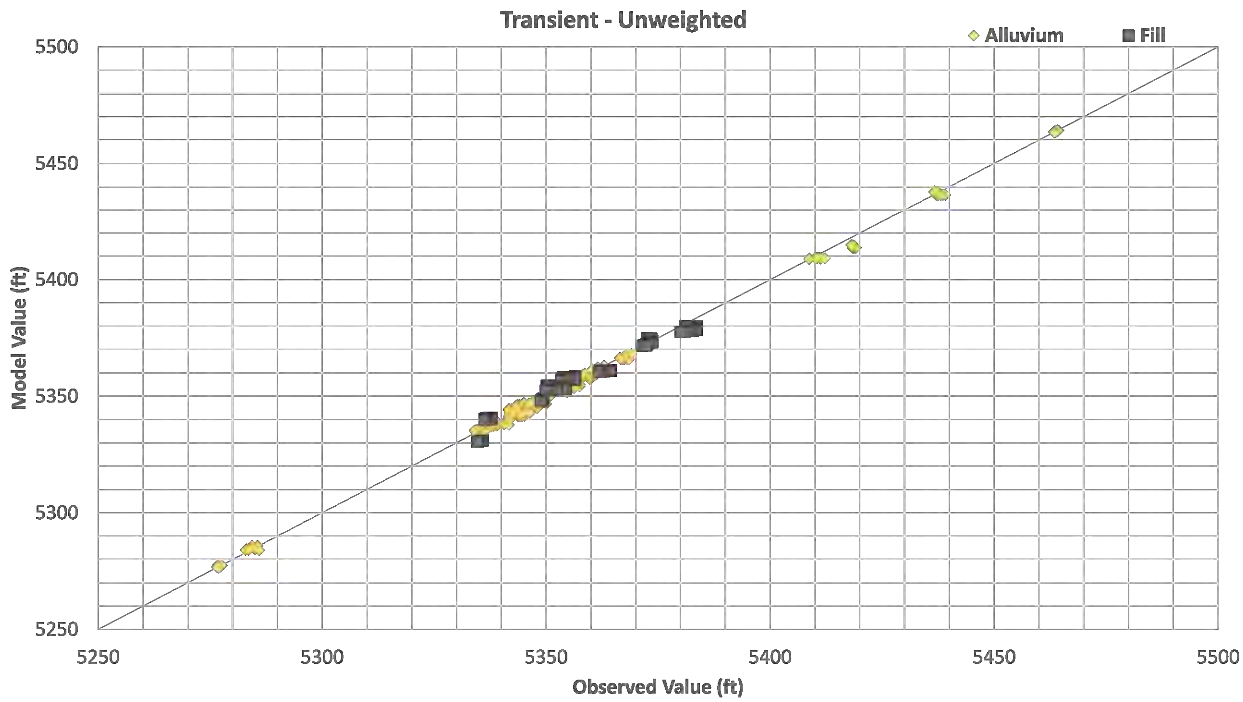

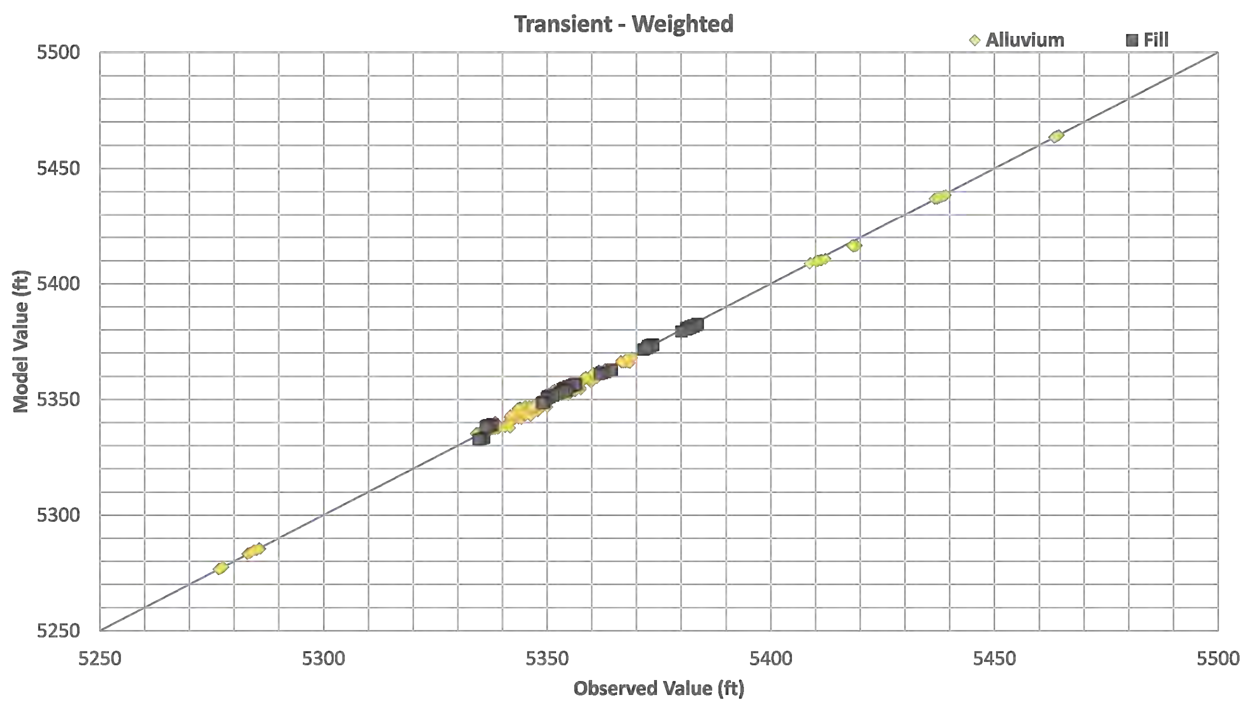

NOTES:

1. MODEL VALUES AND OBSERVED VALUES ARE GROUNDWATER HEAD IN FEET.
2. EACH DATA POINT REPRESENTS ONE STRESS PERIOD FROM AN INDIVIDUAL WELL. WELL LOCATIONS ARE SHOWN ON FIGURE 6.1.

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	HEAD CALIBRATION PLOTS - BASELINE TRANSIENT MODEL
	PROJECT NO. 16134	July 2021 — Figure 6.15

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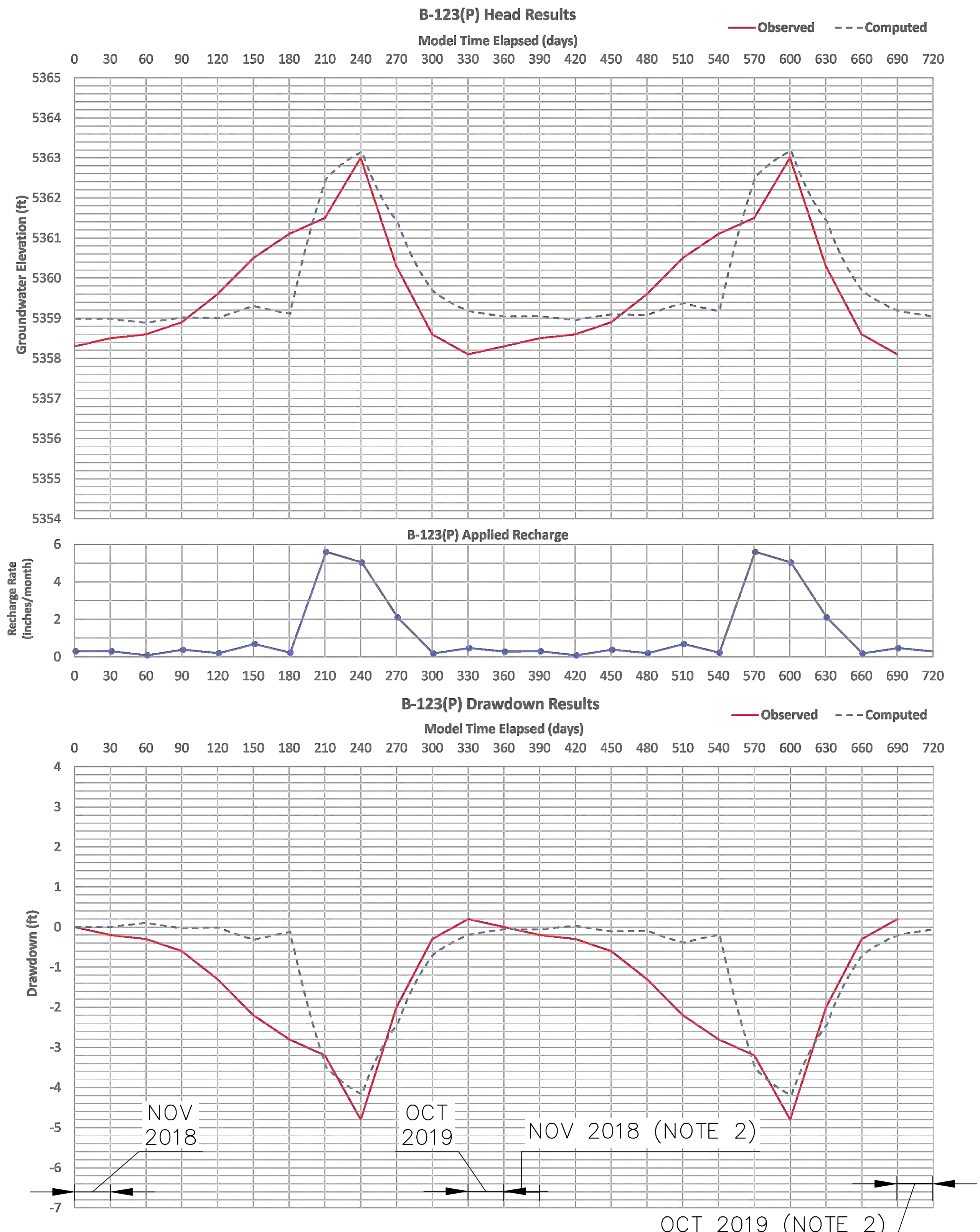

NOTES:

1. NEGATIVE DRAWDOWN REPRESENTS A RISE IN WATER LEVEL.
2. THE SECOND YEAR OF THE TWO-YEAR SIMULATION REPEATED THE CONDITIONS FROM NOV 2018 THROUGH OCT 2019.

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	WELL HEAD AND DRAWDOWN RESULTS - B-123(P)
	PROJECT NO. 16134	July 2021 **Figure 6.16**

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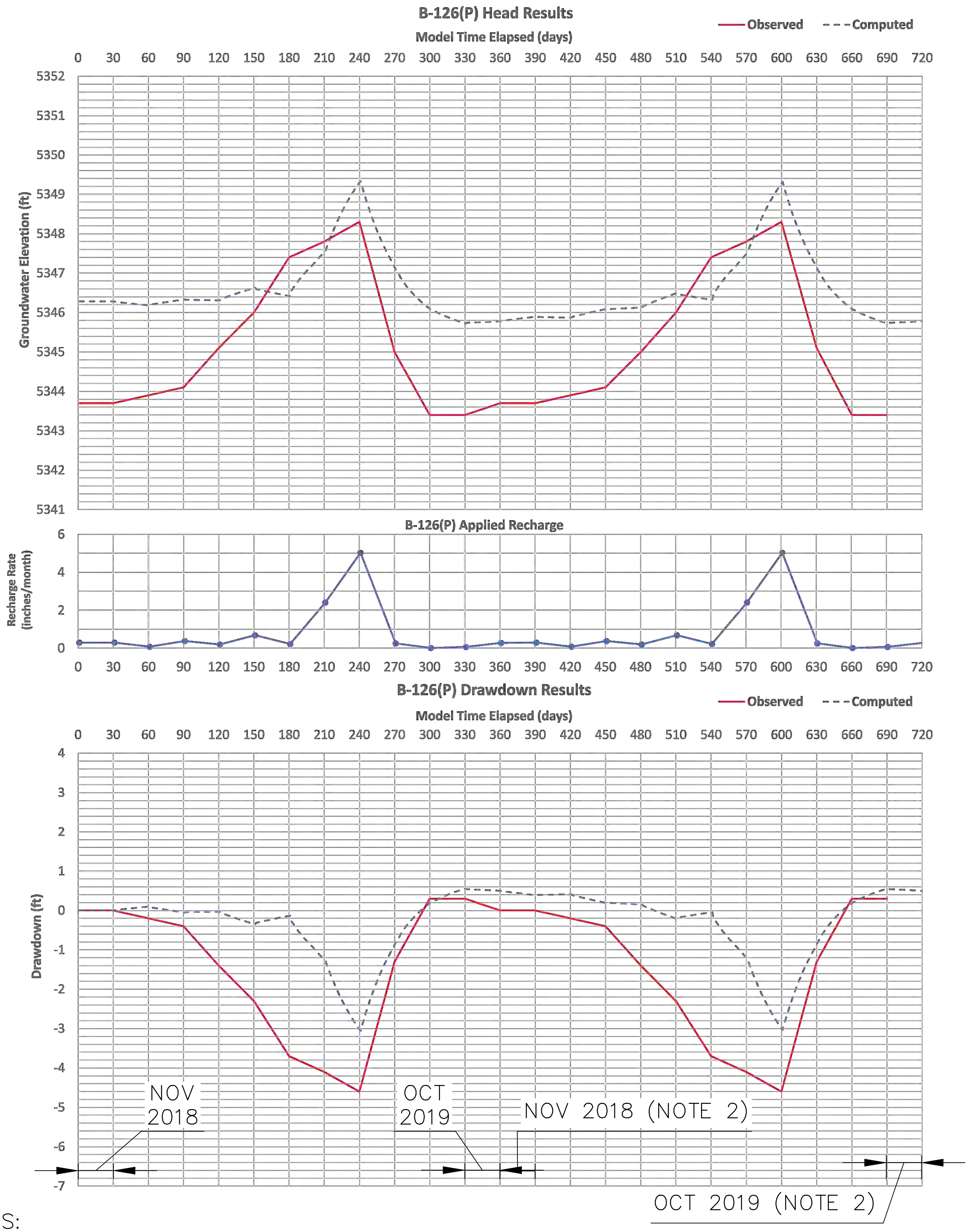

NOTES:

1. NEGATIVE DRAWDOWN REPRESENTS A RISE IN WATER LEVEL.
2. THE SECOND YEAR OF THE TWO-YEAR SIMULATION REPEATED THE CONDITIONS FROM NOV 2018 THROUGH OCT 2019.

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	WELL HEAD AND DRAWDOWN RESULTS - B-126(P)
	PROJECT NO. 16134	July 2021 **Figure 6.17**

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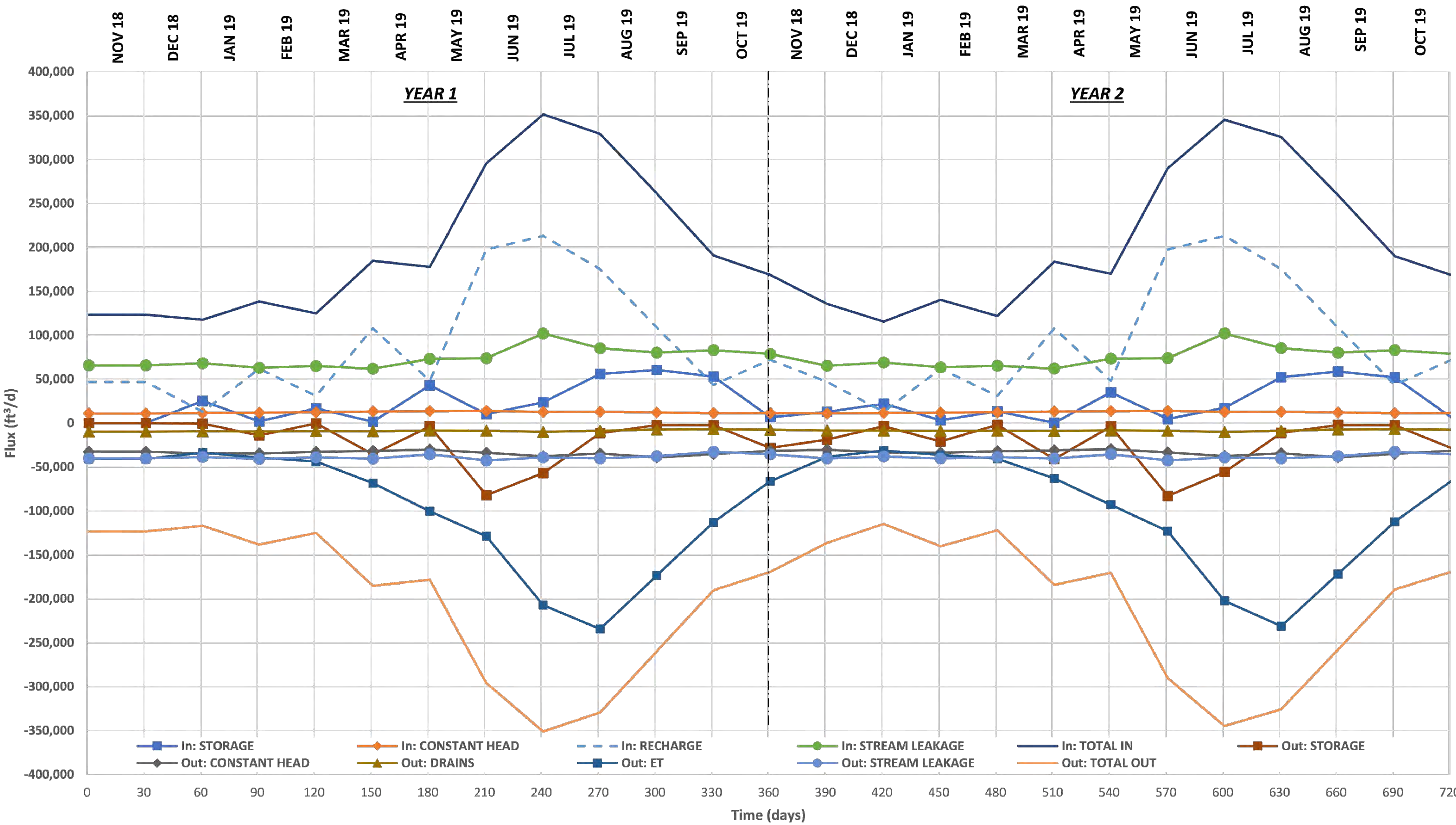

NOTES:

1. POSITIVE FLUX VALUES ARE FLOW INTO THE MODEL AND NEGATIVE FLUX VALUES ARE FLOW OUT OF THE MODEL.
2. THE SECOND YEAR OF THE TWO-YEAR TRANSIENT SIMULATION REPEATED THE CONDITIONS FROM NOV 2018 THROUGH OCT 2019.
3. INFLOW FROM DRAINS, INFLOW FROM ET, AND OUTFLOW FROM RECHARGE WERE ZERO THROUGHOUT EVERY TIME STEP AND ARE NOT SHOWN ON THIS FIGURE FOR CLARITY.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	GLOBAL WATER BUDGET COMPONENTS
PROJECT NO. 16134	July 2021 **Figure 6.18**

NOTES:

1. HYDROSTRATIGRAPHIC UNIT (HSU) ALIGNMENTS ARE PRESENTED ON FIGURE 5.1.
2. THE SECOND YEAR OF THE TWO-YEAR TRANSIENT SIMULATION REPEATED THE CONDITIONS FROM NOV 2018 THROUGH OCT 2019.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	BASELINE MODEL FLOW BENEATH US36	
PROJECT NO. 16134	July 2021	Figure 6.19

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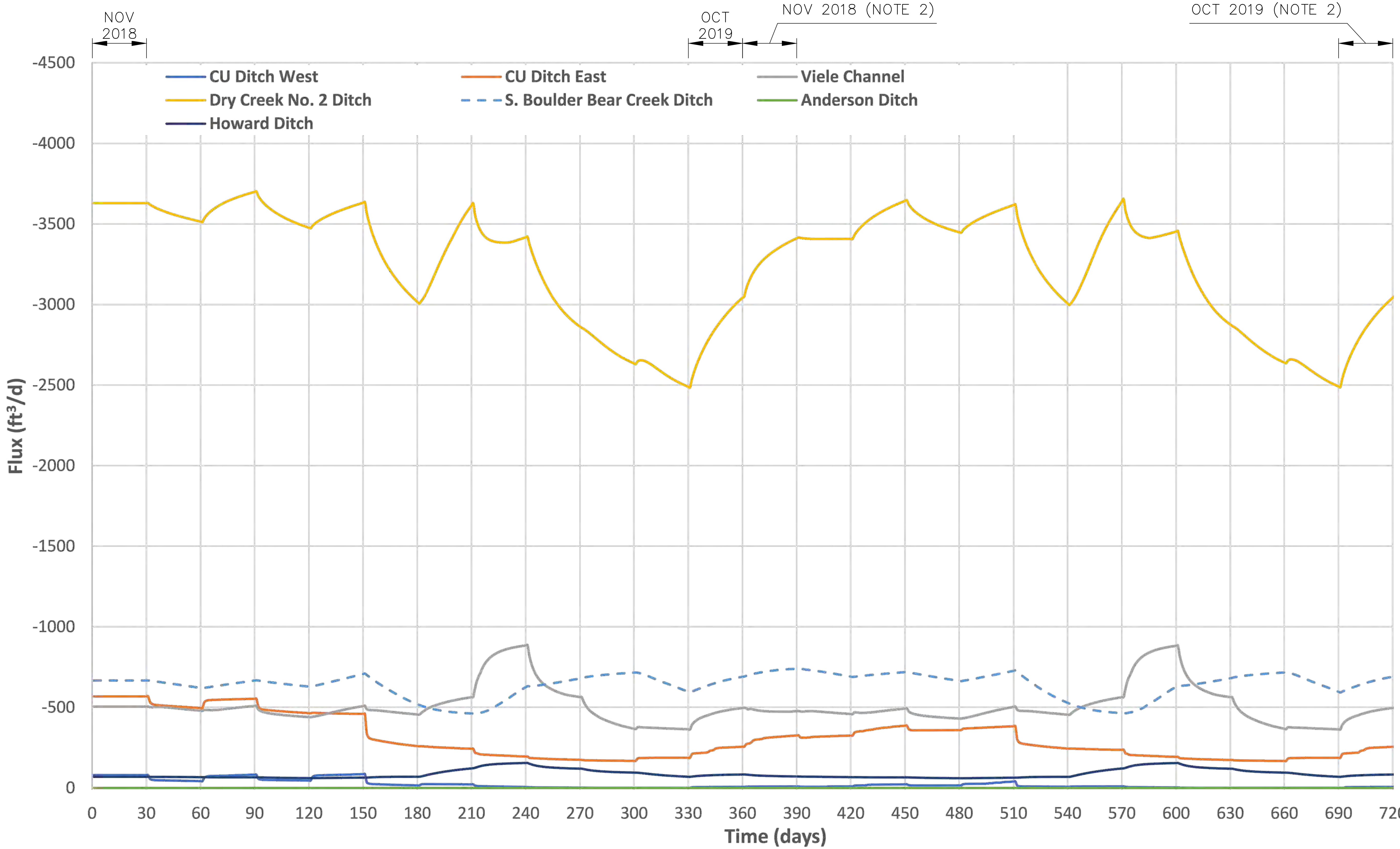

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\BASELINE_REPORT\16134_3004_FIGURES_DRAIN_FLUX.DWG 6/16/2021 9:26 AM

NOTES:

1. NEGATIVE VALUES ARE FLOW OUT OF THE GROUNDWATER SYSTEM AND INTO THE DITCH.
2. THE SECOND YEAR OF THE TWO-YEAR TRANSIENT SIMULATION REPEATED THE CONDITIONS FROM NOV 2018 THROUGH OCT 2019.

CITY OF BOULDER	RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	DRAIN BOUNDARY CONDITION FLUX
		PROJECT NO. 16134	July 2021 — Figure 6.20

SECTION 7 - SENSITIVITY TESTING

7.1 General

During the numerical modeling process, RJH adjusted several input parameters before arriving at the calibrated model. Attempts to improve model calibration in certain locations (e.g., in specific wells or stress periods) would often result in deterioration of the calibration in other locations without significantly changing the overall normalized RMS. Furthermore, input adjustments that produced visible changes in the head and drawdown curves (Appendix K.3) also did not result in significant changes to the overall normalized RMS. Therefore, in our opinion the calibrated model is stable and performs well over a range of reasonable input parameters.

RJH performed a preliminary sensitivity analysis in general accordance with ASTM D5611 (ASTM, 2016) to evaluate the sensitivity of the Baseline Model results to irrigation recharge, alluvium properties (hydraulic conductivity, anisotropy ratio, and specific yield), and Pierre Shale hydraulic conductivity. These parameters were selected for analyses because:

1. They were anticipated to significantly affect model calibration in the vicinity of the irrigated OSMP fields upstream and downstream of US36 based on RJH's calibration process and judgement.
2. There is considerable uncertainty and variability associated with these parameters.

For each of the evaluated parameters except Pierre Shale hydraulic conductivity, the sensitivity analysis included one value that was higher and one value that was lower than the value used in the calibrated Baseline Model. For the Pierre Shale hydraulic conductivity, the sensitivity analysis only considered one value that was lower than the value used in the calibrated Baseline Model. In our opinion, the bedrock hydraulic conductivity used in the calibrated Baseline Model represents a practical upper bound for this input. The evaluated ranges of each parameter were developed based on Project-specific data, published typical values for similar materials, and judgement. The values selected for the sensitivity analyses are summarized in Table 7.1.

TABLE 7.1
PARAMETERS AND RANGES FOR SENSITIVITY ANALYSIS

Parameter		Low Value	Calibrated Value	High Value	Notes
Alluvium Horizontal Hydraulic Conductivity (cm/s)	Zone A	1.9x10^{-3} [QalK1][1]	1.9x10^{-2}	3.1x10^{-2} [QalK2]	Low value was either one order of magnitude less than the calibrated value or the lowest value measured during in-situ tests, whichever is higher. High value was either one order of magnitude more than the calibrated value or the highest value measured during in-situ tests, whichever is lower.
	Zone B	5.6x10^{-5} [QalK1]	3.5x10^{-4}	3.5x10^{-3} [QalK2]	
	Zone C	7.1x10^{-5} [QalK1]	7.1x10^{-4}	7.1x10^{-3} [QalK2]	
Alluvium Anisotropy Ratio (Kh/Kv)		1 [Aniso1]	10	100 [Aniso2]	High and low values were selected based on typical published data for similar materials (Note 2) and judgement.
Alluvium Specific Yield (Percent)		3 [Sy1]	10	24 [Sy2]	High and low values were selected based on typical published data for similar materials (Note 3).
Irrigation Recharge (Percent)		50 [Irr1]	100	150 [Irr2]	Low value is 50 percent of the irrigation recharge rate applied to the calibrated model. The high value is 150 percent of the irrigation recharge rate applied to the calibrated model or all of the water available in the ditch each month, whichever is less. This recharge rate includes both irrigation recharge and background recharge.
Pierre Shale Horizontal Hydraulic Conductivity (cm/s)	Weathered	1.8x10^{-7} [KpK1]	1.4x10^{-4}	Note 4	Low value is considered to be reasonable for simulating a low-permeable aquitard.
	Unweathered	1.8x10^{-7} [KpK1]	2.5x10^{-5}	Note 4	

Notes:
1. Names in brackets are used to identify each sensitivity analysis in Appendix K.5.
2. Typical published values for similar materials are presented in Table 4.1.
3. Typical published values for similar materials are presented in Table 4.2.
4. Sensitivity analyses were not performed for a high value of Pierre Shale hydraulic conductivity. In our opinion, the values used in the calibrated Baseline Model were relatively high and represent reasonable upper bounds for this input.

A one-year transient simulation was used for the sensitivity analyses to evaluate model behavior over one annual hydrologic cycle. Sensitivity analyses were not performed for two-year simulations because we observed, during previous modeling efforts, that the second year of a two-year simulation produced results that were similar to the first year.

Results from the sensitivity analyses are presented in Appendix K.5 and are described in the following sections.

7.2 Overall Sensitivity of Heads

Five plots are included in Appendix K.5.1 to illustrate the sensitivity of overall model residuals to changes in the evaluated parameters in general accordance with ASTM D5611 (ASTM, 2016). The results of the sensitivity analysis generally show the following behavior for overall model calibration relative to the Baseline Model:

- Model calibration to head is relatively insensitive to the following:
  - Increases or decreases to alluvium anisotropy.
  - Increases to alluvium specific yield.
  - Decreases to irrigation recharge.
- Model calibration to head is moderately sensitive to increases or decreases to alluvium hydraulic conductivity, or decreases in bedrock hydraulic conductivity.
- Model calibration to head is relatively sensitive to the following:
  - Decreases to alluvium specific yield.
  - Increases to irrigation recharge.
- The Baseline Model produces a better calibration to heads than either the high or low values of the parameters evaluated during the sensitivity analysis. The high and low values generally produced a higher standard deviation of residuals and higher scaled RMS than the calibrated values of the input parameters.
- The overall model calibration to heads (e.g., scaled RMS) is not strongly affected by the ranges of parameters evaluated during the sensitivity analysis.

The sensitivity analyses performed for the Baseline Model evaluated how selected input parameters affect calibration residuals, which is only part of the sensitivity testing described by ASTM D5611. Additional sensitivity testing should be performed to evaluate how selected input parameters affect the model's predictive results when the proposed Project facilities are included in the model.

7.3 Transient Sensitivity of Heads

Appendix K.5.1 includes drawdown curves for three selected monitoring wells (B-108[P], B-123[P], and B-125[P]) located near irrigated fields adjacent to US36. These drawdown curves illustrate the predicted behavior at individual wells for the parameter ranges evaluated during the sensitivity analyses. These drawdown curves show the following about model sensitivity:

- The predicted behavior at these wells is most sensitive to irrigation rate and specific yield, which generally agrees with the results described above for the overall model calibration.
- The drawdown curves illustrate that the parameter ranges evaluated during the sensitivity analyses can produce significant variability during specific time periods at specific wells.

7.4 Local Sensitivity of Heads

A residual range exists for each well within each particular model. This residual range is equal to the difference between the largest residual and smallest residual at the well obtained from each of the stress periods. We evaluated how these residual ranges vary between the Baseline Model and each of the models performed for the sensitivity analyses.

Appendix K.5.2 includes five figures (Figure K.5.1 through K.5.5) that show normalized residual ranges. The normalized residual ranges are equal to the difference between the residual range obtained from a sensitivity analysis and the residual range obtained from the Baseline Model at each well. A positive value means the sensitivity analysis produced a larger residual range than the Baseline Model and a negative value means the sensitivity analyses produced a smaller residual range than the Baseline Model. A value of zero means the sensitivity analysis and the Baseline Model produced equal residual ranges. However, the magnitude of the residual ranges does not necessarily correspond to overall model calibration because it does not account for how the residuals from each stress period vary between the maximum and minimum observed residual values.

Large values (high positive values and high negative values) mean the simulated groundwater levels at the well were highly sensitive to the parameter evaluated by the sensitivity analysis whereas values near zero means the well location was not highly sensitive to the evaluated parameter.

The figures in Appendix K.5.2 show the following about the relative sensitivity of heads throughout the model:

- Residual ranges are relatively insensitive to (residual ranges mostly near zero):
    - Increases or decreases to the alluvium anisotropy (Figure K.5.2).
    - Decreases in Pierre Shale hydraulic conductivity (Figure K.5.5).
- Residual ranges are moderately sensitive to (residual ranges generally less than +/- 1 foot):
    - Increases or decreases in alluvium hydraulic conductivity (Figure K.5.1).
    - Increases in alluvium-specific yield (red values on Figure K.5.3).
    - Decreases in irrigation recharge (black values on Figure K.5.4).
- Residual ranges are highly sensitive to (residual ranges exceeding +/- 1 foot):
    - Decreases in alluvium-specific yield (black values on Figure K.5.3).
    - Increases in irrigation recharge (red values on Figure K.5.4).

7.5 Sensitivity of Flows

Appendix K.5.3 presents plots that illustrate how the predicted flows through the model varied during sensitivity analyses. The plots show how flow through the model varied over time within soil, bedrock, and each of the individual HSUs. HSUs used to evaluate flows through the model are described in Section 6.3.1 and shown on Figure 5.1.

We conclude the following from the results shown in Appendix K.5.3:

- The predicted flow through alluvium is highly sensitive to the hydraulic conductivity of alluvium, which is expected.
- The predicted flow through alluvium is moderately sensitive to decreases in specific yield and increases in irrigation recharge.
- The predicted flow through alluvium is not highly sensitive to the other parameters evaluated during the sensitivity analyses.
- The predicted flow through bedrock is highly sensitive to the hydraulic conductivity of the bedrock, which is expected.
- The predicted flow through bedrock is moderately sensitive to alluvium hydraulic conductivity, alluvium specific yield, and irrigation recharge. However, the

bedrock is still predicted to produce much less flow than the alluvium for all of the parameter ranges considered during the sensitivity analyses.

7.6 Sensitivity Summary

Based on the results of the sensitivity analyses presented throughout Section 7, the Baseline Model is most sensitive to decreases in specific yield and increases in irrigation recharge, which affect both heads and flows. Changes in hydraulic conductivity affect flows through the model but have relatively lesser effects on head calibration. Increases in alluvium specific yield, decreases in irrigation rate, and changes to alluvium anisotropy do not significantly affect heads or flows within the model.

SECTION 8 - CONCLUSIONS

We conclude the following from the information presented in this Report:

- A Baseline Model was developed based on currently available data and our interpretation of the hydrogeologic system.
- The Baseline Model was calibrated to one-year of available data (November 2018 to October 2019) and provides a reasonable approximation of the existing groundwater system in the Project vicinity.
  - The model was calibrated to both steady-state and transient behaviors.
  - Simulated heads predicted by the model were calibrated to observed well levels within industry-accepted statistical limits. Unweighted scaled RMS errors were 1.1 to 1.2 percent.
  - Simulated heads calibrated well in the OSMP fields adjacent to US36. Unweighted residual heads were predominantly within +/-1.0 foot and were usually within +/- 0.5 foot during both irrigation and non-irrigation seasons. One well on OSMP fields north of US36 (B-126(P)) produced difficulties during head calibration and had head residuals of -2.1 to -2.6 feet.
  - Total flows through the model vary from about 350,000 cubic feet per day during the summer to 115,000 cubic feet per day during the winter. The predominant components of the water budget are inflow from recharge, outflow from evapotranspiration, and interactions with surface water in SBC.
  - The total groundwater flow beneath US36 was generally about 6,000 cubic feet per day. The majority of this flow is predicted to occur through alluvium in the western portion of the model. This area of alluvium was simulated based on model calibration using a higher hydraulic conductivity than alluvium farther east along US36. A relatively minor amount of flow is predicted to occur through bedrock.
  - Simulated drawdown in OSMP fields adjacent to US36 generally follow observed seasonal patterns.
  - Simulated flows throughout the model calibrated qualitatively to observed site conditions.
  - SBC does not appear to be strongly gaining or losing water through the Study Area.

- The model is suitable for evaluating impacts that Project components could have on the hydrogeologic system, and for supporting design of features to mitigate groundwater impacts.
    - The model calibration results are relatively sensitive to increased values of irrigation recharge and decreased values of alluvium specific yield, which affect both heads and flows. Changes in hydraulic conductivity affect flows through the model but have lesser impacts on heads. The calibration results are less sensitive to decreased values of irrigation recharge, increased values of alluvium specific yield, or to changes to alluvium anisotropy.
    - It is not known how sensitive model predictions will be to input parameters once proposed Project facilities are simulated. The effects of Project facilities will be simulated for a range of reasonable input parameters, and safety factors will be included in the design of Project facilities to address uncertainties.

SECTION 9 - LIMITATIONS

This Report has been prepared for the exclusive use of RJH, the City, and other Project partners for evaluating existing groundwater flow patterns in the vicinity of the proposed Project. The Baseline Model described in this Report will be used to support preliminary design of Project components; incorporation of Project components will be presented in separate reports. The Baseline Model is based on data, information, and analyses described in this Report.

The intent of the Baseline Model is to reasonably approximate the existing groundwater system for the period of November 2018 to October 2019. The developed model is not unique; other combinations of input parameters might also calibrate to the observed Site conditions. The model is not intended to be used for appropriation of available water or other uses beyond the intent for which it was developed.

RJH is not responsible for technical interpretations of this data by others. RJH has endeavored to conduct our professional services for this Project in a manner consistent with a level of care and skill ordinarily exercised by members of the engineering profession currently practicing in Colorado under similar conditions as this Project. RJH makes no other warranty, expressed or implied.

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APPENDIX A

STUDY AREA CLIMATE AND EVAPOTRANSPIRATION DATA

Purpose:

To present typical climate data and evapotranspiration data for the Study Area for the South Boulder Creek Regional Detention Project (Project). Also present a comparison of climate data for 2019 to the average of 1991 through 2019.

Available Data:

- Climate conditions near the Study Area are available online through the National Weather Service (NWS) website: https://w2.weather.gov/climate/xmacis.php?wfo=bou. The NWS website reports climate data for the Denver-Boulder Forecast Office (NOAA Earth System Research Laboratory), which is located approximately 2 miles northeast of the Study Area. The climate data evaluated are: precipitation, snowfall, maximum temperature, minimum temperature, and average temperature.
- Local and regional typical values of evapotranspiration rates and extinction depths for the general vegetative cover and crop type in the Study Area are available from:
  - Northern Water at https://www.northernwater.org/WaterConservation/WeatherandETData.aspx.
  - Colorado State University, Colorado Water newsletter Vol. 34, Issue 1 (Norton, 2017).
  - USGS Water-Resources Investigations Report No. 94-4111 (Kimbrough, 1995).
  - USGS Water Supply Paper No. 1423 (Robinson, 1958).

Approach:

- Where possible, comparison of average historical data was within the range of 1991 through 2019 to cover the largest time period of available monitoring well data (i.e., historical OSMP monitoring well data and Project monitoring well data).
- The climate data reported on the NWS website for the Denver-Boulder Forecast Office is considered to be representative of the model extent.
- Evapotranspiration data consists of evapotranspiration rates and extinction depth estimates for various vegetation types.
- The general vegetative cover and crop type in the Study Area are: irrigated grasses, native/natural grasses, and riparian/phreatophyte (e.g., cottonwood trees).

Methods:

1. Use historic and publicly available climate data from the NWS website: https://w2.weather.gov/climate/xmacis.php?wfo=bou.
2. Compare the Study Area climate data for 2019 to average historical data from 1991 through 2019 to identify if 2019 was a typical season in terms of precipitation, snowfall, maximum temperature, minimum temperature, and average temperature (p. _3-7_). ✓
3. Use publicly available local data for evapotranspiration values for grass and pan evaporation (i.e., for Study Area ponds) from the Northern Water website: https://www.northernwater.org/WaterConservation/WeatherandETData.aspx. (p. _8-12__) ✓

4. Evapotranspiration values, extinction depths, and general information for riparian/phreatophyte areas are estimated using cottonwood trees. Local and regional data by Norton (2017), Kimbrough (1995), and Robinson (1958) are provided on p. _13-16_. ✓

data published for

References:

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Robinson, T.W. (1958). Phreatophytes. U.S. Geological Survey, Water Supply Paper No. 1423. Available at: https://pubs.er.usgs.gov/publication/wsp1423.

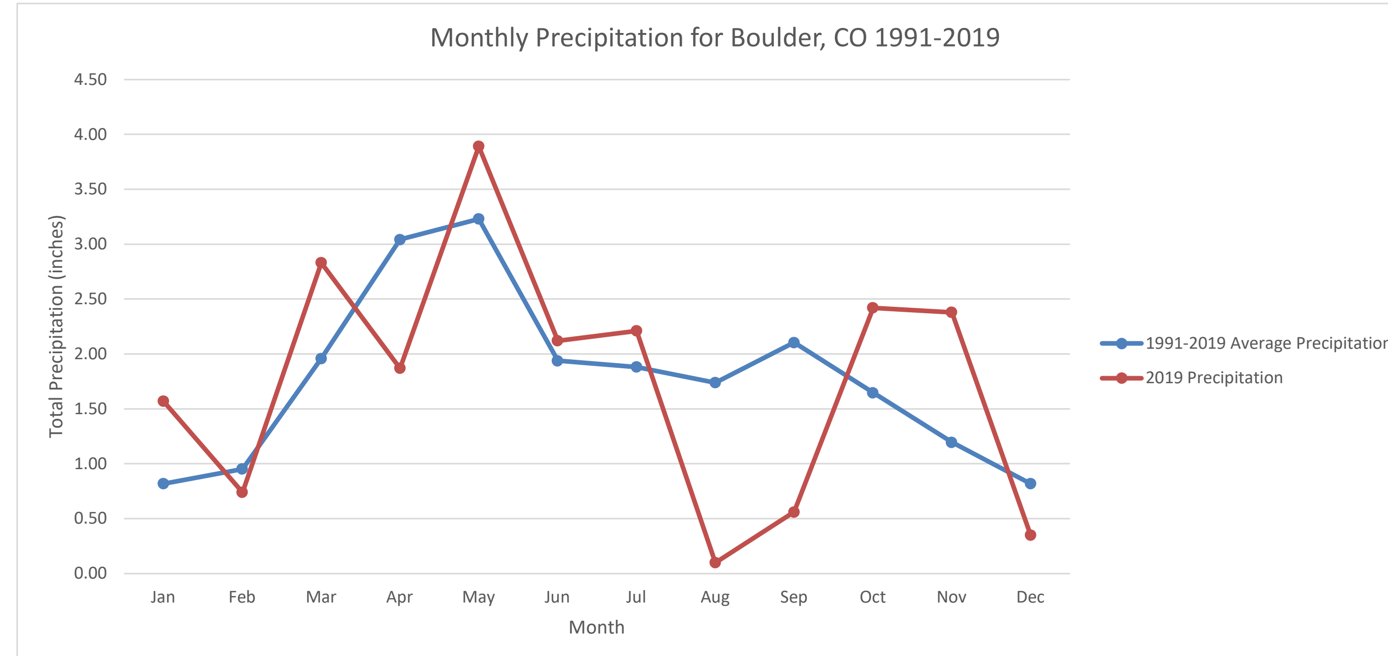
Results:

- See p. ___3-7____ for tables of climate data and graphs comparing the historical average to 2019. 2019 appears to generally correspond to typical weather conditions observed from 1991 through 2019 for precipitation, snowfall, maximum temperature, minimum temperature, and average temperature:
  - 2019 follows the general pattern of precipitation for average historical data from January through July. Precipitation in August and September were considerably lower than the average; however, October and November were higher than average. (pg. _3_). ✓
  - The 2018/2019 winter season generally followed the average snowfall pattern. Higher than average and then lower than average snowfall amounts occurred in November and December, respectively. (pg. _4_). ✓
  - 2019 closely follows the average historical data for maximum temperature, minimum temperature, and average temperature. (pg. _5-7_). ✓
- Regional and local ranges of values for evapotranspiration rate, pan evapotranspiration rate, and extinction depths are presented for the general vegetation types in the Study Area (p. _8-16_). ✓ These values were used during the model calibration and adjusted accordingly.

RJH Consultants, Inc.
16134 - South Boulder Creek
Boulder, CO Weather Station Monthly Data - Precipitation

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/29/2020
Approved: ABP Date: 7/30/2020

Monthly Total Precipitation for BOULDER, CO													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1991	1.05	0.15	0.43	2.41	2.90	3.59	3.11	2.08	1.21	0.93	3.30	0.01	21.17
1992	0.67	T	5.17	0.46	1.70	0.96	1.13	3.08	0.02	0.79	2.56	0.84	17.38
1993	0.25	0.90	2.15	2.56	1.73	3.38	1.40	M	3.32	2.42	2.17	0.55	M
1994	0.86	1.37	1.61	3.46	1.35	0.93	0.35	2.56	0.54	1.02	2.25	0.49	16.79
1995	0.64	1.53	1.21	4.95	9.59	4.03	0.72	1.45	2.96	0.59	1.51	0.25	29.43
1996	2.19	0.29	2.16	1.49	4.63	2.77	1.96	0.63	3.48	0.28	1.43	0.37	21.68
1997	0.87	1.83	0.91	5.77	2.19	3.69	1.14	5.27	1.92	2.70	1.52	0.68	28.49
1998	1.07	0.23	3.41	4.56	1.82	1.85	4.02	0.97	0.66	1.12	1.53	1.05	22.29
1999	0.65	0.08	1.09	7.55	1.84	0.82	2.54	5.54	2.62	1.33	0.81	1.01	25.88
2000	0.14	0.55	2.56	1.50	1.60	1.53	2.09	0.72	2.51	1.28	0.89	0.44	M
2001	0.73	0.86	2.01	2.94	3.62	1.09	1.76	1.64	1.77	0.40	1.02	0.36	18.20
2002	1.07	0.44	1.50	0.20	3.20	1.18	0.09	1.44	1.52	2.44	0.78	0.02	13.88
2003	0.09	1.52	5.44	2.99	2.62	2.69	0.71	3.52	0.35	0.45	0.80	0.84	22.02
2004	0.82	1.31	1.09	5.66	1.28	3.96	3.44	2.88	2.07	2.32	1.99	0.35	27.17
2005	1.40	0.31	1.22	3.86	1.91	2.68	0.42	1.63	0.42	2.80	0.34	0.43	17.42
2006	0.44	0.68	2.08	1.04	1.14	1.32	2.63	1.23	1.25	3.71	0.74	3.05	19.31
2007	1.68	0.86	1.69	2.24	1.79	0.38	0.80	1.92	1.92	1.38	0.47	2.10	17.23
2008	0.46	0.63	1.47	1.13	4.21	1.58	0.09	2.97	1.84	1.18	0.13	1.33	17.02
2009	0.62	0.27	1.89	5.88	3.08	2.70	1.42	0.33	0.42	3.26	0.93	1.39	22.19
2010	0.28	1.37	3.30	3.63	2.71	3.36	2.31	1.07	0.25	0.94	0.61	0.48	20.31
2011	0.96	1.02	0.33	2.41	5.16	1.35	2.87	1.08	2.56	1.65	0.98	1.92	22.29
2012	0.38	1.94	0.01	1.31	1.78	0.38	4.99	0.36	2.27	1.44	0.28	0.51	15.65
2013	0.27	1.13	1.72	4.14	2.66	0.61	1.03	1.40	18.16	2.24	0.29	0.50	34.15
2014	1.67	0.68	1.62	1.87	4.43	0.84	4.57	1.60	2.88	1.16	0.88	1.37	23.57
2015	0.38	3.69	0.38	4.50	7.82	1.76	2.98	0.31	0.14	2.02	1.83	1.11	26.92
2016	0.37	1.44	3.84	3.34	2.01	2.37	0.61	1.06	0.45	0.38	0.47	0.91	17.25
2017	1.41	0.73	1.45	3.15	6.29	0.45	1.30	1.62	1.92	2.42	0.57	0.68	21.99
2018	0.74	1.04	2.23	1.35	4.76	1.82	1.84	0.24	1.02	2.68	1.19	0.34	19.25
2019	1.57	0.74	2.83	1.87	3.89	2.12	2.21	0.10	0.56	2.42	2.38	0.35	21.04
2020 •	T	2.19	2.88	3.17	2.3	M	M	M	M	M	M	M	M
1991-2019 Mean •	0.82	0.95	1.96	3.04	3.23	1.94	1.88	1.74	2.10	1.65	1.19	0.82	21.48
1991-Current Mean •	0.79	0.99	1.99	3.05	3.20	1.94	1.88	1.74	2.10	1.65	1.19	0.82	21.48
Max	2.19	3.69	5.44	7.55	9.59	4.03	4.99	5.54	18.16	3.71	3.3	3.05	34.15
Max Year	1996	2015	2003	1999	1995	1995	2012	1999	2013	2006	1991	2006	2013
Min	T	T	0.01	0.2	1.14	0.38	0.09	0.1	0.02	0.28	0.13	0.01	13.88
Min Year	2020	1992	2012	2002	2006	2012	2008	2019	1992	1996	2008	1991	2002

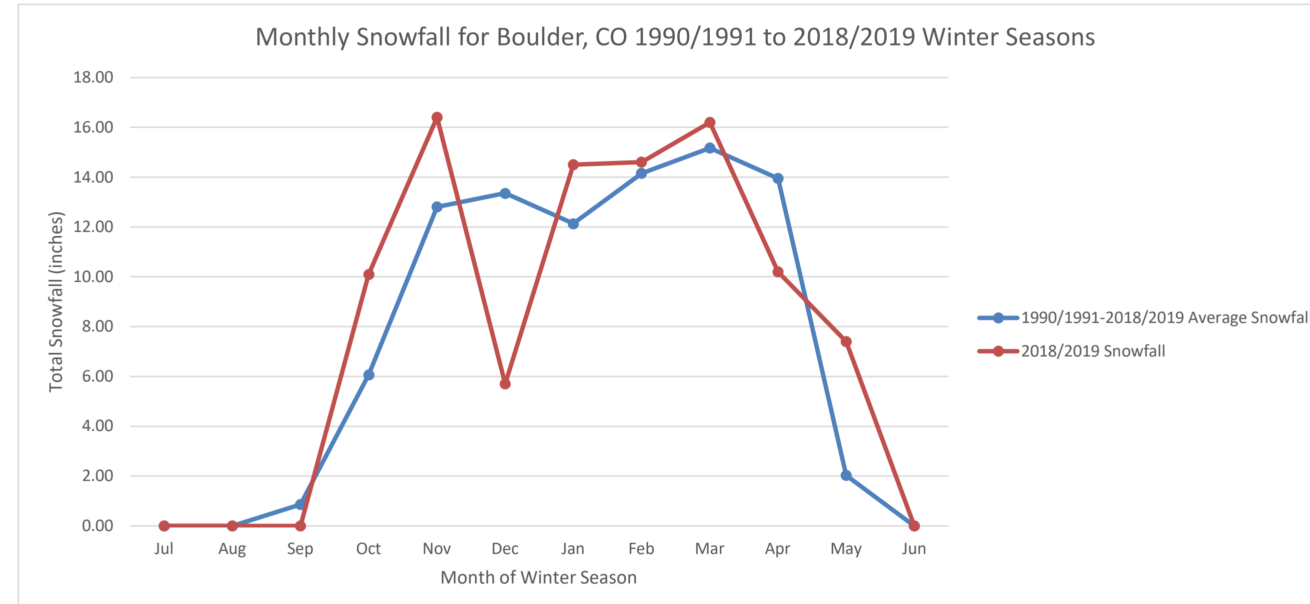


Notes:
1. T means trace and is counted as zero.
2. M is for data that was not recorded or has not been recorded yet and is not considered in calculations.

RJH Consultants, Inc.
16134 - South Boulder Creek
Boulder, CO Weather Station Monthly Data - Snowfall

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/29/2020
Approved: ABP Date: 7/30/2020

Monthly Total Snowfall for BOULDER, CO													
Year	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Season**
1990-1991	0.0	0.0	0.0	6.1	17.1	12.7	17.0	2.8	2.0	19.1	0.4	0.0	77.2
1991-1992	0.0	0.0	0.0	13.6	28.9	0.2	10.9	T	M	0.0	0.0	0.0	M
1992-1993	0.0	0.0	0.0	T	44.7	18.8	5.8	9.3	11.9	4.7	T	0.0	95.2
1993-1994	0.0	M	1.4	10.5	27.0	9.0	11.5	15.4	14.9	22.8	0.0	0.0	M
1994-1995	0.0	0.0	0.4	T	23.7	10.3	12.0	16.3	16.4	24.1	0.8	0.0	104.0
1995-1996	0.0	0.0	8.6	3.1	17.8	3.4	24.4	5.9	17.7	7.6	0.0	0.0	88.5
1996-1997	0.0	0.0	6.1	0.1	16.6	6.1	19.0	28.8	14.1	38.6	T	0.0	129.4
1997-1998	0.0	0.0	0.0	30.1	18.2	9.9	10.4	1.7	42.9	19.4	0.0	T	132.6
1998-1999	0.0	0.0	0.0	0.0	9.5	17.8	9.7	0.6	6.6	37.2	T	0.0	81.4
1999-2000	0.0	0.0	1.6	6.1	10.5	8.8	4.0	5.4	26.6	8.9	0.0	0.0	71.9
2000-2001	0.0	0.0	6.5	0.9	10.9	8.5	10.3	13.1	16.6	10.5	6.5	T	83.8
2001-2002	0.0	0.0	T	0.3	7.3	4.7	18.5	8.3	22.6	0.1	1.6	0.0	63.4
2002-2003	0.0	0.0	0.0	16.1	13.0	0.5	0.5	22.8	34.7	6.2	5.2	0.0	99.0
2003-2004	0.0	0.0	0.0	0.4	7.5	9.9	12.0	18.0	7.9	14.9	T	0.0	70.6
2004-2005	0.0	0.0	0.0	0.0	17.6	6.7	15.9	3.3	11.2	21.8	0.2	T	76.7
2005-2006	0.0	0.0	0.0	T	1.9	6.3	5.5	11.4	23.3	2.9	0.1	T	51.4
2006-2007	0.0	0.0	0.0	15.2	12.0	45.5	27.5	15.3	4.5	2.2	T	0.0	122.2
2007-2008	T	0.0	0.0	0.1	5.9	30.0	10.3	10.4	17.6	7.9	0.7	0.0	82.9
2008-2009	0.0	0.0	0.0	0.2	1.3	20.9	13.0	3.9	21.4	20.4	0.0	0.0	81.1
2009-2010	0.0	0.0	0.0	30.1	8.9	27.8	4.6	23.0	28.7	5.8	5.6	0.0	134.5
2010-2011	0.0	0.0	0.0	T	2.0	9.5	18.2	13.2	0.7	3.5	0.2	0.0	47.3
2011-2012	0.0	0.0	0.0	11.5	8.6	33.1	7.8	32.1	T	1.6	T	0.0	94.7
2012-2013	0.0	0.0	0.0	7.9	0.8	11.7	3.7	18.5	22.8	47.6	12.3	0.0	125.3
2013-2014	0.0	0.0	0.0	5.4	6.3	9.0	27.2	11.7	11.2	12.2	6.8	0.0	89.8
2014-2015	0.0	0.0	0.5	0.0	16.9	19.8	6.0	54.6	8.0	7.4	3.9	T	117.1
2015-2016	0.0	0.0	0.0	0.0	11.5	17.4	4.1	21.8	32.5	21.4	1.0	0.0	109.7
2016-2017	0.0	0.0	0.0	0.0	4.4	13.0	18.7	9.9	T	19.4	6.1	0.0	71.5
2017-2018	0.0	0.0	0.0	8.0	4.1	10.2	8.8	18.5	6.8	6.0	0.0	0.0	62.4
2018-2019	0.0	0.0	0.0	10.1	16.4	5.7	14.5	14.6	16.2	10.2	7.4	0.0	95.1
2019-2020	0.0	0.0	0.0	26.4	29.5	3.4	T	39.1	16.3	37.3	0.0	M	M
1990/1991-2018/2019 Mean	0.00	0.00	0.87	6.06	12.80	13.35	12.13	14.16	15.17	13.94	2.03	0.00	91.06
1990/1991-Current Mean	0.00	0.00	0.84	6.74	13.36	13.02	11.73	14.99	15.20	14.72	1.96	0.00	91.06
Max	T 2007	0 2019	8.6 1995	30.1 2009	44.7 1992	45.5 2006	27.5 2007	54.6 2015	42.9 1998	47.6 2013	12.3 2013	T 2015	134.5 2010
Min	0 2019	0 2019	0 2019	0 2016	0.8 2012	0.2 1991	T 2020	T 1992	T 2017	0 1992	0 2020	0 2019	47.3 2011



Notes:
1. T means trace and is counted as zero.
2. M is for data that was not recorded or has not been recorded yet and is not considered in calculations.

RJH Consultants, Inc.
16134 - South Boulder Creek
Boulder, CO Weather Station Monthly Data - Max Temp

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/29/2020
Approved: ABP Date: 7/30/2020

Monthly Highest Max Temperature for BOULDER, CO

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1991	58	65	69	80	84	95	96	91	85	87	69	63	96
1992	63	69	65	87	87	90	98	94	89	84	67	61	98
1993	61	57	72	75	83	94	96	M	90	85	66	63	96
1994	61	62	76	87	91	101	98	96	90	77	73	67	101
1995	66	71	76	74	82	90	97	99	95	83	71	69	99
1996	69	70	70	82	93	89	94	99	91	87	73	68	99
1997	70	65	80	76	85	90	96	89	85	84	69	63	96
1998	66	62	76	79	85	93	100	93	94	78	72	68	100
1999	62	70	76	76	80	90	96	90	85	83	75	66	96
2000	64	66	73	79	95	96	98	97	93	84	56	58	98
2001	65	59	67	79	84	97	99	95	93	84	74	66	99
2002	69	74	70	80	90	97	101	100	92	77	70	65	101
2003	69	69	74	79	95	86	101	94	87	87	72	64	101
2004	61	67	77	78	87	95	96	92	90	75	74	63	96
2005	73	63	71	75	90	89	101	96	91	89	78	68	101
2006	69	74	71	83	92	100	100	94	86	84	77	70	100
2007	62	67	76	82	82	97	98	97	91	83	76	70	98
2008	64	65	73	80	82	90	98	99	86	81	78	67	99
2009	71	69	76	80	87	89	95	96	89	83	77	57	96
2010	61	49	79	76	91	94	98	95	94	81	76	66	98
2011	68	66	75	82	86	95	98	98	94	86	69	61	98
2012	69	62	81	87	89	102	100	96	94	85	73	71	102
2013	65	61	76	77	87	98	98	97	95	77	70	68	98
2014	63	65	72	76	85	94	97	92	93	83	73	65	97
2015	72	72	80	79	86	93	93	96	92	86	77	68	96
2016	63	73	72	78	80	99	99	95	92	84	80	67	99
2017	63	76	80	77	85	98	100	94	97	85	76	68	100
2018	69	66	72	81	87	98	97	94	94	85	65	63	98
2019	61	63	74	79	82	94	98	98	100	80	79	64	100
2020 •	65	75	69	83	87	93	100	M	M	M	M	M	100
1991-2019 Mean •	65	66	74	79	87	94	98	95	91	83	73	65	98
1991-Current Mean •	65	66	74	80	87	94	98	95	91	83	73	65	99
Max	73 2005	76 2017	81 2012	87 2012	95 2003	102 2012	101 2005	100 2002	100 2019	89 2005	80 2016	71 2012	102 2012
Min	58 1991	49 2010	65 1992	74 1995	80 2016	86 2003	93 2015	89 1997	85 1999	75 2004	56 2000	57 2009	96 2015

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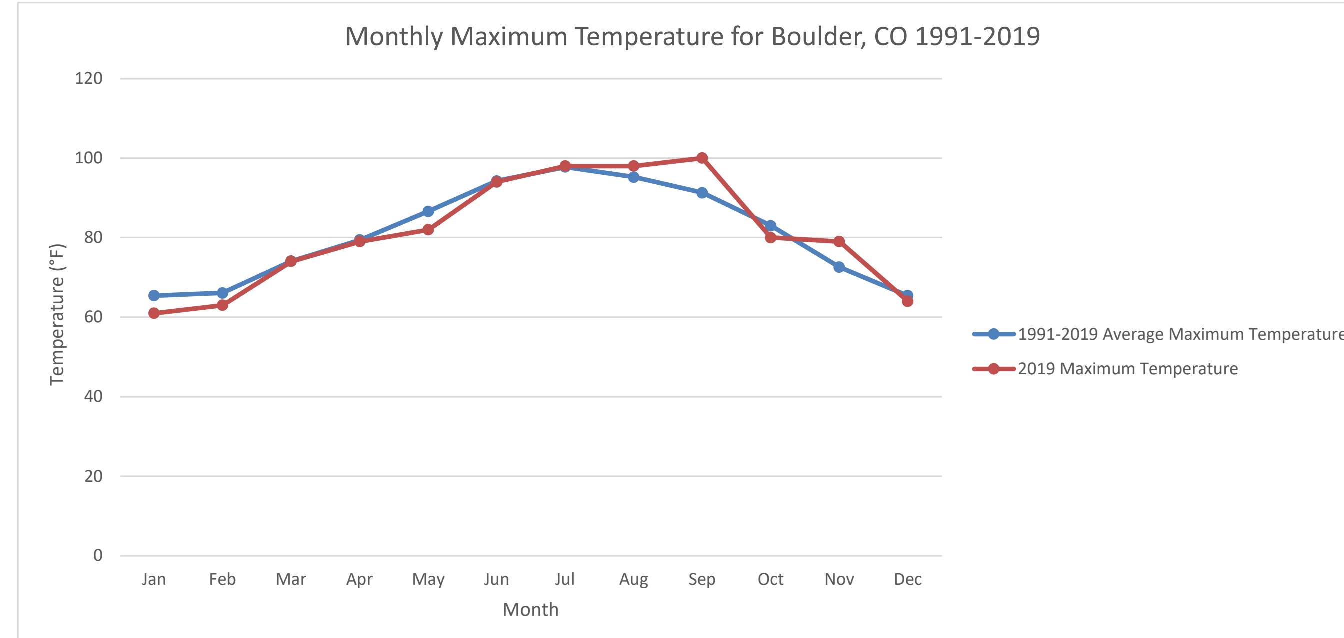
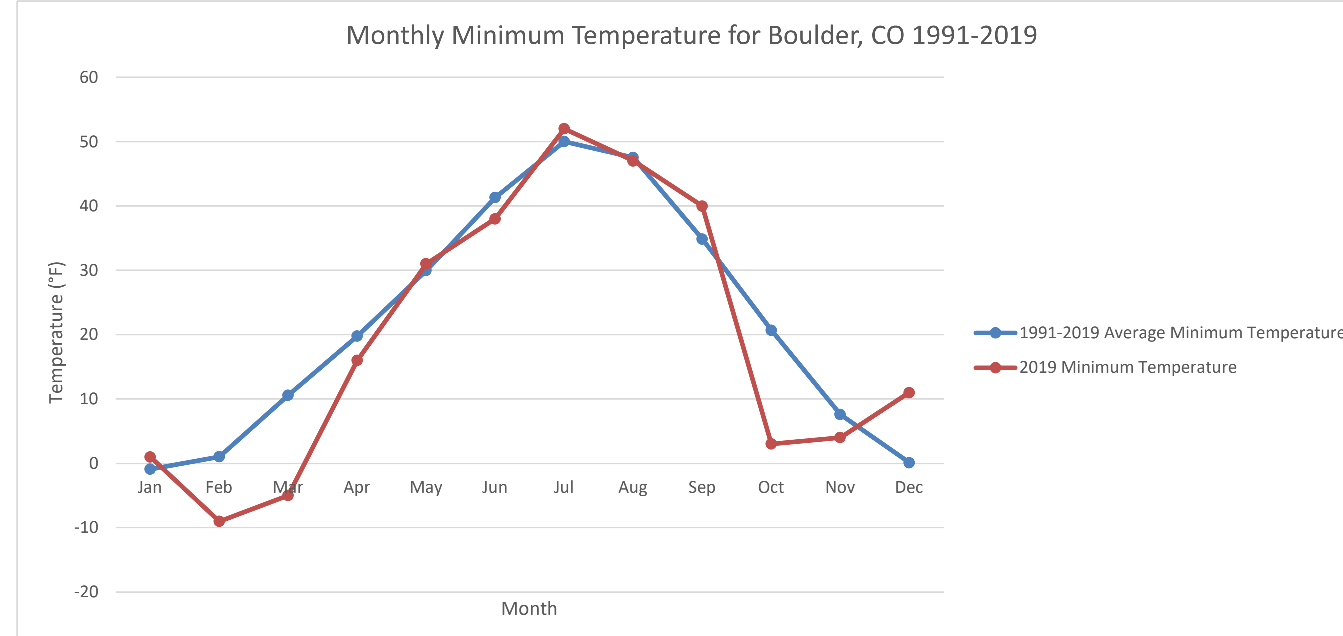


RJH Consultants, Inc.
16134 - South Boulder Creek
Boulder, CO Weather Station Monthly Data - Min Temp

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/29/2020
Approved: ABP Date: 7/30/2020

Monthly Lowest Min Temperature for BOULDER, CO													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1991	-2	8	20	19	29	47	50	51	35	5	-1	8	-2
1992	-5	19	13	21	37	39	44	42	36	23	4	1	-5
1993	-6	-8	5	27	32	40	46	M	28	6	-8	2	-8
1994	-3	-1	12	21	31	43	45	50	29	25	9	7	-3
1995	-4	1	10	17	32	40	46	44	23	25	11	4	-4
1996	-7	-16	-2	22	36	42	51	48	24	23	5	-6	-16
1997	-12	10	10	2	29	47	46	49	38	13	1	11	-12
1998	6	16	-1	24	33	33	53	50	44	28	17	-13	-13
1999	7	18	17	17	27	41	51	50	25	15	11	10	7
2000	12	15	20	17	28	40	53	49	28	27	1	1	1
2001	2	-5	18	24	26	37	54	50	33	25	7	12	-5
2002	2	-4	-6	21	25	43	53	44	39	15	8	9	-6
2003	12	-4	8	19	31	37	53	52	34	23	-2	11	-4
2004	-7	-6	22	22	29	39	49	40	36	31	3	-6	-7
2005	2	13	13	22	30	39	50	48	37	28	13	-10	-10
2006	14	-14	12	25	29	45	51	46	32	23	0	3	-14
2007	-4	-13	12	21	32	34	53	50	38	25	12	3	-13
2008	-5	7	13	18	25	40	50	45	39	21	18	-15	-15
2009	-6	11	12	15	36	41	47	46	36	15	12	-12	-12
2010	-7	1	6	25	28	45	45	50	39	23	13	2	-7
2011	-4	-17	19	21	30	44	52	52	37	14	15	-4	-17
2012	2	5	17	30	33	46	55	46	42	22	15	0	0
2013	-4	8	3	2	17	40	51	50	33	26	13	-9	-9
2014	-7	-14	3	14	30	37	51	49	32	29	-11	-14	-14
2015	0	-1	4	26	29	47	52	44	40	28	5	4	-1
2016	3	6	14	22	27	46	53	43	38	26	15	-10	-10
2017	-7	10	21	21	30	44	49	50	40	20	19	-2	-7
2018	0	-6	17	22	37	44	46	46	36	13	11	5	-6
2019	1	-9	-5	16	31	38	52	47	40	3	4	11	-9
2020 •	11	-3	14	9	33	42	48	M	M	M	M	M	-3
1991-2019 Mean •	-1	1	11	20	30	41	50	48	35	21	8	0	-8
1991-Current Mean •	-1	1	11	19	30	41	50	48	35	21	8	0	-7
Max	14 2006	19 1992	22 2004	30 2012	37 2018	47 2015	55 2012	52 2011	44 1998	31 2004	19 2017	12 2001	7 1999
Min	-12 1997	-17 2011	-6 2002	2 2013	17 2013	33 1998	44 1992	40 2004	23 1995	3 2019	-11 2014	-15 2008	-17 2011



Note:
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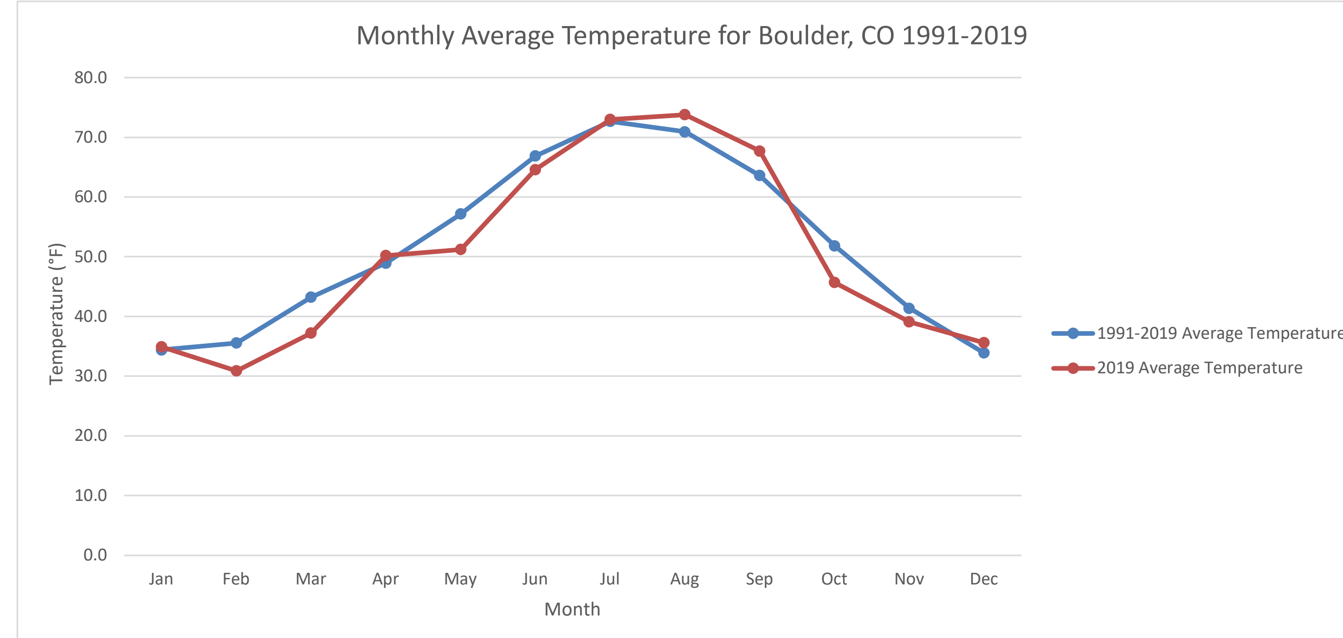
RJH Consultants, Inc.
16134 - South Boulder Creek
Boulder, CO Weather Station Monthly Data - Avg Temp

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/29/2020
Approved: ABP Date: 7/30/2020

Monthly Mean Avg Temperature for BOULDER, CO													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1991	29.9	41.0	42.8	47.8	58.2	66.6	70.5	69.2	61.7	52.4	37.1	35.3	51.0
1992	35.3	40.6	43.3	54.2	59.1	62.9	68.3	66.3	64.4	54.0	34.1	29.3	51.0
1993	28.3	30.6	43.2	47.6	57.5	64.5	69.5	M	58.7	48.6	35.6	35.6	47.2
1994	36.6	32.8	43.8	47.6	60.8	70.0	71.1	70.9	64.9	50.5	36.5	36.1	51.8
1995	34.5	38.6	42.1	45.1	50.9	62.3	70.5	74.0	60.4	51.5	44.9	36.2	50.9
1996	29.9	37.7	37.9	50.4	58.8	66.9	71.5	69.5	60.8	53.0	40.6	36.5	51.1
1997	31.2	32.7	45.5	42.8	57.4	66.5	71.4	68.7	64.0	52.7	37.9	33.8	50.4
1998	36.5	36.4	38.6	46.5	58.8	62.7	72.8	70.7	67.0	50.3	44.0	32.2	51.4
1999	36.2	42.1	46.0	44.7	55.6	64.8	73.3	69.3	58.5	51.9	48.4	36.9	52.3
2000	36.6	41.1	43.0	51.0	61.1	67.8	74.3	73.0	62.8	49.6	31.3	31.2	51.9
2001	32.9	32.3	40.8	50.6	58.4	68.5	75.0	71.9	65.0	53.8	43.9	35.0	52.3
2002	33.1	36.0	38.0	52.9	56.2	70.5	76.8	71.3	64.1	45.9	40.3	36.6	51.8
2003	40.2	31.6	43.7	50.6	57.4	62.8	75.8	72.9	60.5	57.4	38.9	36.4	52.4
2004	35.4	33.9	48.0	49.2	60.0	62.7	69.2	66.4	62.9	51.9	39.7	36.5	51.3
2005	35.4	37.9	42.0	48.4	57.6	65.4	75.0	69.7	66.2	53.1	44.6	33.5	52.4
2006	40.7	33.7	39.4	53.9	61.0	71.6	74.4	71.6	58.4	51.0	43.4	35.3	52.9
2007	27.2	34.6	47.6	47.8	58.0	67.7	74.8	73.6	64.4	55.2	44.9	30.1	52.2
2008	31.6	36.1	41.0	47.8	57.0	66.0	75.0	69.6	60.9	51.8	46.0	31.1	51.2
2009	38.2	39.7	44.2	47.3	59.3	62.9	69.5	69.5	63.1	44.5	43.8	26.7	50.7
2010	33.0	30.2	42.7	48.8	53.9	66.9	72.5	72.4	66.6	54.9	39.8	37.2	51.6
2011	33.0	31.9	45.2	48.9	53.7	67.6	73.5	75.1	63.3	52.9	42.3	32.1	51.6
2012	38.8	32.2	50.8	54.3	60.1	74.1	74.8	73.2	65.9	50.8	46.1	33.7	54.6
2013	33.0	32.1	40.5	43.7	57.6	69.8	72.2	72.2	65.1	47.8	43.2	31.5	50.7
2014	34.6	32.0	43.6	49.8	56.5	66.2	72.2	69.2	63.8	55.3	38.3	33.8	51.3
2015	36.4	36.6	46.1	50.0	52.4	68.3	70.3	71.8	68.1	56.2	40.8	33.1	52.5
2016	34.1	40.8	43.0	49.0	54.0	70.5	74.0	70.4	64.9	58.7	47.5	32.0	53.2
2017	32.1	42.3	50.3	48.9	55.7	68.7	73.9	68.9	63.5	51.5	47.5	36.4	53.3
2018	37.7	32.5	43.4	49.1	59.7	69.9	72.5	70.9	66.7	50.4	39.4	33.8	52.2
2019	34.9	30.9	37.2	50.2	51.2	64.6	73.0	73.8	67.7	45.7	39.1	35.6	50.3
2020	36.2	32.4	43	47.6	59	69.2	74.1	M	M	M	M	M	51.6
1991-2019 Mean	34.4	35.5	43.2	48.9	57.2	66.9	72.7	70.9	63.6	51.8	41.4	33.9	51.6
1991-Current Mean	34.5	35.4	43.2	48.9	57.2	67.0	72.7	70.9	63.6	51.8	41.4	33.9	51.6
Max	40.7 2006	42.3 2017	50.8 2012	54.3 2012	61.1 2000	74.1 2012	76.8 2002	75.1 2011	68.1 2015	58.7 2016	48.4 1999	37.2 2010	54.6
Min	27.2 2007	30.2 2010	37.2 2019	42.8 1997	50.9 1995	62.3 1995	68.3 1992	66.3 1992	58.4 2006	44.5 2009	31.3 2000	26.7 2009	47.2



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Weather & ET Data | Crop & Turf Water Use | Background Info

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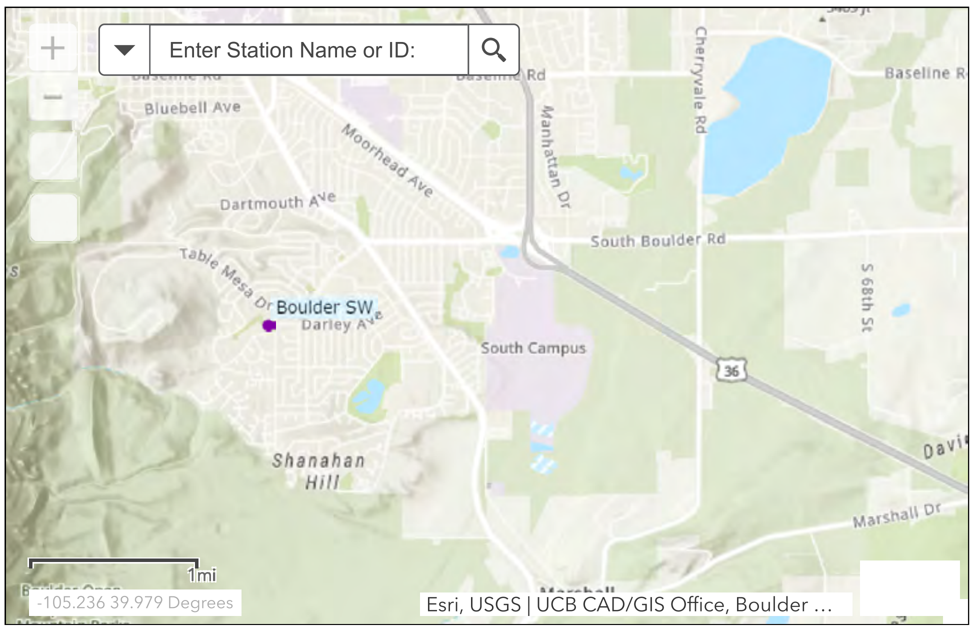
Favorites

Step 1: Select Weather Stations

Select one or more weather stations from the list, then click Step 2.

[ ]	108	Sterling
[ ]	109	Crook
[ ]	110	Ovid
[ ]	111	Johnson's Corner
[ ]	220	Berthoud
[ ]	222	Fort Morgan
[ ]	224	Greeley West
[ ]	225	Fort Lupton
[ ]	226	Longmont West
[ ]	228	Fort Collins Central
[x]	230	Boulder South West
[ ]	233	Boulder North West
[ ]	350	Windy Gap
[ ]	352	Shadow Mountain



Step 2: Select Weather Categories

Weather categories are grouped by their measurement type. Select one or more weather categories, then click Step 3. (Please note: the graph display is limited to two weather category types.)

Select All | Select None

Temperature
- [ ] Max Air Temp (°F)
- [ ] Min Air Temp (°F)
- [ ] Ave Air Temp (°F)
- [ ] Dewpoint Temp (°F)
- [ ] Ave Soil Temp (°F)

Relative Humidity
- [ ] Rel Humidity (%)

Vapor Pressure
- [ ] Vapor Pressure (kPa)

Evapotranspiration
- [ ] ETrs Alfalfa Tot (in)
- [x] ETos Grass Tot (in)
- [ ] kp EvapPan

Precipitation ?
- [ ] Rain (TB) (in)
- [ ] Catch (WB) (in)
- [ ] Precip (WB) (in)

Wind Speed
- [ ] Max Wind Speed (3m) (mph)
- [ ] Ave Wind Speed (3m) (mph)
- [ ] Ave Wind Speed (2m) (mph)
- [ ] WindVec Vel (3m) (mph)
- [ ] Wind Travel Tot (3m) (miles)

Wind Direction
- [ ] WindVec Dir (3m) (°)
- [ ] WindVec Std Dev Dir (°)

Solar Radiation
- [ ] Solar Rad Tot (cal/cm2)
- [ ] Rso Clear Sky (cal/cm2)

9/16

CLS 7/29/2020

ABP 7/30/2020

Tabular Results Graph Results

Click a column title to sort data. Hold and drag a column to move it. To export data, choose an Export to: format.

Station Name	Code	Date/Time	ETos Grass Tot (in)
Boulder South West	230	Nov 2018	
Boulder South West	230	Nov 2018	2.029
Boulder South West	230	Dec 2018	
Boulder South West	230	Dec 2018	1.558
Boulder South West	230	Jan 2019	
Boulder South West	230	Jan 2019	1.709
Boulder South West	230	Feb 2019	
Boulder South West	230	Feb 2019	1.723
Boulder South West	230	Mar 2019	
Boulder South West	230	Mar 2019	2.579
Boulder South West	230	Apr 2019	
Boulder South West	230	Apr 2019	3.987
Boulder South West	230	May 2019	

Export to: Excel

Tabular Results Graph Results

Click a column title to sort data. Hold and drag a column to move it. To export data, choose an Export to: format.

Station Name	Code	Date/Time	ETos Grass Tot (in)
Boulder South West	230	May 2019	
Boulder South West	230	May 2019	3.964
Boulder South West	230	Jun 2019	
Boulder South West	230	Jun 2019	5.358
Boulder South West	230	Jul 2019	
Boulder South West	230	Jul 2019	6.285
Boulder South West	230	Aug 2019	
Boulder South West	230	Aug 2019	5.724
Boulder South West	230	Sep 2019	
Boulder South West	230	Sep 2019	4.649
Boulder South West	230	Oct 2019	
Boulder South West	230	Oct 2019	2.704

Export to: Excel

Monthly ET rates for irrigated grass

CLS 7/29/2020

ABP 7/30/2020

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☐	233	Boulder North West
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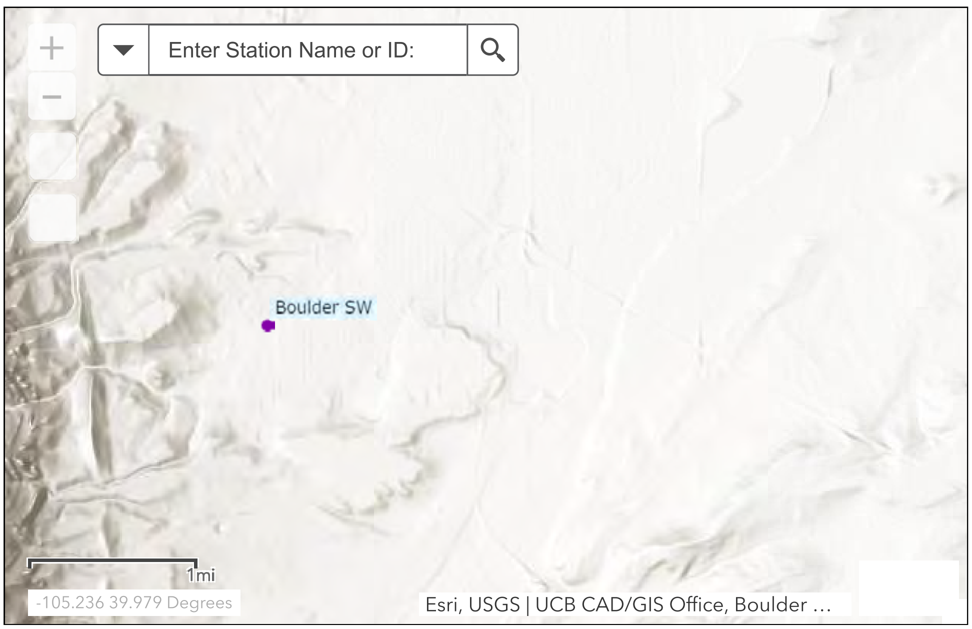
☐	352	Shadow Mountain



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- ☐ Max Air Temp (°F)
- ☐ Min Air Temp (°F)
- ☐ Ave Air Temp (°F)
- ☐ Dewpoint Temp (°F)
- ☐ Ave Soil Temp (°F)

Relative Humidity
- ☐ Rel Humidity (%)

Vapor Pressure
- ☐ Vapor Pressure (kPa)

Evapotranspiration
- ☐ ETrs Alfalfa Tot (in)
- ☐ ETos Grass Tot (in)
- ☑ kp EvapPan

Precipitation ?
- ☐ Rain (TB) (in)
- ☐ Catch (WB) (in)
- ☐ Precip (WB) (in)

Wind Speed
- ☐ Max Wind Speed (3m) (mph)
- ☐ Ave Wind Speed (3m) (mph)
- ☐ Ave Wind Speed (2m) (mph)
- ☐ WindVec Vel (3m) (mph)
- ☐ Wind Travel Tot (3m) (miles)

Wind Direction
- ☐ WindVec Dir (3m) (°)
- ☐ WindVec Std Dev Dir (°)

Solar Radiation
- ☐ Solar Rad Tot (cal/cm2)
- ☐ Rso Clear Sky (cal/cm2)

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Tabular Results Graph Results

Northern Water Pan Evap Data

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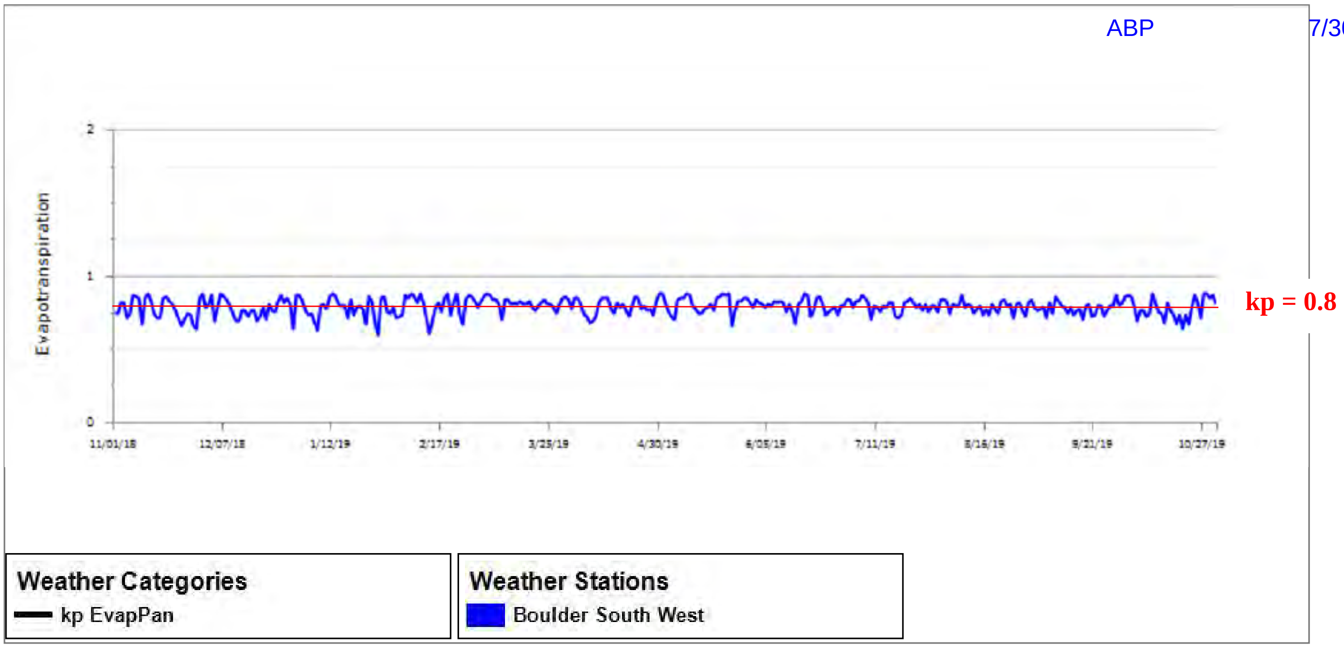

Standardized reference evapotranspiration – Evapotranspiration from a uniform surface of dense, actively growing vegetation having specified height and surface resistance, not short of soil water, and representing an expanse of at least 100 meters of the same or similar vegetation. Full-cover alfalfa (0.5-meter or 20-inch height) is typically considered the tall crop representative of ETrs. Clipped, cool-season grass (0.12 meter or 4.7-inch height) is typically considered the short crop for ETos. Calculation of reference evapotranspiration by Northern Water follows 'ASCE Standardized Reference Evapotranspiration Equation', 2005, American Society of Civil Engineers. This is a very well regarded, nationally standardized method of calculating reference ET.

Kc – Or crop curve factors are used to factor ETrs or ETos to derive crop and turf water use or ETc. The crop curves utilized by Northern Water are traceable to curves derived by J. Wright (1982) based on lysimeter measurements at Kimberly, Idaho. Wright's time-based, basal crop curves were published in ASCE Manual 70, 'Evapotranspiration and Irrigation Water Requirements', M. Jensen, 1990.

Kp – Class A pan coefficient is part of the FAO-24 Pan Evaporation Method as presented in ASCE Manual 70, 'Evapotranspiration and Irrigation Water Requirements', M. Jensen and R. Allen, 2016, pp. 214-218. Basically, ETo = Kp x Epan. Although pan evaporation or Epan is a simple, direct measurement, the service and maintenance requirements of a class A pan are very high and fraught with problems. Kp is estimated from the equation in Evaporation, Evapotranspiration, and Irrigation Water Requirements, 2nd Ed. Task Committee on revision of Manual 70, ASCE, Marvin E. Jense, Richard G. Allen, (eds.), 2016. p. 217

Effective precipitation – The fraction of measured precipitation that meets crop water use or ETc. Precipitation that is 'lost' to surface runoff or deep percolation – not stored in the plant root zone – is considered non-effective. By definition, effective precipitation is not included in crop and turf water use calculations or ETc. It is included in calculations of the irrigation requirement where it is subtracted from ETc.

Tipping bucket rain gauges – Measure liquid rainfall utilizing small 'buckets' balanced on a pivot, much like a seesaw. Falling rain drops into a funnel, which directs the water into the bucket on one side of the seesaw. When the bucket fills, its increased weight tips the seesaw, emptying that bucket but bringing the bucket on the other side upwards and into position to capture the water draining from the funnel. Each tip of the seesaw closes a reed switch, triggering an electrical pulse to the data logger. The data logger counts the pulses or tips, with each tip typically representing either 0.01-inches or 0.005-inches of rainfall.

Advantages of tipping bucket rain gauges are:

- Lower equipment costs
- Clear start/stop periods for rainfall events

Disadvantages include:

- If rainfall stops just before a bucket fills and tips, that amount of rain will not be recorded until additional rain occurs (it may evaporate if the delay is significant),
- Heavy rainfall tends to be under measured because of the 'spillage' occurring at the moment the seesaw tips
- The small orifice of the collection funnel is subject to plugging from windblown debris or bird droppings
- Frozen precipitation (hail, snow, etc.) is not measured until it is melted by a heater or by warming air temperatures. None of the tipping buckets at Northern Water weather stations incorporate heating elements, hence they are normally operated from March through October.

Weighing bucket precipitation gauges – Capture all precipitation, whether liquid or frozen, into a catchment or storage bucket. The weight of the bucket is converted to an electronic signal recorded by the data logger. The change or difference in recorded weight overtime represents the measured precipitation.

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We estimated the abundance of any state of Colorado listed weed species by collecting point data every 2 m along each transect. At each point, all listed weeds that touched a vertical measuring rod were recorded a present. In addition, the presence/absence of listed weeds was recorded in a 10 m x 10 m plot every 10 m along each transect. GPS coordinates were recorded every 10 m along each transect using a Trimble GeoXM and post-processed in TerraSync.

Results

We surveyed 873, 10 m x 20 m plots over 15 sites, for a total of 435 acres surveyed. Over all of these sites we collected dbh, height, and canopy condition data from 2182 trees.

Trees

As expected, plains cottonwood (*Populus deltoides*) is the dominant tree species in the South Platte floodplain, comprising more than 45% of the individuals recorded. Basal area (BA) is a common metric used to compare tree volume between sites, and is a measure of the total cross sectional area occupied by trunks. Just over 80% of the total tree basal area for the study area is comprised of plains cottonwood, followed in abundance by peachleaf willow (*Salix amygdaloides*) at nearly 12% of the total basal area. Species not native to Colorado comprise less 6% of basal area over all sites. The most common non-native tree species is Russian olive (*Elaeangus angustifolia*), which comprises 2.21 % of total basal area and 4.54 % of individuals encountered in the surveys.

Shrubs

Coyote willow (*Salix exigua*) was the dominant shrub species found, with approximately 83% of all stems recorded being from this species. Snowberry (*Symphoricarpos occidentalis*) was the next most abundant shrub species, with just over 14% of the total stems.

Saplings

There were far fewer saplings within the study area than trees, with a combined total of 386 saplings over all species over all sites. In contrast to the mature trees, green ash was the most common species of sapling recorded (131), followed by peachleaf willow (103). *Tamarix spp.* was the third most common sapling recorded, with 44, all of which were on a single sandbar at site 11 (Table 1). We suspect that these saplings all originated from one or two large, buried *Tamarix* trees. Although cottonwood is the most dominant tree species over all sites, we only recorded 43 sapling individuals, consistent with the idea that cottonwood recruitment requires a set of specific and relatively infrequent conditions in order for recruitment to occur.

Seedlings

Cottonwood seedlings were by far the most common tree seedling encountered, with more than 100,000 found over the entire survey area (Table 2). The number of cottonwood seedlings recorded was highly variable—ranging from 0 (site 1) to 32,936 at site 14. This variability likely results from the specific environmental requirements for cottonwood seed germination. Cottonwood seeds need bare, moist soil. Where these conditions occur, hundreds to thousands of seedling may germinate per m^2 We found a total of four seedlings of Russian olive, a surprising result given that this species is considered invasive in Colorado and that it is common (though not abundant) in the study area. We found 275 and 32 seedlings for Siberian elm (*Ulmus pumilla*) and *Tamarix* spp., respectively.

One of the questions raised, is to what degree cottonwood and willow are still reproducing within the study area. With altered flow regimes and channel narrowing, it is possible that these pioneer species are in decline and are being replaced by other species, most notably green ash, Russian olive, and Siberian elm. Figures 4a–f illustrate the size-class distribution of saplings and trees for the most common tree species in the area. Note that the single full growing season between the September 2013

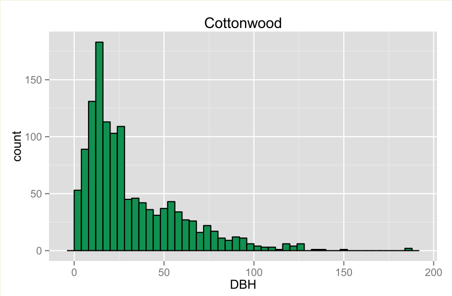

Figure 4a.

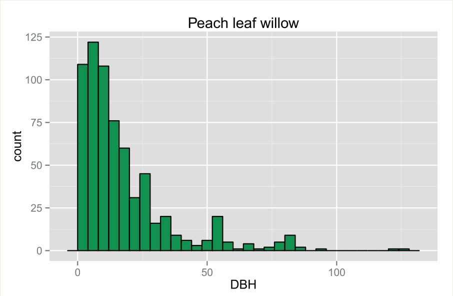

Figure 4b.

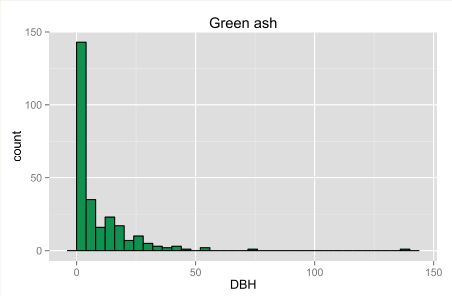

Figure 4c.

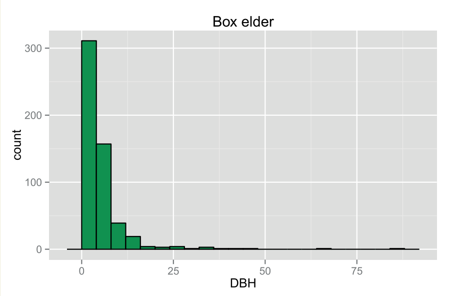

Figure 4d.

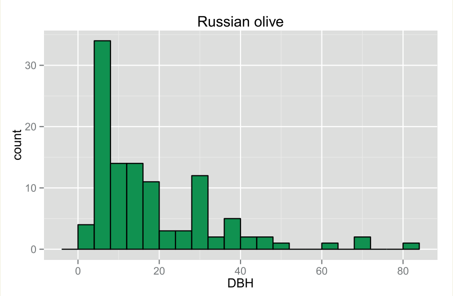

Figure 4e.

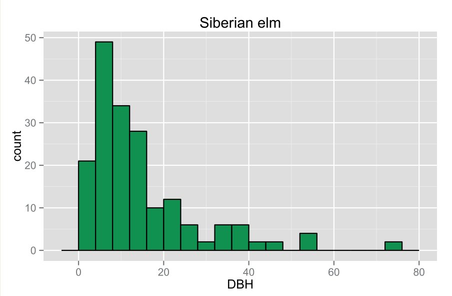

Figure 4f.

Figures 4a-f. Size distributions for trees in the study area. DBH represents the diameter at breast height (cm). Counts include saplings and mature trees.

Kimbrough (1995)

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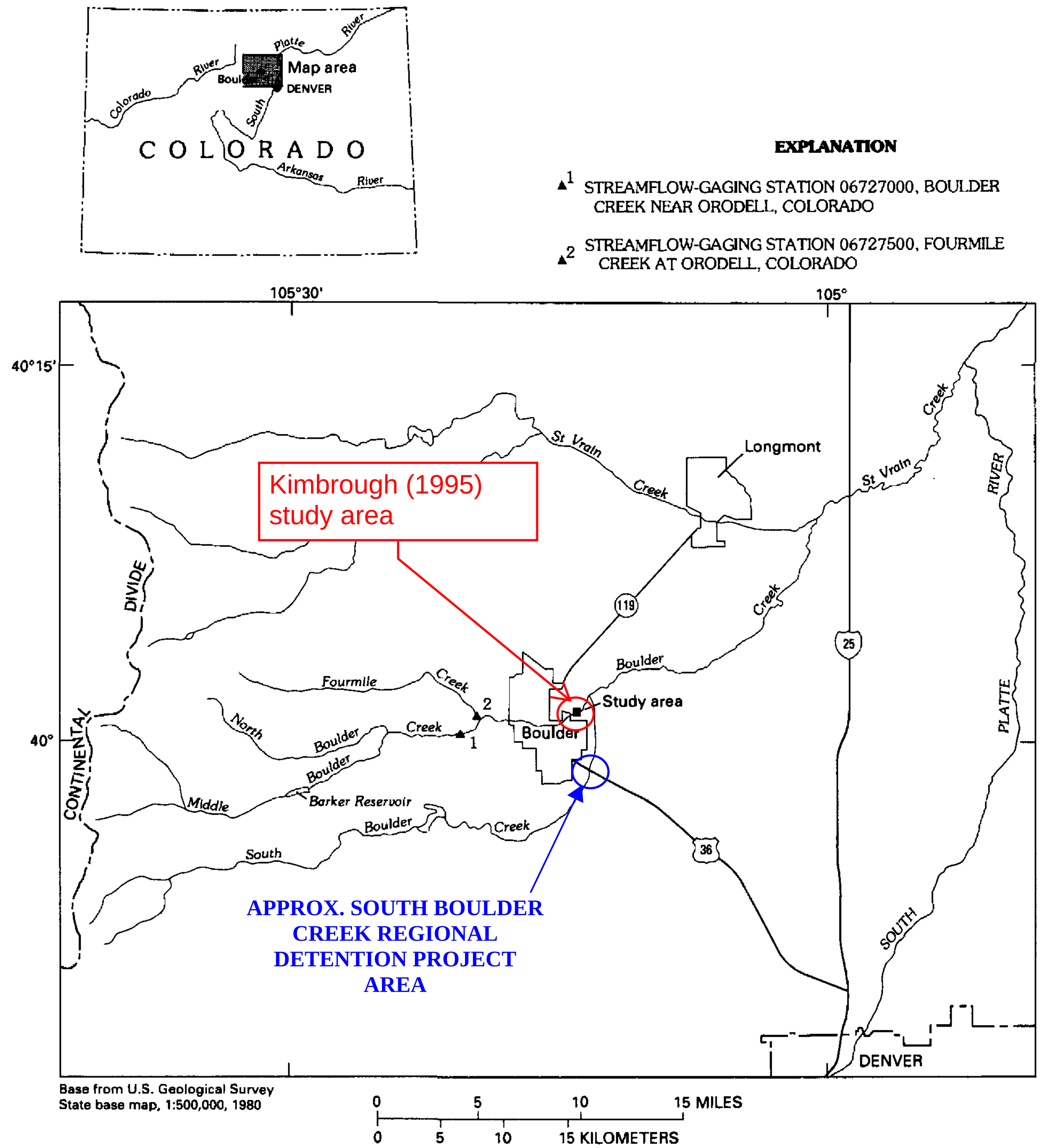


Figure 1. Location of study area and selected streamflow-gaging stations.

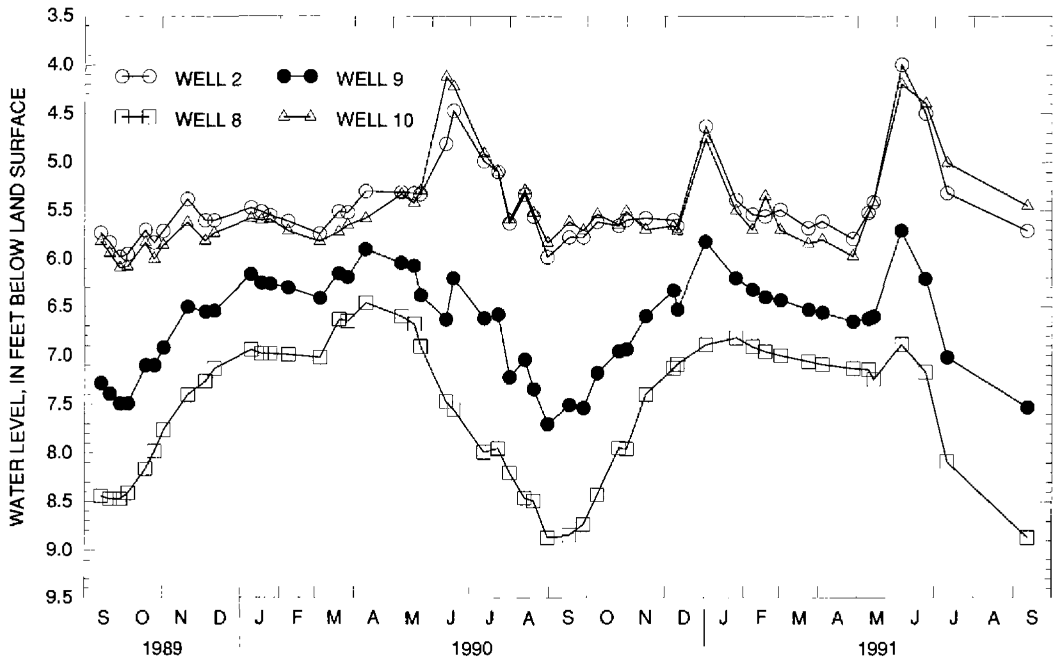


Figure 9. Water levels in wells 2, 8, 9, and 10, defined by discrete measurements, September 1989–September 1991.

high streamflow in June 1991. The timing of annual water-level peaks also varied between wells 2, 8, 9, and 10. The annual water-level peak in wells 2 and 10 coincided with snowmelt runoff, whereas in well 8, the annual peaks occurred in April and January. Well 9 had one annual peak in April 1990 and another during snowmelt runoff in June 1991. Clearly, processes other than stream stage and distance from the stream were affecting water levels in wells 8 and 9 when compared to wells 2 and 10.

Well 8 is located on the established flood plain within Cottonwood Grove where mature plains cottonwood trees are present. Ground water is a primary source of moisture for these riparian trees, thus evapotranspiration may cause ground-water-level declines in these areas. Previous studies have concluded that the quantity of ground water removed by evapotranspiration is substantial. Gatewood and others (1950) documented evapotranspiration rates of 6 ft/yr for cottonwoods along the Gila River in Arizona. Whitcomb (1965) reported that an evapotranspiration rate of 3 ft/yr was reasonable for cottonwood trees in Niobrara County, Wyoming. Eschner and others (1983) assumed a conservative annual evapotranspiration rate of 3.2 ft/yr for vegetation along the Platte River in central Nebraska.

Air temperature greatly affects evapotranspiration (Rosenberg and others, 1983). In general, evapotranspiration increases with increasing air temperature. Plotting the hydrograph for well 8 with monthly mean air temperature indicated a correlation between low water levels and high temperatures (fig. 10). The declining water levels in well 8 coincided with periods of high monthly mean temperature when evapotranspiration demand was high. The lowest water levels in well 8 occurred around September each water year after monthly mean temperatures had remained above 60°F for at least 3 months (National Oceanic and Atmospheric Administration, 1989, 1990b, 1991). The highest water levels in well 8 followed periods when monthly mean temperatures were consistently less than 40°F, the threshold temperature below which evapotranspiration essentially ceases (Linsley and others, 1982). The effect of evapotranspiration on ground-water levels in other parts of the grove is evident in hydrographs for wells 1, 7, 9, 14, and 15 (fig. 9 and the Appendix).

Evapotranspiration also caused ground-water levels to change on a diel basis. During summer, fluctuating water levels were recorded in well 6 during periods of constant or declining stream stage (fig. 11). Between August 21–24, 1991, water levels in well 6 declined between late morning and about 1800 hours in response to consumptive ground-water use by riparian vegetation. Water levels recovered between 2400 hours and 0600 hours when plant stomata were closed and evapotranspiration demand had decreased. Figure 11 also shows the dual effect of stream stage and annual water use, range in depth to water, or chemical quality of the ground water or soil they prefer.

Some of the species listed are widespread in their occurrence; others are quite local. There is also overlapping of species, so that more than one species may be present in a locality. *Populus deltoides* is a large tree of the Eastern United States that extends west into the Plains States. In those States it occupies a belt extending from eastern North Dakota south to eastern Texas. Three cottonwoods, *P. angustifolia, P. sargentii,* and *P. acumenata,* occur in the Rocky Mountain region from Canada almost to Mexico, *P. angustifolia* being the most widespread. *P. sargentii* extends eastward from the mountains into the plains of western Oklahoma, Kansas, Nebraska, and South Dakota. *P. weslizeni* also occurs in the Rocky Mountain region, from central Colorado to Mexico. The poplar *P. balsamifera* prefers the colder part of the Rocky Mountain region from Colorado and Wyoming north to Canada. *P. trichocarpa* grows largely along the Pacific coast in Oregon, Washington and California. *P. texana* is limited to the Panhandle and central part of Texas. *P. fremontii* occurs from western Texas to Nevada, Arizona, and California. It is intolerant of shade, as are most cottonwoods.

Measurements of consumptive use of water by cottonwoods and willows growing in tanks along the San Luis Rey River, Calif., were made by Muckel and Blaney in 1939-44 (1945, p. 54). The average annual use was 5.2 feet with the water table at 4 feet, and 8.1 feet with the water table at 3 feet. Density was 100 percent. Although the trees were dormant during most of the winter months, grass and weeds grew vigorously throughout the year.

As part of the detailed studies of the use of water by bottomland vegetation in the lower Safford Valley, Ariz., cottonwood plants (*P. fremontii*) were grown in tanks. The use of water by the plants during the period October 1, 1943, to September 22, 1944 (Gatewood and others, 1950, p. 138), at 100-percent density was 7.64 feet with the water table at 7.0 feet. In applying the tank data to the areas of cottonwoods in the valley, it was estimated that the annual use for 100-percent volume density was 6.0 feet, including 0.57 foot of precipitation. The water table in the valley ranged in depth from 4 to 30 feet below the land surface.

Information as to the depth that cottonwood will send its roots to the water table is scanty. Meinzer (1927, p. 58) quotes reports of cottonwoods growing where the depth to water was 20 feet. The writer has observed cottonwoods growing in areas where there was reason to believe that the depth to the water table was between 25 and 30 feet. Thirty feet is believed to be near the limit.

APPENDIX B

SOUTH BOULDER CREEK DATA

Purpose:

- Document available flow and stage data at both the Sans Souci and South Boulder Road stream gauges on South Boulder Creek near the South Boulder Creek Regional Detention Project (Project) vicinity for groundwater model inputs.

- Evaluate a 12-month transient modeling period from observed flow and stage data trends.

References:

1. Automated stream stage and flow data is available through the Mile High Flood District (MHFD) ALERT System and OneRain gauge stations at Sans Souci (Site 4830) and South Boulder Road (Site 4870):(p.__2__)
   https://mhfd.onerain.com/site/?site_id=15896&site=f7131450-4dc4-4acb-ad4d-e4f4e94a023f
   https://mhfd.onerain.com/site/?site_id=16270&site=bd452952-f6b4-49e6-85c6-f4112bd59db6

Methods:

Graphical summaries

1. Download stream gauge data from the MHFD website for the Sans Souci and South Boulder Road gauges. Excerpts of the available data are provided on p._3-6_.
2. Multiple readings are reported daily for each gauge; daily maximum and average flow measurements were computed for both gauges using PivotTables. ~~Excerpts~~ of this processed data are provided on p._7-10_.
3. Daily and monthly average measurements were compared to select a 12-month transient modeling period representative of typical seasonal winter-summer-winter groundwater cycles (p._11-14_).

Summary/Conclusions:

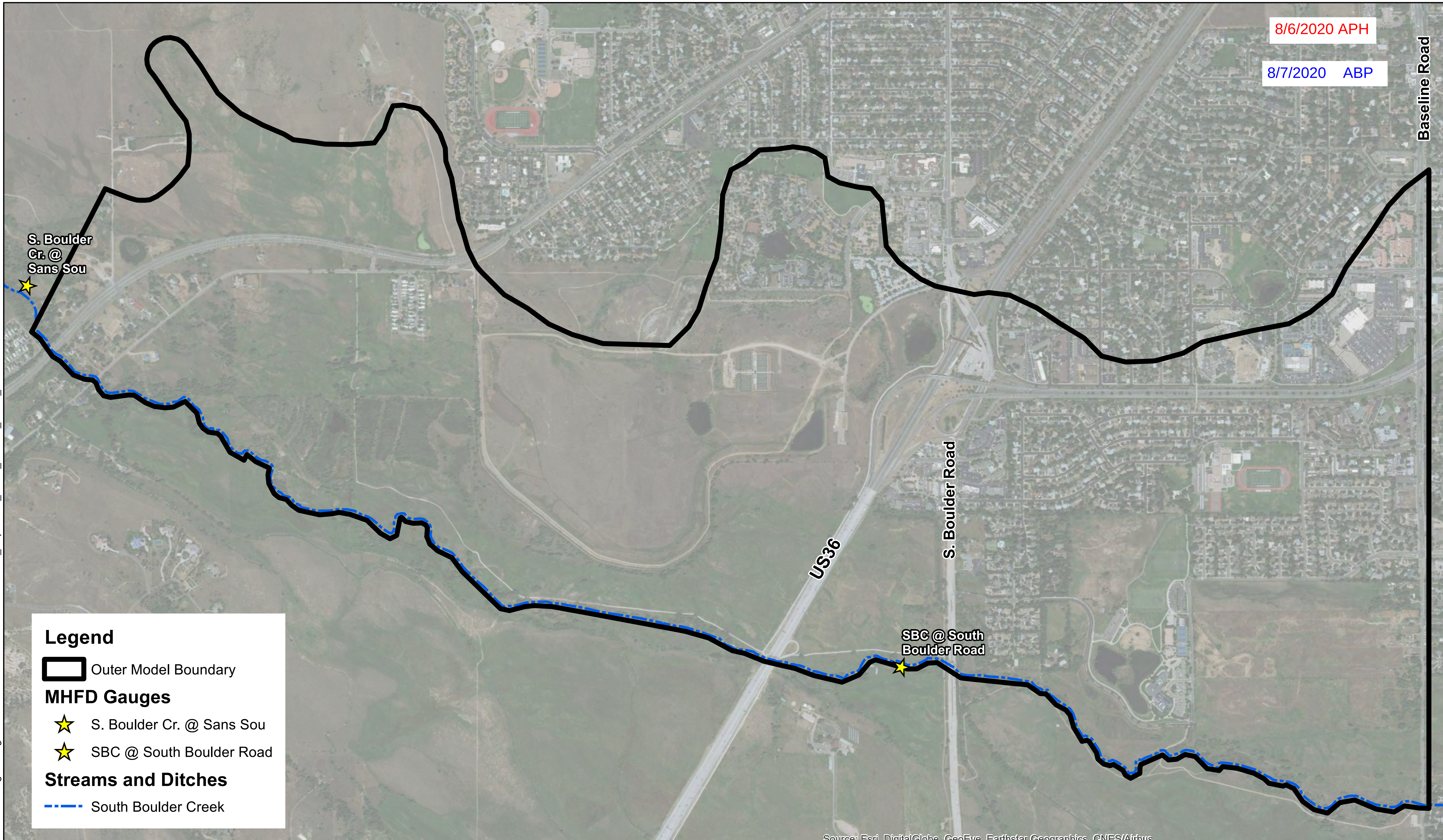
- The period of record varies for each gauge and measurement type:

Record Begins	Sans Souci	South Boulder Road
Stage	1/24/2011 ✓	11/1/2011 ✓
Flow	2/1/2013 ✓	6/27/2018 ✓

- The available flow and stage data show the months between November 2018 and October 2019 to be representative of a complete yearlong cycle from dry-season low stages, through elevated spring and summer stage, and back to dry-season low stages.

- Monthly average stage and flow values from November 2018 to October 2019 for both the Sans Souci and South Boulder Road gauges generally match historic trends observed for the period of record (p._11-14_).

See Note on page 11.



P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline_Report\B.1_South_Boulder_Creek_Data.mxd

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Datum: NAVD 1988

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	SOUTH BOULDER CREEK DATA
PROJECT NUMBER 16134	August 2020 **Figure B.1**

8/6/2020 APH

8/7/2020 ABP

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2013-02-02 13:18:55	36.00	cfs	A
2013-02-02 14:50:18	34.00	cfs	A
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2013-02-03 05:34:06	30.00	cfs	A
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2013-02-05 09:07:10	33.00	cfs	A
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2013-02-08 08:48:19	29.00	cfs	A
2013-02-08 10:14:40	32.00	cfs	A
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2013-02-08 14:38:47	32.00	cfs	A
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Example Data Excerpt

Full datasets are presented in spreadsheet.

at the electronic filepath shown in the footer

8/6/2020 APH
8/7/2020 ABP

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Example Data Excerpt

Full datasets are presented in spreadsheet.

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8/7/2020 ABP

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2018-06-28 14:41:50	45.8	cfs	A
2018-06-28 15:04:51	53.9	cfs	A
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2018-06-29 03:53:58	51.4	cfs	A
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2018-06-29 14:15:53	51.4	cfs	A
2018-06-29 14:41:52	54.7	cfs	A
2018-06-29 17:29:52	46.6	cfs	A
2018-06-30 02:41:53	56.4	cfs	A
2018-06-30 09:53:54	40.6	cfs	A
2018-06-30 11:54:54	48.2	cfs	A
2018-06-30 12:19:54	40.6	cfs	A
2018-06-30 13:59:54	56.4	cfs	A
2018-06-30 14:41:54	52.2	cfs	A
2018-06-30 16:02:55	60.8	cfs	A
2018-06-30 18:08:55	52.2	cfs	A
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2018-07-02 14:12:58	46.6	cfs	A
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Example Data Excerpt

Full datasets are presented in spreadsheet.

at the electronic filepath shown in the footer

8/6/2020 APH

8/7/2020 ABP

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2011-11-01 12:13:50	18.19	ft	A
2011-11-01 12:14:40	18.19	ft	A
2011-11-01 12:15:01	18.19	ft	A
2011-11-01 12:15:39	18.19	ft	A
2011-11-01 12:15:56	15.74	ft	A
2011-11-01 12:16:20	14.61	ft	A
2011-11-01 12:16:52	12.74	ft	A
2011-11-01 12:18:42	18.19	ft	A
2011-11-01 12:18:54	18.19	ft	A
2011-11-01 12:19:30	18.19	ft	A
2011-11-01 12:20:30	15.78	ft	A
2011-11-01 12:21:14	18.19	ft	A
2011-11-01 12:22:02	15.01	ft	A
2011-11-01 12:22:24	12.72	ft	A
2011-11-01 12:22:44	10.93	ft	A
2011-11-01 12:24:11	0.41	ft	A
2011-11-01 12:24:38	0.39	ft	A
2011-11-01 12:24:54	0.23	ft	A
2011-11-01 12:25:09	0.12	ft	A
2011-11-01 12:25:22	0.03	ft	A
2011-11-01 12:27:05	17.25	ft	A
2011-11-01 12:27:25	17.1	ft	A
2011-11-01 12:28:25	17.8	ft	A
2011-11-01 12:29:25	13.64	ft	A
2011-11-01 12:31:25	5.33	ft	A
2011-11-01 12:32:25	2.16	ft	A
2011-11-01 12:33:25	7.99	ft	A
2011-11-01 12:34:25	3.58	ft	A
2011-11-02 00:27:25	0.09	ft	A
2011-11-02 12:27:28	0.06	ft	A
2011-11-03 00:27:28	0.05	ft	A
2011-11-03 04:18:29	0.14	ft	A
2011-11-03 09:16:30	0.14	ft	A
2011-11-03 09:31:30	0.04	ft	A
2011-11-03 12:27:31	0.05	ft	A
2011-11-04 00:27:31	0.05	ft	A

<u>Example Data Excerpt</u>

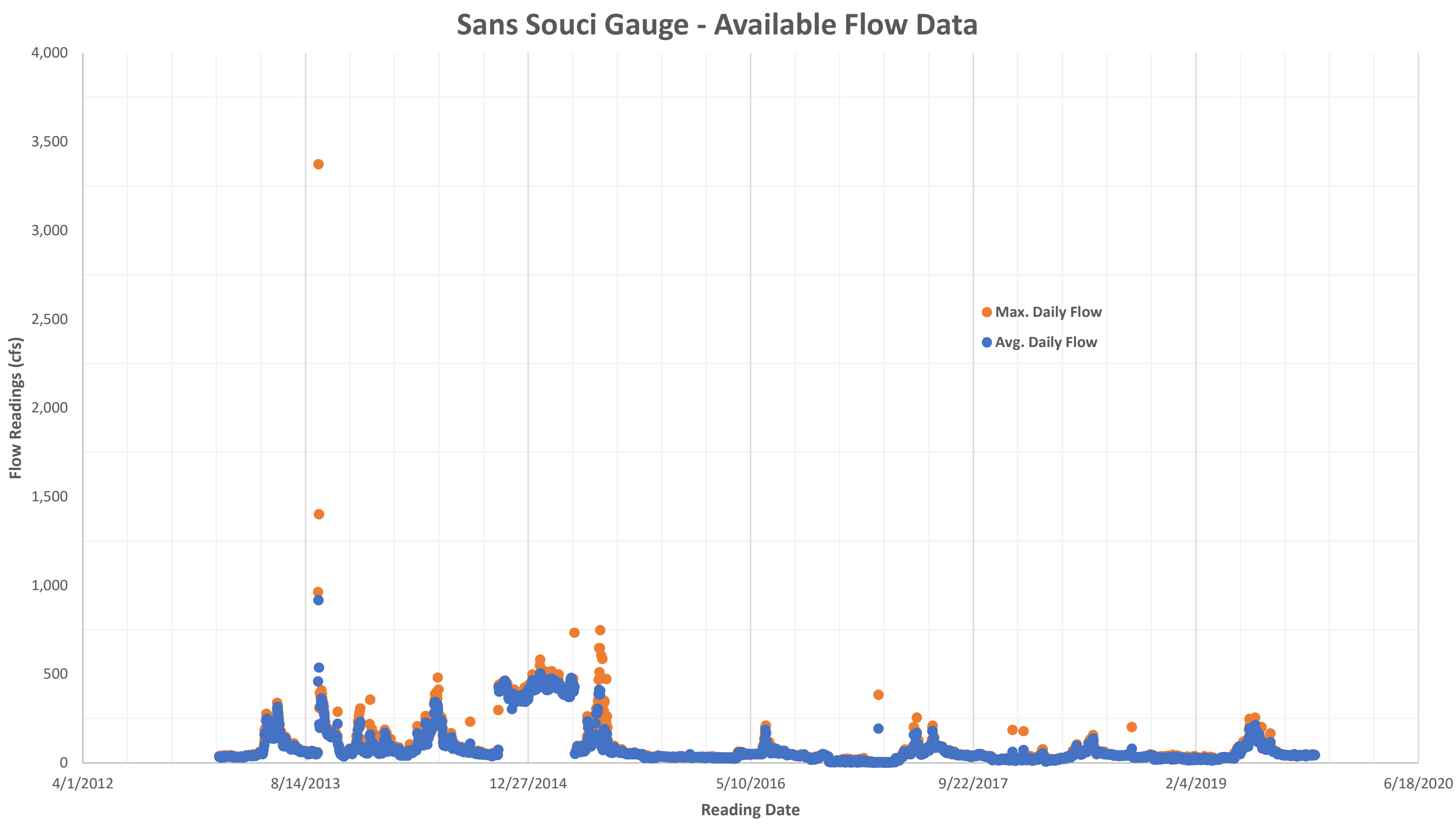
Full datasets are presented in spreadsheet.

at the electronic filepath shown in the footer

Sans Souci Flow Data_Analysis

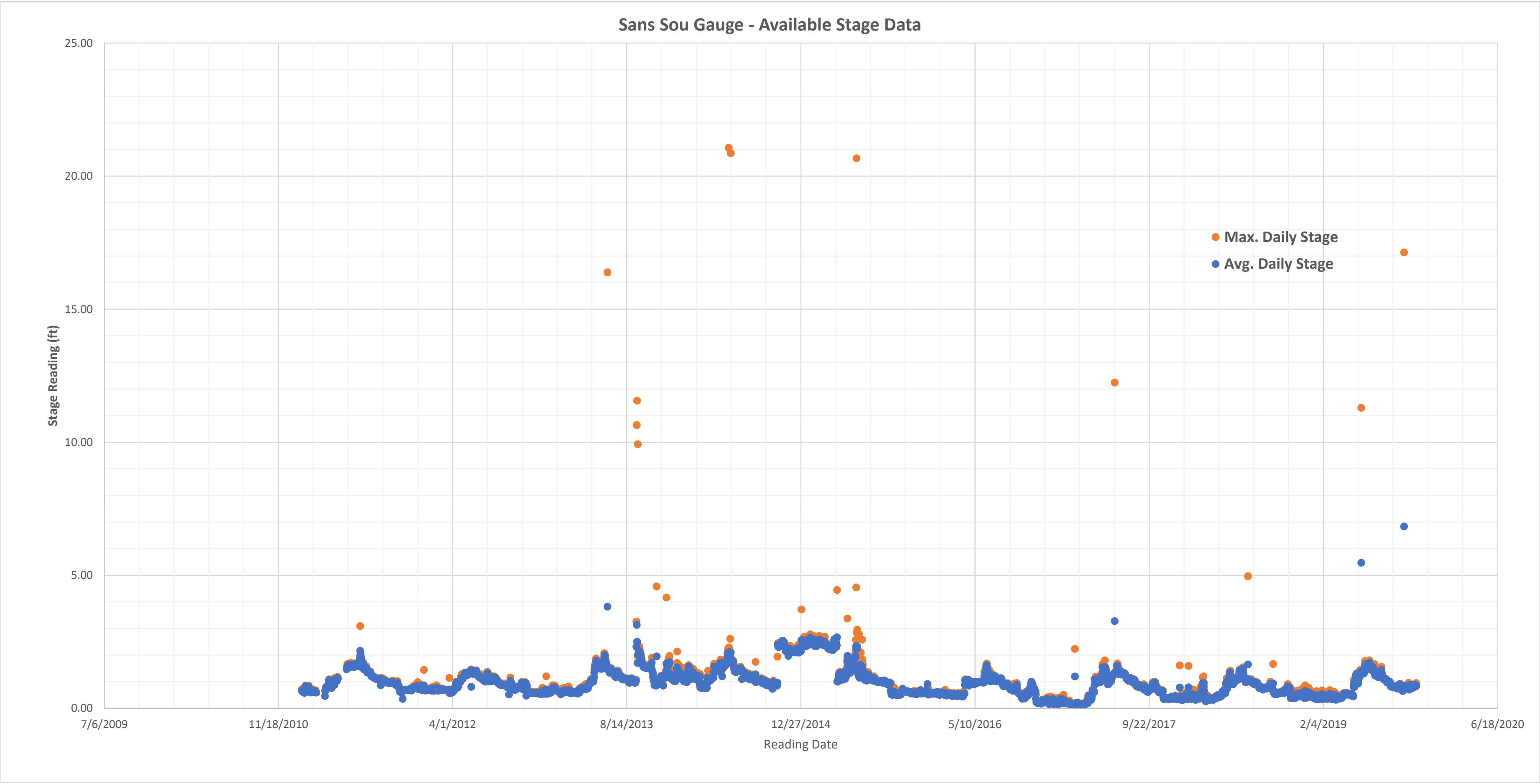
8/6/2020 APH

8/7/2020 ABP



8/6/2020 APH

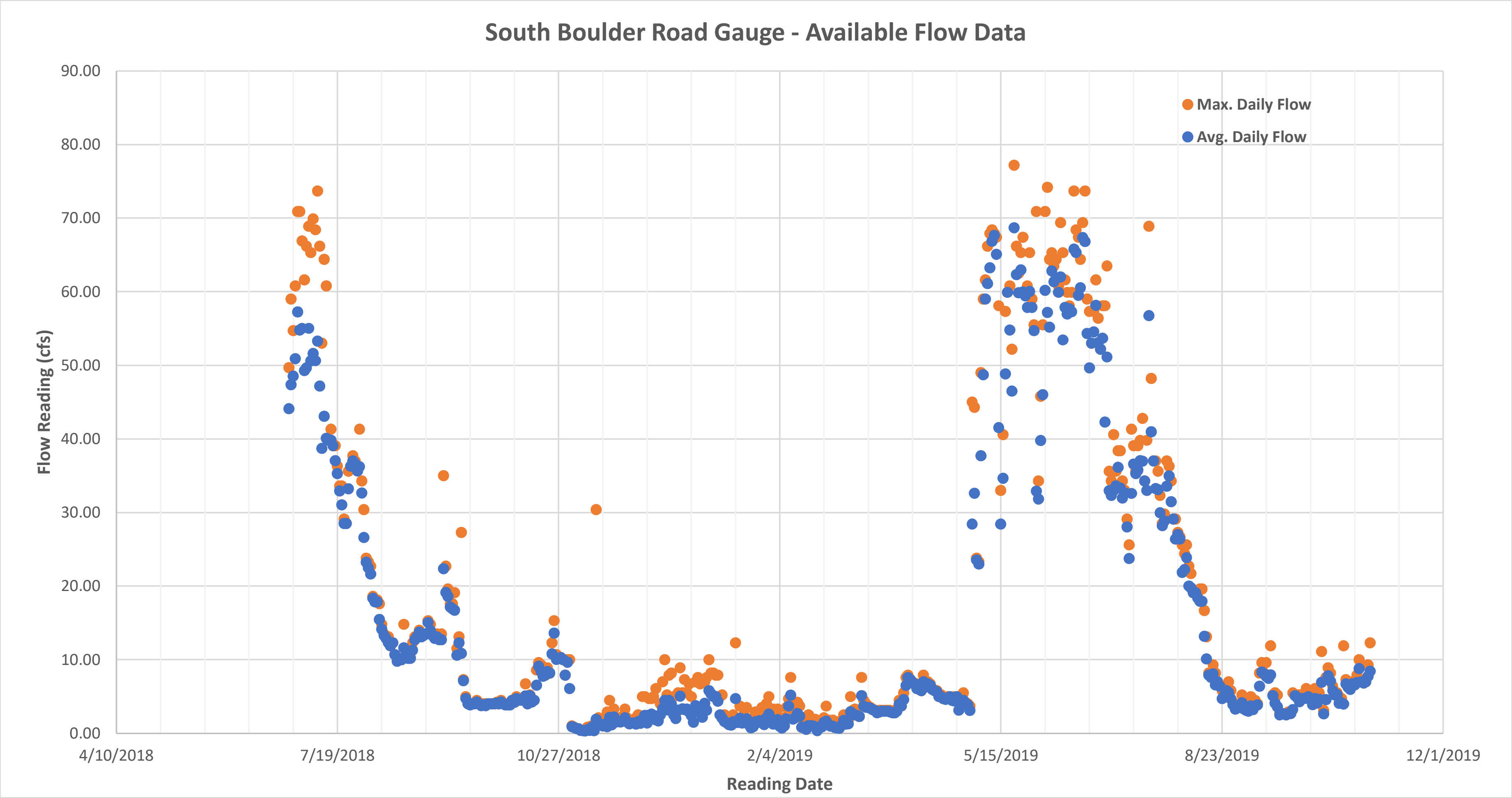
8/7/2020 ABP



P:\16134 - South Boulder Creek\Engineering\Geotechnical\Groundwater\Groundwater_Model\Data_Objects\Supporting_Files\16134_Flow_Stage_DataAnalysis

8/6/2020 APH

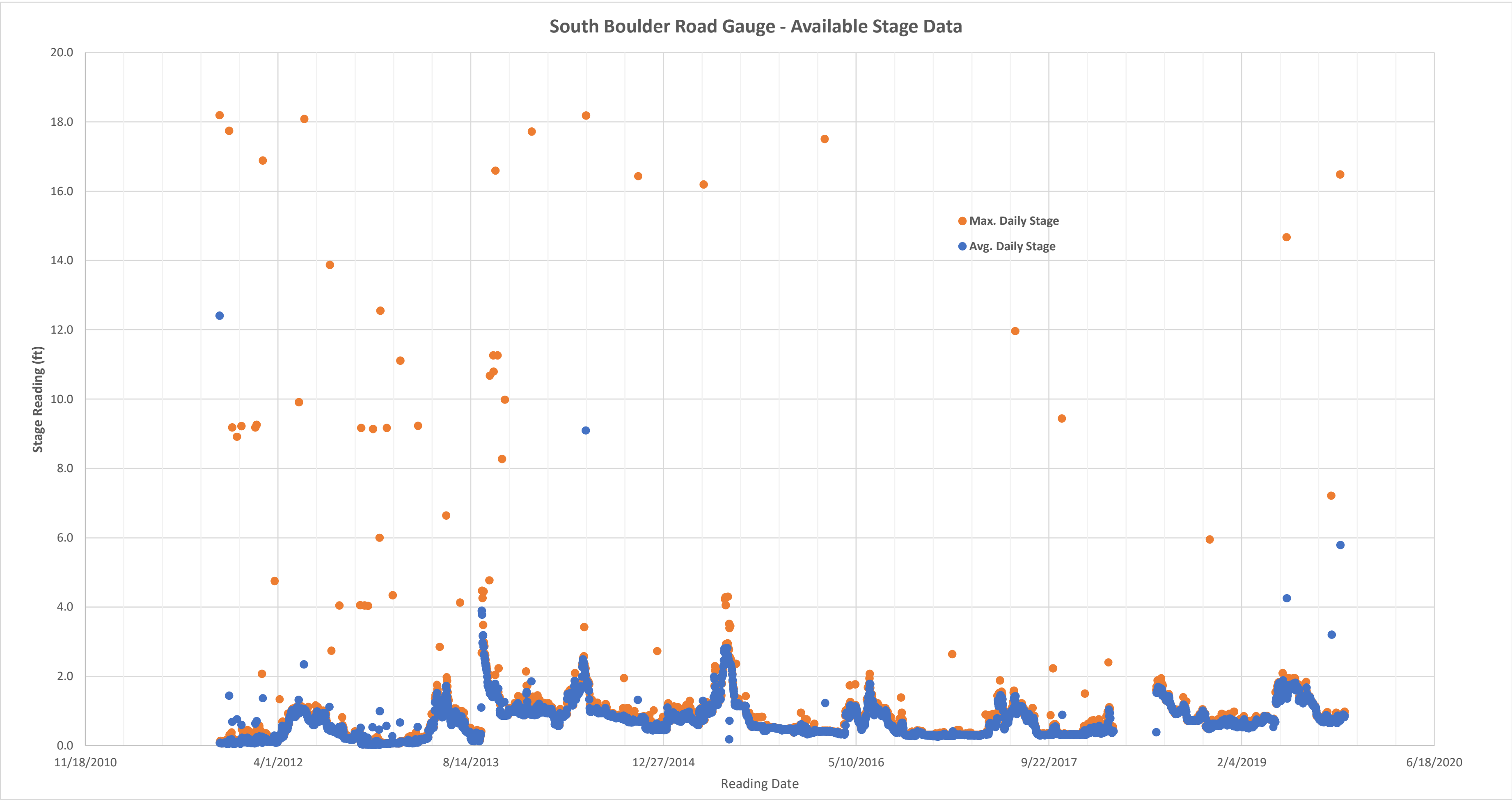
8/7/2020 ABP



SBR Stage Data_Analysis

8/6/2020 APH

8/7/2020 ABP



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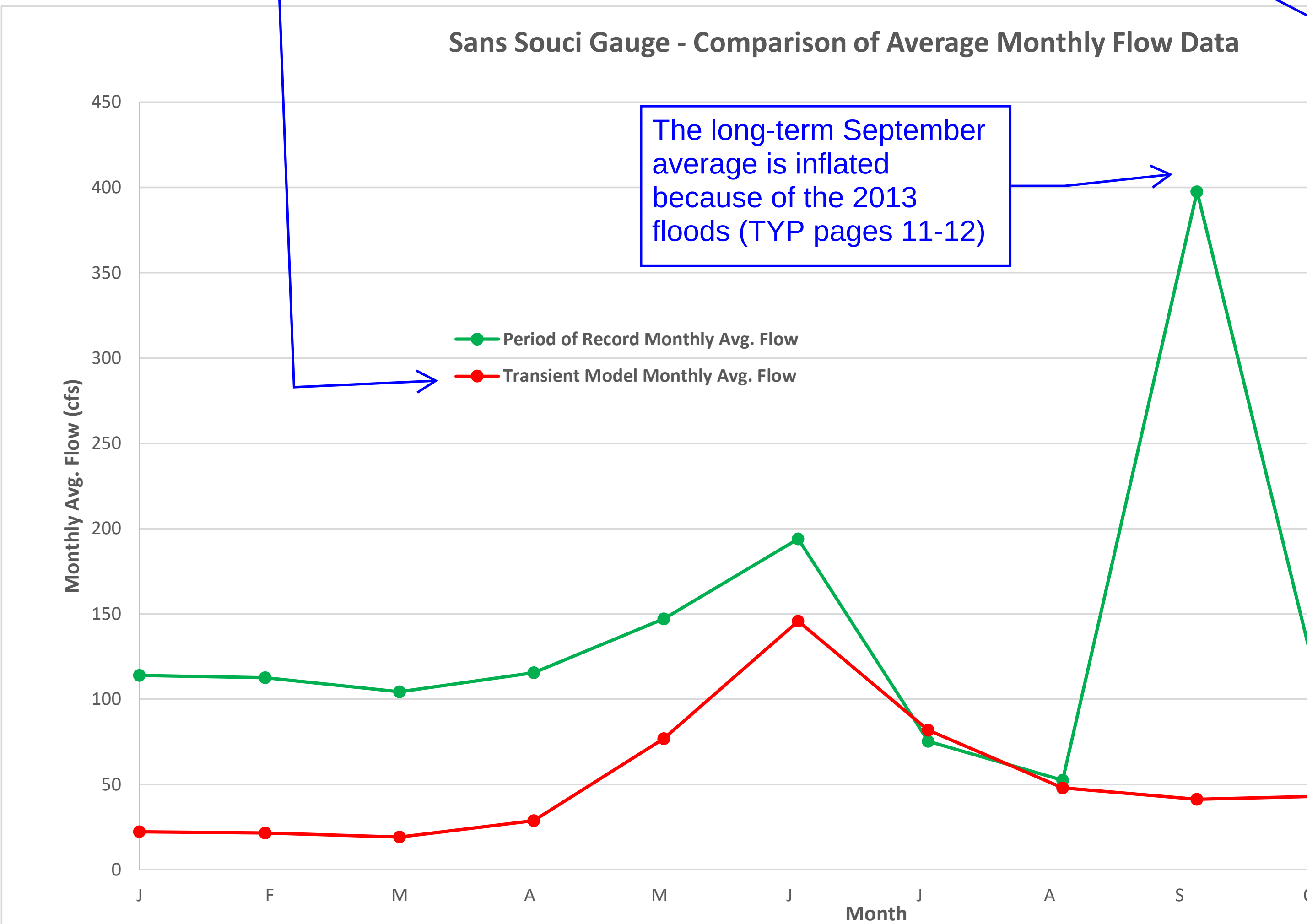
Appendix B

8/6/2020 APH

8/7/2020 ABP

The transient model period consists of November and December 2018, and January through October 2019 (TYP pages 11-14).

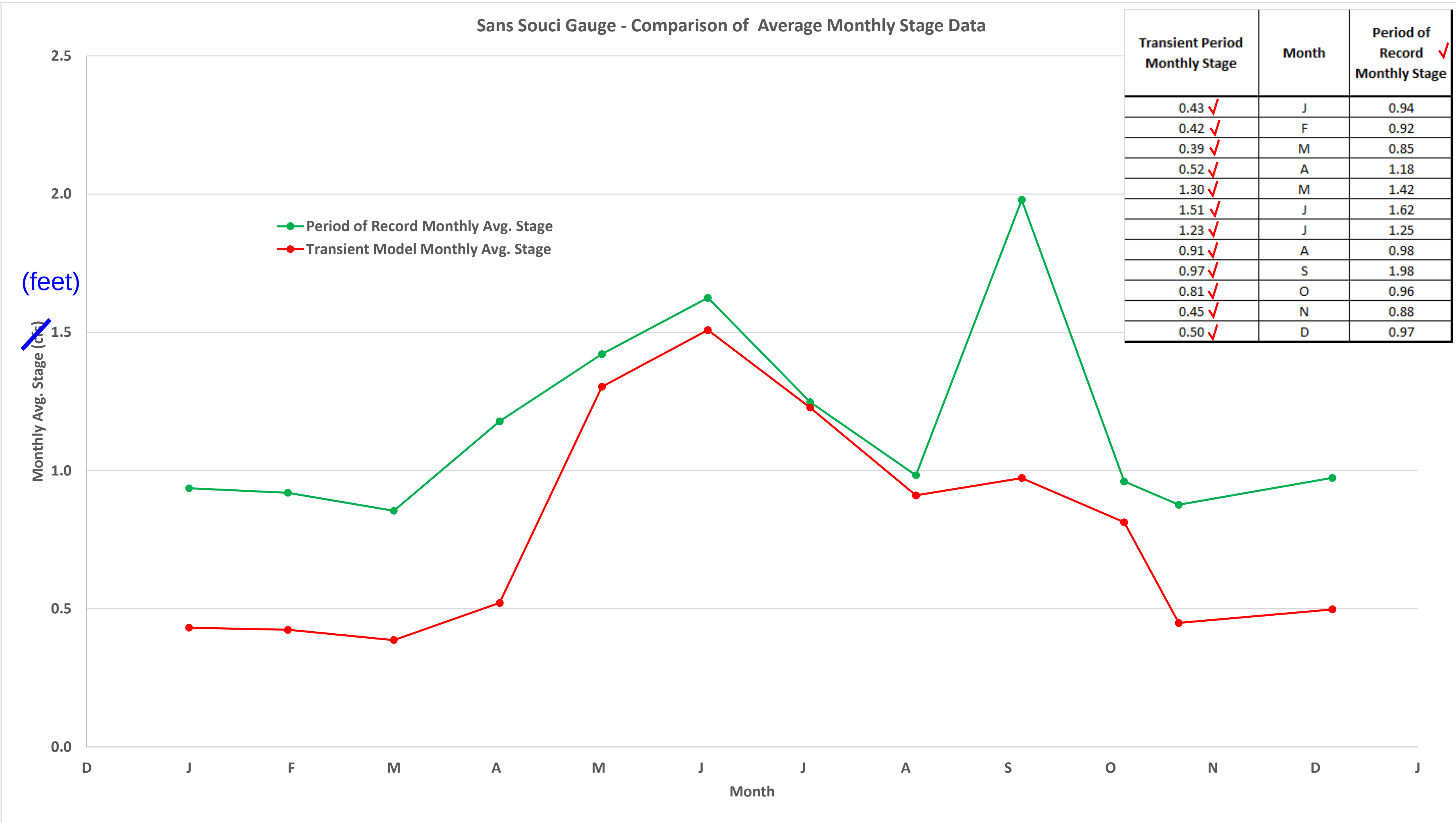


Transient Period Monthly Flows	Month	Period of Record Monthly Flows
22	J	114
21	F	113
19	M	104
29	A	115
77	M	147
146	J	194
82	J	75
48	A	52
41	S	398
43	O	86
24	N	115
27	D	125

Note: The Sans Souci gauge data was used to develop the flow input for the SFR boundary condition for reasons described elsewhere in this Report. The Sans Souci gauge data within the transient model time period (red line) is generally lower than the long-term average monthly flows (green line), however in our opinion it is appropriate to use this data in the model because it represents the stream flows during the same time period as the monitoring well data used for model calibration.

8/6/2020 APH

8/7/2020 ABP

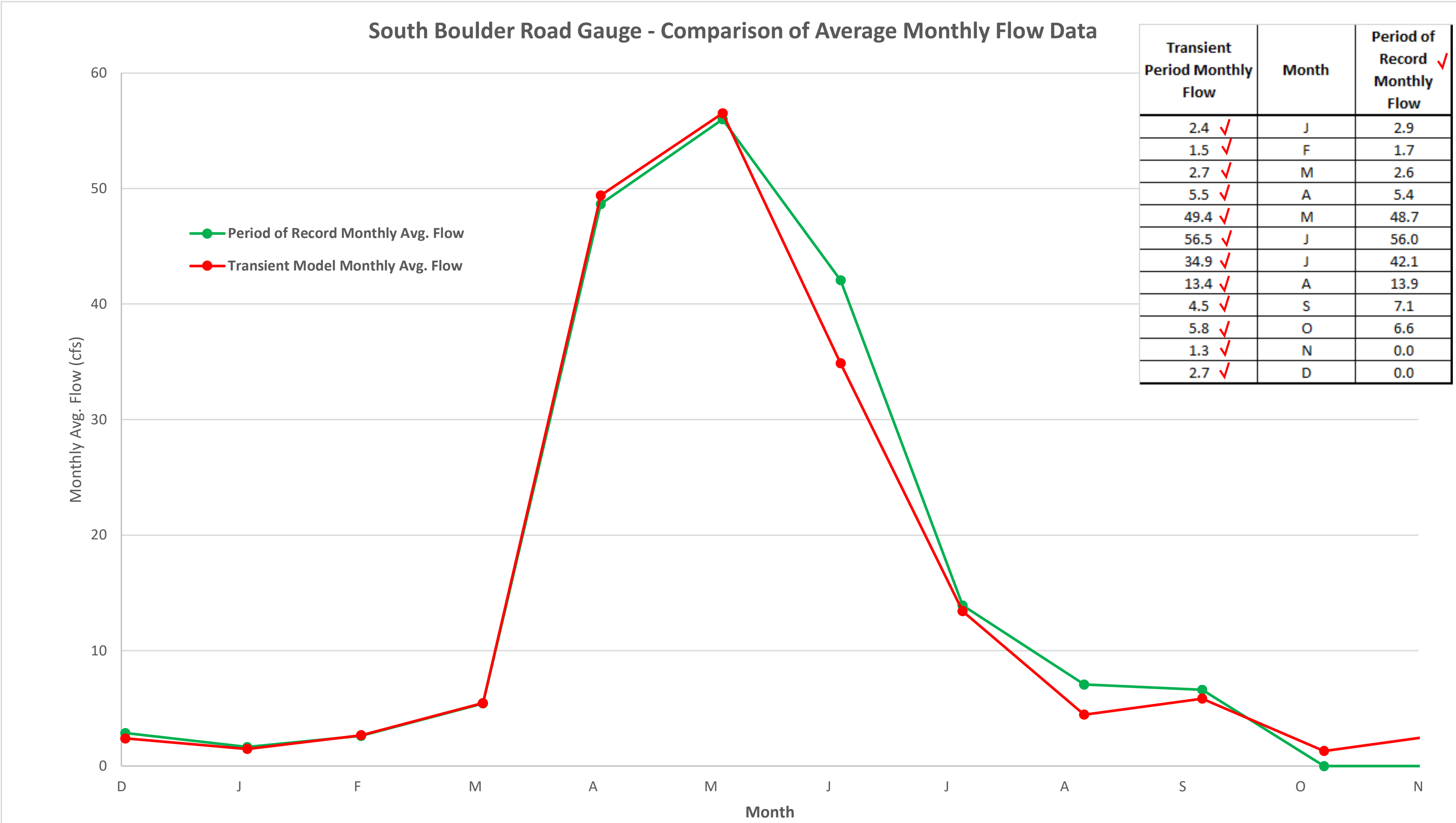


Transient Period Monthly Stage	Month	Period of Record √ Monthly Stage
0.43 √	J	0.94
0.42 √	F	0.92
0.39 √	M	0.85
0.52 √	A	1.18
1.30 √	M	1.42
1.51 √	J	1.62
1.23 √	J	1.25
0.91 √	A	0.98
0.97 √	S	1.98
0.81 √	O	0.96
0.45 √	N	0.88
0.50 √	D	0.97

SBR Flow Data_Analysis

8/6/2020 APH

8/7/2020 ABP



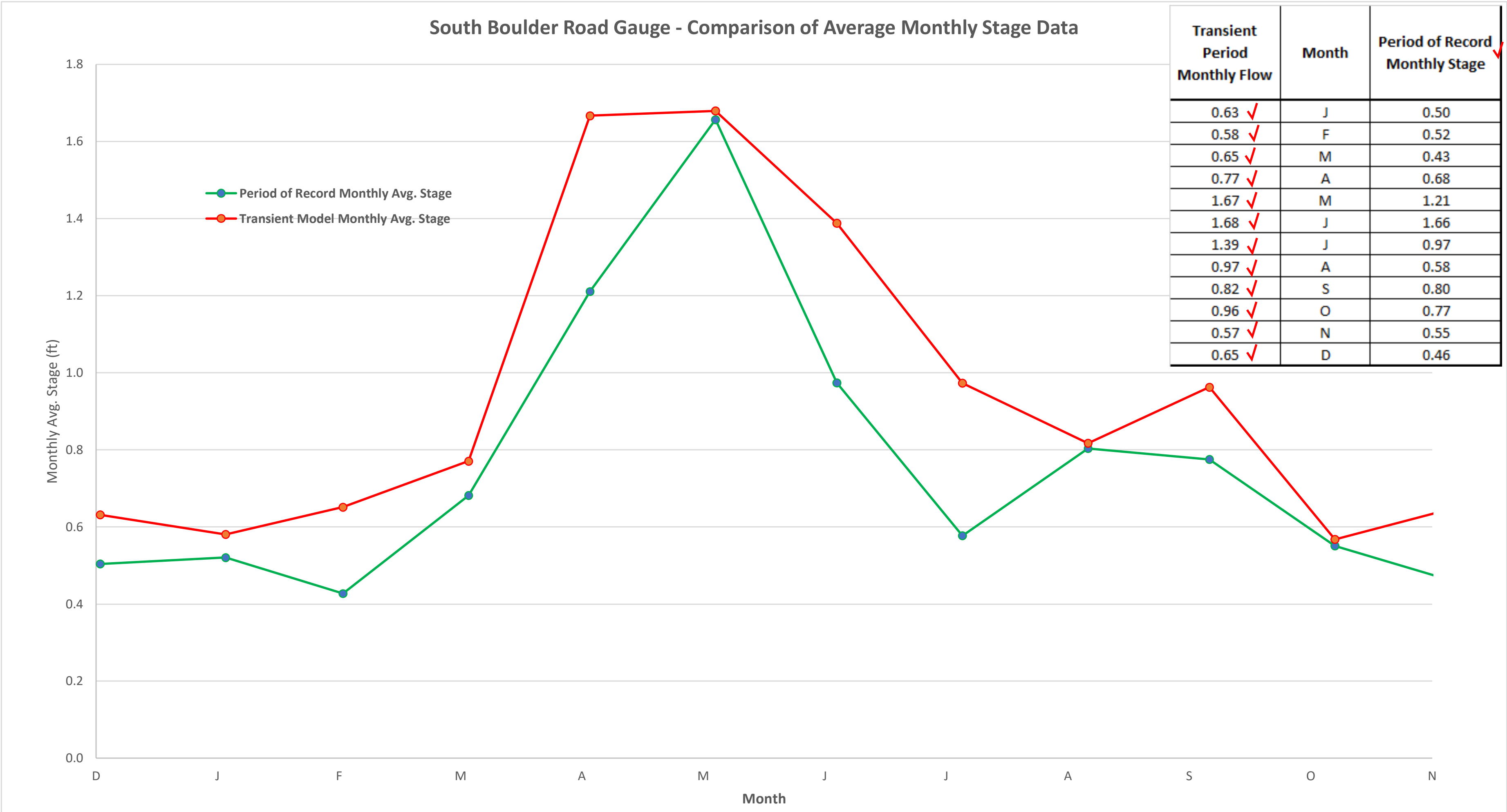
Transient Period Monthly Flow	Month	Period of Record √ Monthly Flow
2.4 √	J	2.9
1.5 √	F	1.7
2.7 √	M	2.6
5.5 √	A	5.4
49.4 √	M	48.7
56.5 √	J	56.0
34.9 √	J	42.1
13.4 √	A	13.9
4.5 √	S	7.1
5.8 √	O	6.6
1.3 √	N	0.0
2.7 √	D	0.0

P:\16134 - South Boulder Creek\Engineering\Geotechnical\Groundwater\Groundwater_Model\Data_Objects\Supporting_Files\16134_Flow_Stage_DataAnalysis

SBR Stage Data_Analysis

8/6/2020 APH

8/7/2020 ABP



Transient Period Monthly Flow	Month	Period of Record Monthly Stage
0.63	J	0.50
0.58	F	0.52
0.65	M	0.43
0.77	A	0.68
1.67	M	1.21
1.68	J	1.66
1.39	J	0.97
0.97	A	0.58
0.82	S	0.80
0.96	O	0.77
0.57	N	0.55
0.65	D	0.46

P:\16134 - South Boulder Creek\Engineering\Geotechnical\Groundwater\Groundwater_Model\Data_Objects\Supporting_Files\16134_Flow_Stage_DataAnalysis

APPENDIX C

DITCH DIVERSION RECORDS

RJH CONSULTANTS, INC.		Project	16134	Page	1/19
		Date	7/28/2020	By	JNH
Client	City of Boulder	Checked	7/29/2020	By	CLS
Subject	Ditch Diversions Records	Approved	7/29/20	By	ABP

Purpose:

To present the available monthly ditch diversions from South Boulder Creek for each ditch that ~~travels within~~ flows through the model extent and for ditch diversions that ~~pull~~ convey water away from the model extent (i.e., divert water to the east). Also present a comparison of average monthly diversions from 1991 through 2019 irrigation years, or from the most recent available data if more recent than 1991, to the 2019 irrigation year.

Note: An Irrigation Year extends from November of the previous calendar year to October of the current calendar year.

Approach:

The following were considered during the evaluation:

- The 2019 irrigation year corresponds to the baseline groundwater model time period.
- There is only one ditch diversion gauge on South Boulder Creek for the diversions to both Upper Bear Creek Ditch and S. Boulder and Bear Creek Ditch. The diversion gauge is named "South Boulder Bear Creek Ditch." The diversion volume to each ditch is unknown.
- Anderson Ditch (diversion gauge "Anderson Extension Ditch") is the only monitored ditch considered that transports water to South Boulder Creek; the remaining ditches divert water away from South Boulder Creek.

Methods:

1. Identify ditches that divert water to/from South Boulder Creek for ditches that ~~travel within~~ flow through the model extent and ditches that divert water away from the model extent.
2. Use historic and publicly available irrigation ditch data from Colorado's Decision Support Systems (CDSS) website at: https://dwr.state.co.us/Tools/Structures for ditches considered.
3. Compare the historical average monthly diversion (i.e., 1991 or most recent irrigation years to 2019) to the 2019 irrigation year monthly diversion.

Results:

- See p. 2-19 for tables of ditch diversion data and graphs comparing the historical average to the 2019 irrigation year monthly diversions.

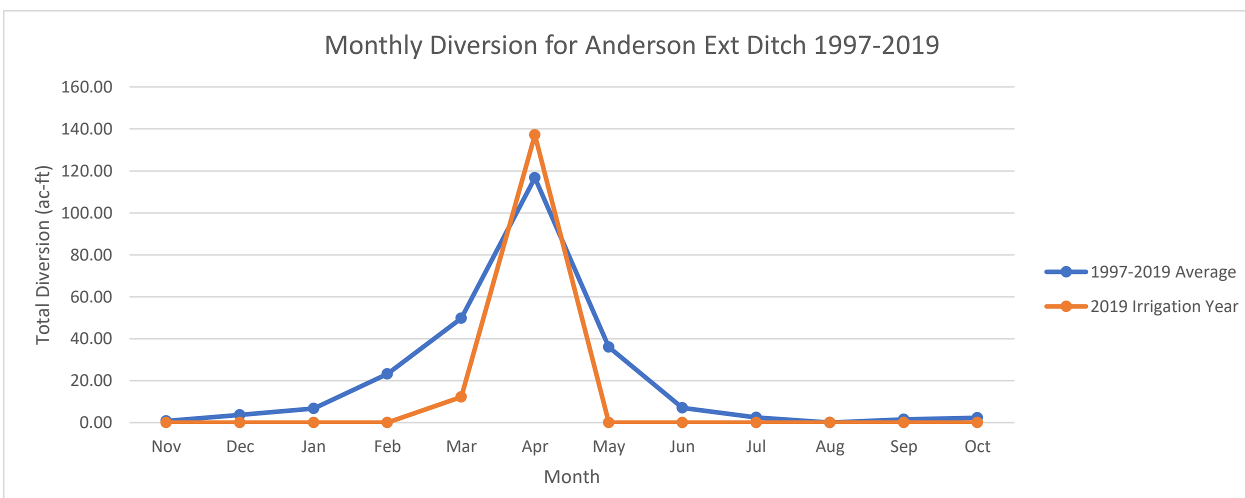
The results on pages 2-19 show that the ditch diversions during the 2019 irrigation year were generally similar to the magnitude and seasonal pattern of the historical average except for the following:
-New Dry Creek Carrier Ditch (page 13) diverted more water in May 2019 than the historical average. The diversion in May 2019 was similar to other high-diversion years, however the average is affected by many years when there were no diversions in May.
-South Boulder Bear Creek Ditch (page 15) had a peak diversion in August 2019, whereas the historical peak occurs in June. The August 2019 peak was similar in magnitude to the historical peak.

RJH Consultants, Inc.
16134 - South Boulder Creek
Anderson Extension Ditch Historic Monthly Flows

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/28/2020
Approved: ABP Date: 7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr																
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified	Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1997				8.19	50.1	238.62	31.28	94.61	32.37				455.17	AF	Approved	9/7/2005 15:16	455.17	0	
1998	15.43	70.57	15.87			174.41							276.28	AF	Approved	9/7/2005 15:16	276.28	0	
1999					4.78	172.45	196.64						373.87	AF	Approved	9/7/2005 15:16	373.87	0	
2000	0.48					24.22	6.55						31.24	AF	Approved	9/7/2005 15:16	31.25	0.01	
2001						104.11	105.15						209.26	AF	Approved	9/7/2005 15:16	209.26	0	
2003			7.91	29.16	78.47	308.85	61.59						485.98	AF	Approved	9/7/2005 15:16	485.98	0	
2004					1.67	77.42		39.59	14.94		28.76	43.48	205.85	AF	Approved	9/7/2005 15:16	205.86	0.01	
2005													4	AF	Approved	6/22/2006 11:15	0	-4	Reported Annual Amount does not match data for Irr Year, do not use
2006					19.1	8.57							27.67	AF	Approved	3/30/2010 17:56	27.67	0	
2007			75.99	139.88	169.13	115.62							500.62	AF	Approved	3/30/2010 17:56	500.62	0	
2008				4.3	7.1	2.98							14.38	AF	Approved	3/12/2009 14:40	14.38	0	
2009						222.21	39.67						261.88	AF	Approved	3/2/2010 7:01	261.88	0	
2010					46.12	151.28							197.4	AF	Approved	3/2/2011 10:51	197.4	0	
2011			5.95	75.53	179.65	87.61							348.74	AF	Approved	5/22/2012 11:31	348.74	0	
2012			14.72	183.73	322.52	93.09							614.05	AF	Approved	2/26/2013 9:11	614.06	0.01	
2013			6.94			132.46	153.7						293.1	AF	Approved	2/24/2014 10:20	293.1	0	
2016					55.14								55.14	AF	Approved	3/16/2017 7:40	55.14	0	
2018						167.01	91.24						258.25	AF	Approved	2/15/2019 11:25	258.25	0	
2019	0	0	0	0	12.3	137.26	0	0	0	0	0	0	149.56	AF	Approved	3/2/2020 15:30	149.56	0	
1997-2019 Mean	0.84	3.71	6.70	23.20	49.79	116.75	36.10	7.06	2.49	0.00	1.51	2.29							

Notes:
1. Blank cells mean no recorded flow. Blank cells were considered to be zero when calculating the average.
2. Data is from Colorado's Decision Support Systems (CDSS) website https://dwr.state.co.us/Tools/Structures/ and is reported as the total diversion for each month in acre-feet.



7/29/2020 CLS

RJH Consultants, Inc.
16134 - South Boulder Creek
Dry Creek No 2 Ditch Historic Monthly Flows

By:	JNH	Date:	7/28/2020
Checked:	CLS	Date:	7/28/2020
Approved:	ABP	Date:	7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr																	
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified		Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1950						218.19	392.73	614.89	495.88				1721.68	AF	Approved	8/14/2001 18:04		1721.69	0.01	
1951							220.17	323.31	658.52	168.6	43.64		1414.24	AF	Approved	8/14/2001 18:04		1414.24	0	
1952								1150.43	844.97	198.35			2193.75	AF	Approved	8/14/2001 18:04		2193.75	0	
1953							450.25	837.04	797.37	103.14			2187.8	AF	Approved	8/14/2001 18:04		2187.8	0	
1954						7.93	712.08	0	75.37				795.38	AF	Approved	8/14/2001 18:04		795.38	0	
1955							349.1	521.66	71.41	398.68	0		1340.85	AF	Approved	8/14/2001 18:04		1340.85	0	
1956							513.73	827.12	101.16	313.39			1755.4	AF	Approved	8/14/2001 18:04		1755.4	0	
1957								357.03	1200.02	995.72	119.01		2671.77	AF	Approved	8/14/2001 18:04		2671.78	0.01	
1958								733.9	277.69				1011.59	AF	Approved	8/14/2001 18:04		1011.59	0	
1959							85.29	597.03	735.88	138.85			1557.05	AF	Approved	8/14/2001 18:04		1557.05	0	
1960						55.54	238.02	852.91	737.86				1884.33	AF	Approved	8/14/2001 18:04		1884.33	0	
1961							37.69	771.58	860.84	99.18			1769.28	AF	Approved	8/14/2001 18:04		1769.29	0.01	
1962							997.7	741.83	646.62	35.7			2421.85	AF	Approved	8/14/2001 18:04		2421.85	0	
1963							503.81	678.36	13.88	19.84	362.98		1578.87	AF	Approved	8/14/2001 18:04		1578.87	0	
1964							612.9	561.33	604.97				1779.2	AF	Approved	8/14/2001 18:04		1779.2	0	
1965							327.28	775.55	593.07	87.27	180.5		1963.67	AF	Approved	8/14/2001 18:04		1963.67	0	
1966							531.58	747.78	97.19				1376.55	AF	Approved	8/14/2001 18:04		1376.55	0	
1967						386.78	368.93	99.18	55.54		283.64		1194.07	AF	Approved	8/14/2001 18:04		1194.07	0	
1968							273.72	658.52	307.44	178.52			1418.2	AF	Approved	8/14/2001 18:04		1418.2	0	
1969								214.22	491.91	39.67	69.42	59.51	874.72	AF	Approved	8/14/2001 18:04		874.73	0.01	
1970							646.62	763.65	404.63	7.93			1822.84	AF	Approved	8/14/2001 18:04		1822.83	-0.01	
1971							400.67	805.3	583.15	31.74			1820.85	AF	Approved	8/14/2001 18:04		1820.86	0.01	
1972							601	718.03	317.36	63.47			1699.86	AF	Approved	8/14/2001 18:04		1699.86	0	
1973								281.66	418.52	210.25			910.43	AF	Approved	8/14/2001 18:04		910.43	0	
1974							361	507.78	672.41	126.94			1668.12	AF	Approved	8/14/2001 18:04		1668.13	0.01	
1975							103.14	414.55	708.11	505.79			1731.6	AF	Approved	8/14/2001 18:04		1731.59	-0.01	
1976							400.67	545.46	515.71	370.91	35.7	61.49	1929.95	AF	Approved	8/14/2001 18:04		1929.94	-0.01	
1977							487.94	739.85	132.89	305.46	5.95		1672.09	AF	Approved	8/14/2001 18:04		1672.09	0	
1978						49.59	29.75	460.17	599.02	186.45			1324.98	AF	Approved	8/14/2001 18:04		1324.98	0	
1979								301.49	610.92	428.44	41.65		1382.5	AF	Approved	8/14/2001 18:04		1382.5	0	
1980								634.72	823.15	146.78			1604.65	AF	Approved	8/14/2001 18:04		1604.65	0	
1981								115.04					115.04	AF	Approved	8/14/2001 18:04		115.04	0	
1982							101.16	277.69	470.09	174.55			1023.49	AF	Approved	8/14/2001 18:04		1023.49	0	
1983							63.47	327.28	275.71	243.97	9.92		920.34	AF	Approved	8/14/2001 18:04		920.35	0.01	
1984						25.79	222.15	579.18	823.15	220.17			1870.44	AF	Approved	8/14/2001 18:04		1870.44	0	
1985						93.22	329.26	503.81	424.47	93.22			1443.99	AF	Approved	8/14/2001 18:04		1443.98	-0.01	
1986						57.52	307.44	299.51	241.99				906.46	AF	Approved	8/14/2001 18:04		906.46	0	
1987							111.87	252.78	163				527.65	AF	Approved	8/14/2001 18:04		527.65	0	
1988							75.06	347.23	137.42				559.7	AF	Approved	8/14/2001 18:04		559.71	0.01	
1989						26.04	231.67	215.71	119.98	23.8	34.95		652.15	AF	Approved	8/14/2001 18:04		652.15	0	
1990						46.41	87.97	369.35	281.58				785.31	AF	Approved	8/14/2001 18:04		785.31	0	
1991							80.23	505.79	311.51	184.25			1081.78	AF	Approved	8/14/2001 18:04		1081.78	0	
1992						35.31	313.53	229.81	229.17				807.82	AF	Approved	8/14/2001 18:04		807.82	0	
1993							101.63	318.15	243.79	48.6			712.18	AF	Approved	8/14/2001 18:04		712.17	-0.01	
1994							165.92	312.36	42.94				521.22	AF	Approved	8/14/2001 18:04		521.22	0	
1995								71.9	248.85	350.42			671.18	AF	Approved	8/14/2001 18:04		671.17	-0.01	
1996						51.33	361.16	337.12	251.43	85.05			1086.09	AF	Approved	8/14/2001 18:04		1086.09	0	
1997						56.65	123.35	277.99	240.1	164.39			862.49	AF	Approved	8/14/2001 18:04		862.48	-0.01	

7/29/2020 CLS

RJH Consultants, Inc.
16134 - South Boulder Creek
Dry Creek No 2 Ditch Historic Monthly Flows

By:	JNH
Date:	7/28/2020
Checked:	CLS
Date:	7/28/2020
Approved:	ABP
Date:	7/29/2020

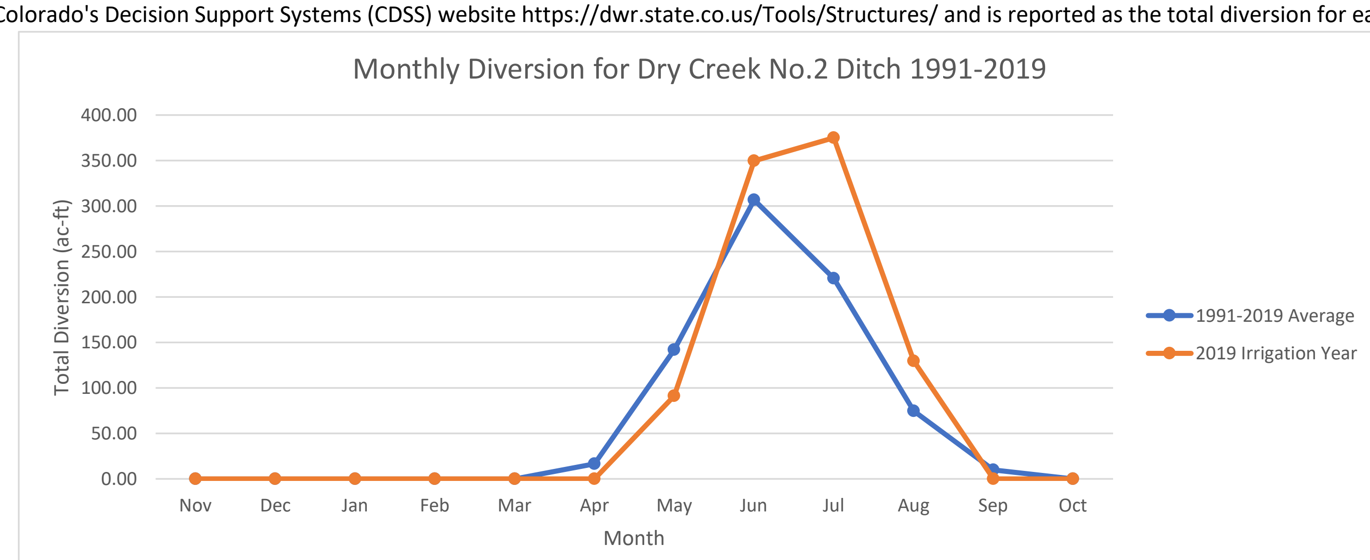
	Previous Calendar Yr		Irrigation Yr = Calendar Yr													
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified
1998							108.89	520.27	207.75	250.67			1087.59	AF	Approved	8/14/2001 18:04
1999						59.51	61.49	625.99	560.76	312.06	74.38		1694.19	AF	Approved	8/14/2001 18:04
2000						69.03	162.96	312.32	167.51				711.82	AF	Approved	8/14/2001 18:04
2001						23.09	228.3	308.04	91.24	31.74			682.4	AF	Approved	5/29/2002 15:57
2002						53.51	134.66	145.29					333.47	AF	Approved	8/8/2003 15:15
2003						64.48	88.4	340.25	187.66		81.32	3.97	766.09	AF	Approved	4/20/2004 17:08
2004							145.99	328.17	87.27	81.32			642.75	AF	Approved	4/6/2005 11:37
2005							245.76	413.08	160.66				819.5	AF	Approved	6/22/2006 11:13
2006							152.13	385.81	383.21				921.16	AF	Approved	3/30/2010 17:28
2007							130.87	371.99	237.62				740.48	AF	Approved	3/30/2010 17:29
2008							162.29	382.42	317.76	0			862.47	AF	Approved	3/12/2009 14:40
2009							178.1	235.01	259.34				672.45	AF	Approved	3/2/2010 7:01
2010							166.02	280.31	144.34	45.42			636.09	AF	Approved	3/2/2011 10:51
2011							286.77	343.92	224.99	109.57	25.47		990.72	AF	Approved	5/22/2012 11:31
2012						54.72	228.3	149.83	61.21	13.92			507.99	AF	Approved	2/26/2013 9:11
2013							75.89	331.13	327.81	66.23			801.06	AF	Approved	2/24/2014 10:20
2014							131.25	343.15	285.98	180.56	112.17		1053.1	AF	Approved	1/28/2015 10:21
2015								10.04	191.88	27.43			229.35	AF	Approved	1/28/2016 15:31
2016							28.76	223.8	156.14				408.7	AF	Approved	3/16/2017 7:40
2017						15.17	166.69	242.5	247.3	83.17			754.84	AF	Approved	3/9/2018 8:55
2018								197.77	146.34				344.12	AF	Approved	2/15/2019 11:25
2019	0	0	0	0	0	0	91.44	349.69	375.08	129.52	0	0	945.73	AF	Approved	3/2/2020 15:30
1991-2019 Mean	0.00	0.00	0.00	0.00	0.00	16.65	142.10	306.69	220.33	74.63	10.12	0.14				

Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1087.58	-0.01	
1694.19	0	
711.82	0	
682.41	0.01	
333.46	-0.01	
766.08	-0.01	
642.75	0	
819.5	0	
921.15	-0.01	
740.48	0	
862.47	0	
672.45	0	
636.09	0	
990.72	0	
507.98	-0.01	
801.06	0	
1053.11	0.01	
229.35	0	
408.7	0	
754.83	-0.01	
344.11	-0.01	
945.73	0	

Notes:

Blank cells were considered to be zero when calculating the average.

1. Blank cells mean no recorded flow.
2. Data is from Colorado's Decision Support Systems (CDSS) website https://dwr.state.co.us/Tools/Structures/ and is reported as the total diversion for each month in acre-feet.



RJH Consultants, Inc.
16134 - South Boulder Creek
East Boulder Ditch Historic Monthly Flows

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/28/2020
Approved: ABP Date: 7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr																
Irr Year	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Annual Amount**	**Units**	**Data Status**	**Modified**	**Irr Year Sum**	**Irr Year Sum - Annual Amounts**	**Notes**
1950						19.84	319.34	281.66	341.16	97.19	146.78	7.93	1213.9	AF	Approved	8/14/2001 18:04	1213.9	0	
1951							184.47	315.38	426.45	279.67	146.78	71.41	1424.15	AF	Approved	8/14/2001 18:04	1424.16	0.01	
1952							182.48	507.78	470.09	456.21	182.48		1799.03	AF	Approved	8/14/2001 18:04	1799.04	0.01	
1953							194.38	515.71	333.23	230.09			1273.41	AF	Approved	8/14/2001 18:04	1273.41	0	
1954					23.8	51.57	462.16	606.95	612.9	180.5	0		1937.88	AF	Approved	8/14/2001 18:04	1937.88	0	
1955						39.67	480.01	386.78	335.21	323.31	109.09	23.8	1697.88	AF	Approved	8/14/2001 18:04	1697.87	-0.01	
1956							339.18	440.34	317.36	299.51			1396.38	AF	Approved	8/14/2001 18:04	1396.39	0.01	
1957								188.43	327.28	295.54	156.7	41.65	1009.6	AF	Approved	8/14/2001 18:04	1009.6	0	
1958							134.88	245.95	493.89	299.51	19.84		1194.07	AF	Approved	8/14/2001 18:04	1194.07	0	
1959							132.89	452.24	412.57	289.59			1287.29	AF	Approved	8/14/2001 18:04	1287.29	0	
1960						81.32	210.25	456.21	378.85	220.17	111.08		1457.87	AF	Approved	8/14/2001 18:04	1457.88	0.01	
1961							297.53	279.67	339.18	438.35	99.18		1453.91	AF	Approved	8/14/2001 18:04	1453.91	0	
1962						109.09	335.21	476.04	448.27	75.37			1443.99	AF	Approved	8/14/2001 18:04	1443.98	-0.01	
1963						160.66	466.12	297.53	226.12	357.03	432.4	35.7	1975.57	AF	Approved	8/14/2001 18:04	1975.56	-0.01	
1964							370.91	384.8	438.35	293.56			1487.63	AF	Approved	8/14/2001 18:04	1487.62	-0.01	
1965						156.7	317.36	257.86	261.82	327.28	9.92		1330.93	AF	Approved	8/14/2001 18:04	1330.94	0.01	
1966						69.42	345.13	372.9	311.41	158.68	37.69		1295.23	AF	Approved	8/14/2001 18:04	1295.23	0	
1967						19.84	234.05	315.38	75.37	128.93	148.76	49.59	971.92	AF	Approved	8/14/2001 18:04	971.92	0	
1968							299.51	247.94	521.66	241.99	257.86	67.44	1636.39	AF	Approved	8/14/2001 18:04	1636.4	0.01	
1969						49.59	111.08	132.89	323.31	257.86	257.86	55.54	1188.12	AF	Approved	8/14/2001 18:04	1188.13	0.01	
1970							299.51	208.27	305.46	200.33	53.55	0	1067.12	AF	Approved	8/14/2001 18:04	1067.12	0	
1971						85.29	253.89	353.06	275.71	253.89	247.94		1469.77	AF	Approved	8/14/2001 18:04	1469.78	0.01	
1972						303.48	200.33	228.1	333.23	107.11	216.2	5.95	1394.4	AF	Approved	8/14/2001 18:04	1394.4	0	
1973							101.16	305.46	347.11	275.71	218.19	0	1247.62	AF	Approved	8/14/2001 18:04	1247.63	0.01	
1974							263.81	357.03	255.87	105.13			981.83	AF	Approved	8/14/2001 18:04	981.84	0.01	
1975							218.19	240	317.36	283.64	63.47		1122.66	AF	Approved	8/14/2001 18:04	1122.66	0	
1976							271.74	321.33	313.39	265.79	249.92	23.8	1445.97	AF	Approved	8/14/2001 18:04	1445.97	0	
1977							337.2	301.49	293.56	152.73	3.97		1088.94	AF	Approved	8/14/2001 18:04	1088.95	0.01	
1978							287.61	706.13	428.44	212.23			1634.4	AF	Approved	8/14/2001 18:04	1634.41	0.01	
1979							65.46	458.19	464.14	305.46	113.06		1406.3	AF	Approved	8/14/2001 18:04	1406.31	0.01	
1980							7.93	323.31	285.62	91.24			708.11	AF	Approved	8/14/2001 18:04	708.1	-0.01	
1981						61.49	323.31	362.98	283.64	55.54			1086.96	AF	Approved	8/14/2001 18:04	1086.96	0	
1982						81.32	464.14	507.78	341.16	261.82	166.61		1822.84	AF	Approved	8/14/2001 18:04	1822.83	-0.01	
1983							321.33	130.91	414.55	194.38			1061.17	AF	Approved	8/14/2001 18:04	1061.17	0	
1984							150.75	273.72	194.38	251.9	0		870.76	AF	Approved	8/14/2001 18:04	870.75	-0.01	
1985						128.93	228.1	329.26	240	144.8			1071.09	AF	Approved	8/14/2001 18:04	1071.09	0	
1986						93.22	480.01	517.69	382.82				1473.74	AF	Approved	8/14/2001 18:04	1473.74	0	
1987						25.19	106.06	384.56	131.63	84.18	25.63		757.24	AF	Approved	8/14/2001 18:04	757.25	0.01	
1988							154.73	56.95	216.1	149.69			577.48	AF	Approved	8/14/2001 18:04	577.47	-0.01	
1989						82.61	231.97	534.24	388.87	285.47			1523.15	AF	Approved	8/14/2001 18:04	1523.16	0.01	
1990							169.33	184.51	274.5	266.36	394.9	191.47	1481.06	AF	Approved	8/14/2001 18:04	1481.07	0.01	
1991						40.32	85.96	123.61	420.01	312.76			982.67	AF	Approved	8/14/2001 18:04	982.66	-0.01	
1992						22.22	137.73	152.59	348.6	137.52	155.9		954.56	AF	Approved	8/14/2001 18:04	954.56	0	
1993						27.33	60.22	91.97	77.85	280.43	167.45		705.25	AF	Approved	8/14/2001 18:04	705.25	0	
1994						74.34	63.85	101.56	243.89	198.77			682.4	AF	Approved	8/14/2001 18:04	682.41	0.01	
1995						53.89	88.13	100.56	111.43	113.3	93.86		561.17	AF	Approved	8/14/2001 18:04	561.17	0	
1996						11.5	109.77	130.63	102.75	43.4			398.05	AF	Approved	8/14/2001 18:04	398.05	0	
1997						40.28	70.95	252.08	221.16	341.92	125.97	37.65	1090.01	AF	Approved	8/14/2001 18:04	1090.01	0	

RJH Consultants, Inc.
16134 - South Boulder Creek
East Boulder Ditch Historic Monthly Flows

By:	JNH	Date:	7/28/2020
Checked:	CLS	Date:	7/28/2020
Approved:	ABP	Date:	7/29/2020

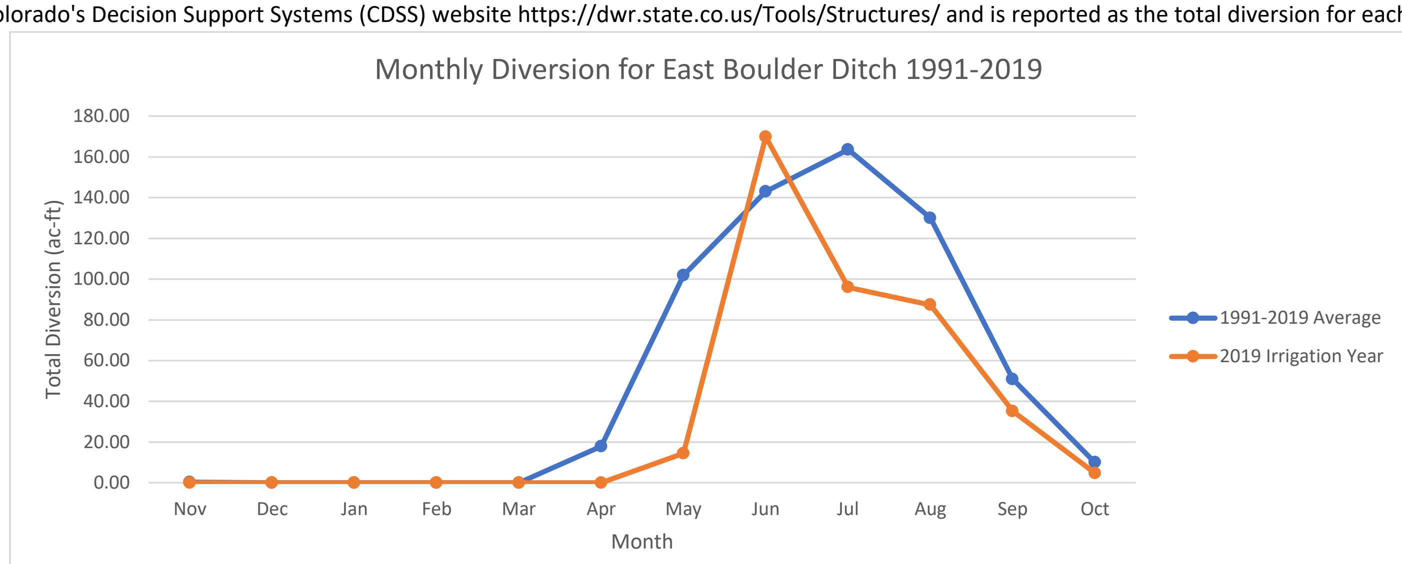
	Previous Calendar Yr		Irrigation Yr = Calendar Yr													
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified
1998							89.3	124.68	270.99	232.33	236.93	77.18	1031.4	AF	Approved	8/14/2001 18:04
1999						1.37	1.05	127.92	86.08	175.1	103.86	39.49	534.87	AF	Approved	8/14/2001 18:04
2000							194.92	223.94	110.88				529.73	AF	Approved	8/14/2001 18:04
2001							66.57	162.81	137.36	148.25			514.98	AF	Approved	5/29/2002 15:57
2002						68.31	181.57	168.76	96				514.64	AF	Approved	8/8/2003 15:15
2003						52.42	304.19	297.49	241.35	39.11			934.57	AF	Approved	4/20/2004 17:08
2004						9.28	141.34	174.92	148.43	163.5	0		637.48	AF	Approved	4/6/2005 11:37
2005						23.8	43.99	112.37	117.86	153.28	7.4		458.7	AF	Approved	6/22/2006 11:13
2006							205.19	195.65	198.49	153.32			752.66	AF	Approved	3/30/2010 17:29
2007							320.91	181.89	232.35	88.48	77.46		901.08	AF	Approved	3/30/2010 17:30
2008							106.63	128.93	135.12	184.84	150.75	30.13	736.39	AF	Approved	3/12/2009 14:40
2009							174.77	183.16	164.57	96.62	17.61		636.72	AF	Approved	3/2/2010 7:01
2010							28.21	118.89	176.29	101.34	0		424.73	AF	Approved	3/2/2011 10:51
2011						13.77	81.52	146.78	177.58	122.92	82.37	16.13	641.07	AF	Approved	5/22/2012 11:31
2012						54.19	105.13	93.26	114.84	33.18	16.58		417.19	AF	Approved	2/26/2013 9:11
2013						1.79	135.53	150.39	109.81	125.91	50.86		574.28	AF	Approved	2/24/2014 10:20
2014								51.55	118.83	95.09	83.07	83.94	432.48	AF	Approved	1/28/2015 10:21
2015	10.91							78.43	184.03	103.84			377.2	AF	Approved	1/28/2016 15:31
2016						18.29	31.12	116.19	148.8	78.25			392.65	AF	Approved	3/16/2017 7:40
2017						6.96	84.18	124.62	92.63	97.67	16.07		422.13	AF	Approved	3/9/2018 8:55
2018							26.28	60.04	58.26	61.71	53.61		259.9	AF	Approved	2/15/2019 11:25
2019	0	0	0	0	0	0	14.48	169.77	96	87.37	35.11	4.76	407.49	AF	Approved	3/2/2020 15:30
1991-2019 Mean	0.38	0.00	0.00	0.00	0.00	17.93	101.84	142.95	163.53	130.01	50.86	9.98				

Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1031.41	0.01	
534.87	0	
529.74	0.01	
514.99	0.01	
514.64	0	
934.56	-0.01	
637.47	-0.01	
458.7	0	
752.65	-0.01	
901.09	0.01	
736.4	0.01	
636.73	0.01	
424.73	0	
641.07	0	
417.18	-0.01	
574.29	0.01	
432.48	0	
377.21	0.01	
392.65	0	
422.13	0	
259.9	0	
407.49	0	

Notes:
1. Blank cells mean no recorded flow.

Blank cells were considered to be zero when calculating the average.

2. Data is from Colorado's Decision Support Systems (CDSS) website https://dwr.state.co.us/Tools/Structures/ and is reported as the total diversion for each month in acre-feet.



RJH Consultants, Inc.
16134 - South Boulder Creek
Howard Ditch Historic Monthly Flows

By:	JNH	Date:	7/28/2020
Checked:	CLS	Date:	7/28/2020
Approved:	ABP	Date:	7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr																	
Irr Year	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Annual Amount**	**Units**	**Data Status**	**Modified**		**Irr Year Su**	**Irr Year Sum - Annual Amounts**	**Notes**
1950						192.4	305.46	557.36	922.33	811.25	444.3	134.88	3367.98	AF	Approved	8/14/2001 18:04		3367.98	0	
1951	3.97						559.35	702.16	618.85	303.48	487.94	79.34	2755.08	AF	Approved	8/14/2001 18:04		2755.09	0.01	
1952							291.57	688.27	529.59	841	343.15	105.13	2798.72	AF	Approved	8/14/2001 18:04		2798.71	-0.01	
1953					23.8	17.85	392.73	946.13	723.98	527.61	315.38	230.09	3177.57	AF	Approved	8/14/2001 18:04		3177.57	0	
1954						249.92	341.16	819.19	575.22	347.11	263.81	31.74	2628.14	AF	Approved	8/14/2001 18:04		2628.15	0.01	
1955						210.25	257.86	517.69	1025.47	704.14	481.99	107.11	3304.51	AF	Approved	8/14/2001 18:04		3304.51	0	
1956						23.8	341.16	628.77	416.54	299.51	265.79	257.86	2233.42	AF	Approved	8/14/2001 18:04		2233.43	0.01	
1957	0						51.57	533.56	991.75	446.29	174.55	194.38	2392.1	AF	Approved	8/14/2001 18:04		2392.1	0	
1958						39.67	77.36	642.65	470.09	511.74	357.03	234.05	2332.6	AF	Approved	8/14/2001 18:04		2332.59	-0.01	
1959							87.27	995.72	938.2	674.39	319.34	0	3014.92	AF	Approved	8/14/2001 18:04		3014.92	0	
1960						180.5	220.17	745.8	872.74	894.56	464.14	182.48	3560.38	AF	Approved	8/14/2001 18:04		3560.39	0.01	
1961							206.28	1203.98	938.2	543.48	134.88	0	3026.82	AF	Approved	8/14/2001 18:04		3026.82	0	
1962						39.67	638.69	549.43	527.61	527.61	450.25	154.71	2887.98	AF	Approved	8/14/2001 18:04		2887.97	-0.01	
1963	144.8					299.51	727.94	505.79	904.48	452.24	269.76	194.38	3498.89	AF	Approved	8/14/2001 18:04		3498.9	0.01	
1964	0					101.16	702.16	345.13	626.79	595.05	368.93	434.39	3173.6	AF	Approved	8/14/2001 18:04		3173.61	0.01	
1965	61.49					166.61	539.51	361	549.43	390.75	243.97	196.37	2509.13	AF	Approved	8/14/2001 18:04		2509.13	0	
1966							450.25	589.1	593.07	480.01	478.02	117.03	2707.48	AF	Approved	8/14/2001 18:04		2707.48	0	
1967						174.55	156.7	39.67	186.45	531.58	158.68	275.71	1523.33	AF	Approved	8/14/2001 18:04		1523.34	0.01	
1968						29.75	230.09	690.26	491.91	351.08	426.45	253.89	2473.42	AF	Approved	8/14/2001 18:04		2473.43	0.01	
1969						154.71	55.54	261.82	567.28	733.9	424.47	111.08	2308.79	AF	Approved	8/14/2001 18:04		2308.8	0.01	
1970							440.34	376.87	466.12	472.07	466.12		2221.52	AF	Approved	8/14/2001 18:04		2221.52	0	
1971						35.7	166.61	527.61	450.25	370.91	172.56		1723.66	AF	Approved	8/14/2001 18:04		1723.64	-0.02	
1972						101.16	230.09	372.9	196.37	622.82	194.38	148.76	1866.47	AF	Approved	8/14/2001 18:04		1866.48	0.01	
1973							23.8	243.97	216.2	438.35	287.61		1209.94	AF	Approved	8/14/2001 18:04		1209.93	-0.01	
1974							188.43	361	527.61	444.3	345.13	51.57	1918.04	AF	Approved	8/14/2001 18:04		1918.04	0	
1975							154.71	166.61	523.64	539.51	398.68	57.52	1840.69	AF	Approved	8/14/2001 18:04		1840.67	-0.02	
1976						55.54	295.54	335.21	357.03	337.2	311.41	69.42	1761.35	AF	Approved	8/14/2001 18:04		1761.35	0	
1977							228.1	295.54	287.61	263.81	224.14	174.55	1473.74	AF	Approved	8/14/2001 18:04		1473.75	0.01	
1978						39.67	37.69	253.89	299.51	323.31	212.23	55.54	1221.84	AF	Approved	8/14/2001 18:04		1221.84	0	
1979							55.54	148.76	182.48	222.15	224.14	95.21	928.28	AF	Approved	8/14/2001 18:04		928.28	0	
1980							7.93	501.83	204.3	357.03	230.09	87.27	1388.45	AF	Approved	8/14/2001 18:04		1388.45	0	
1981						63.47	154.71	158.68	180.5	291.57	230.09	101.16	1180.18	AF	Approved	8/14/2001 18:04		1180.18	0	
1982						79.34	174.55	166.61	230.09	142.81	180.5	71.41	1045.3	AF	Approved	8/14/2001 18:04		1045.31	0.01	
1983							109.09	214.22	174.55	198.35	238.02	67.44	1001.67	AF	Approved	8/14/2001 18:04		1001.67	0	
1984	51.57					39.67	329.26	295.54	281.66	353.06	228.1	29.75	1608.62	AF	Approved	8/14/2001 18:04		1608.61	-0.01	
1985						99.18	337.2	283.64	303.48	206.28	241.99	29.75	1501.51	AF	Approved	8/14/2001 18:04		1501.52	0.01	
1986						57.52	144.8	174.55	372.9	424.47	263.81	0	1438.04	AF	Approved	8/14/2001 18:04		1438.05	0.01	
1987							158.22	188.97	229.49	387.85	366.51	162.83	1493.87	AF	Approved	8/14/2001 18:04		1493.87	0	
1988						9.42	166.73	193.61	184.7	197.36	100.82	35.43	888.07	AF	Approved	8/14/2001 18:04		888.07	0	
1989						175.62	153.34	175.84	181.77	156.91	69.5	33.7	946.68	AF	Approved	8/14/2001 18:04		946.68	0	
1990						58.43	115.62	305.64	299.85	177.46	155.51	136.98	1249.49	AF	Approved	8/14/2001 18:04		1249.49	0	
1991						123.99	95.51	125.08	167.72	191.43	141.46	141.46	986.65	AF	Approved	8/26/2009 12:26		986.65	0	
1992						13.41	316.05	160.41	208.6	187.54	164.33	65.42	1115.76	AF	Approved	8/14/2001 18:04		1115.76	0	
1993						143.21	188.27	275.89	191.51	171.22	191.25	128.51	1289.85	AF	Approved	8/14/2001 18:04		1289.86	0.01	
1994						71.01	173.52	257.02	254.15	356.87	610.96	397.26	2120.78	AF	Approved	8/14/2001 18:04		2120.79	0.01	
1995						47.52	72.7	142.26	237.56	318.61	314.38	23.29	1156.32	AF	Approved	8/14/2001 18:04		1156.32	0	
1996						91.36	281.18	330.85	308.3	246.41	246.69	213.52	1718.31	AF	Approved	8/14/2001 18:04		1718.31	0	

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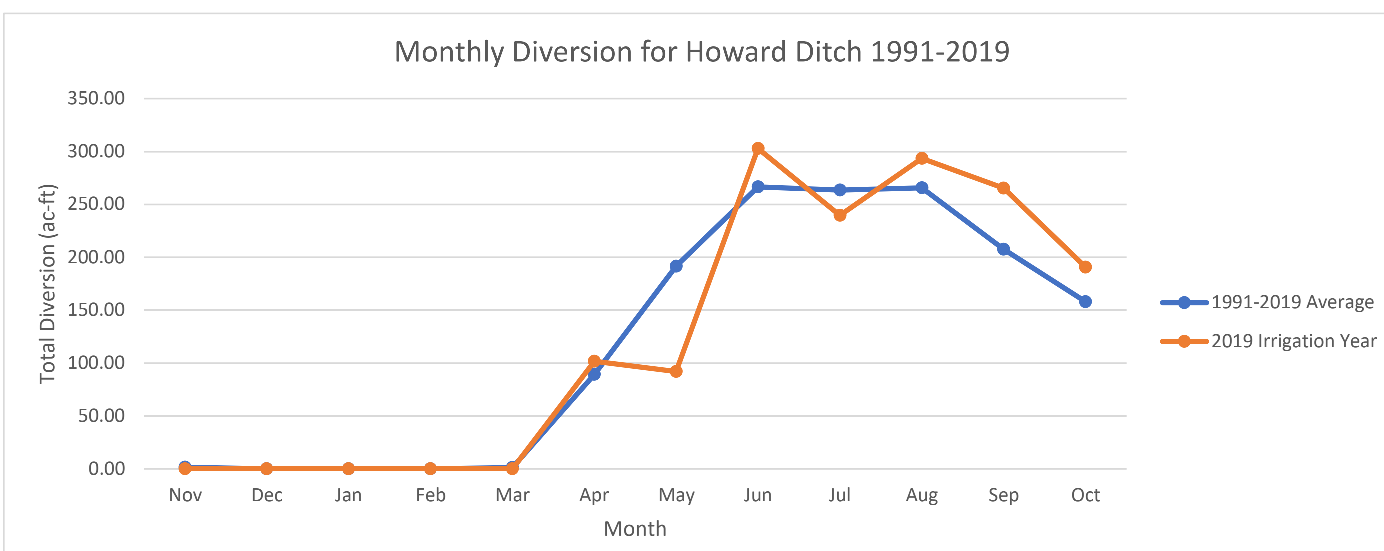
	Previous Calendar Yr		Irrigation Yr = Calendar Yr																
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified	Irr Year Su	Irr Year Sum - Annual Amounts	Notes
1997						117.03	213.52	230.19	365.2	259.36	266.27	249.25	1700.81	AF	Approved	8/14/2001 18:04	1700.82	0.01	
1998						98.96	331.48	356.14	257.54	303.69	291.04	208.74	1847.59	AF	Approved	8/14/2001 18:04	1847.59	0	
1999						63.49	199	315.57	277.35	199.04	153.82	172.8	1381.09	AF	Approved	8/14/2001 18:04	1381.07	-0.02	
2000						40.38	142.36	225.8	277.31	204.64	107.17	119.17	1116.83	AF	Approved	8/14/2001 18:04	1116.83	0	
2001						44.51	289.89	419.37	385.73	482.92	220.49	254.92	2097.83	AF	Approved	5/29/2002 15:57	2097.83	0	
2002						103.88	164.95	252.2	362.8	123.18	176.67	206.03	1389.7	AF	Approved	8/8/2003 15:15	1389.71	0.01	
2003						43.16	148.13	247.14	367.76	367.44	114.35	74.92	1362.9	AF	Approved	4/20/2004 17:08	1362.9	0	
2004						69.24	211.22	389.52	93.92	109.79	217.71	100.09	1191.49	AF	Approved	4/6/2005 11:37	1191.49	0	
2005						139.4	201.7	304.71	147.83	239.53	135.83	166.75	1335.75	AF	Approved	6/22/2006 11:13	1335.75	0	
2006						123.23	223.22	262.06	251.03	257.58	88.74	61.77	1267.64	AF	Approved	4/2/2007 13:37	1267.63	-0.01	
2007	0					34.89	163.48	180.32	303.95	265.89	218.24	153.42	1320.2	AF	Approved	2/12/2009 12:11	1320.19	-0.01	
2008						53.16	188.99	237.37	270.13	265.55	231.49	205.61	1452.3	AF	Approved	3/12/2009 14:40	1452.3	0	
2009					40.42	59.09	268.21	238.4	263.27	178.1	162.87	164.95	1375.3	AF	Approved	3/2/2010 7:01	1375.31	0.01	
2010						64.25	161	370.12	206.52	339.87	252.46	206.66	1600.88	AF	Approved	3/2/2011 10:51	1600.88	0	
2011						124.6	180.5	274.02	177.9	276.7	206.66	143.96	1384.34	AF	Approved	5/22/2012 11:31	1384.34	0	
2012						176.59	262.22	220.37	268.57	360.82	243.18	166.99	1698.73	AF	Approved	2/26/2013 9:11	1698.74	0.01	
2013						121.83	236.37	334.4	346.76	315.24	91.72		1446.31	AF	Approved	2/24/2014 10:20	1446.32	0.01	
2014						85.59	162.67	296.3	289.37	232.82	158.01	95.7	1320.46	AF	Approved	1/28/2015 10:21	1320.46	0	
2015						114.67	129.5	162.61	212	231.81	197.56	187.92	1236.06	AF	Approved	1/28/2016 15:31	1236.07	0.01	
2016	31					104.79	125.99	286.93	209.95	277.23	172.07	154.53	1362.51	AF	Approved	3/16/2017 7:40	1362.49	-0.02	
2017	14					132.64	206.9	238.6	339.6	272.53	175.02	174.23	1553.52	AF	Approved	3/9/2018 8:55	1553.52	0	
2018						84.38	129.15	295.12	362.64	377.56	203.92	155.41	1608.18	AF	Approved	2/15/2019 11:25	1608.18	0	
2019	0	0	0	0	0	101.85	91.97	302.88	239.55	293.46	265.25	190.71	1485.68	AF	Approved	3/2/2020 15:30	1485.67	-0.01	
1991-2019 Mean	1.55	0.00	0.00	0.00	1.39	89.38	191.71	266.61	263.60	265.75	207.57	158.07							

Notes:
1. Blank cells mean no recorded flow.
2. Data is from Colorado's Decision Support Systems (CDSS) website https://dwr.state.co.us/Tools/Structures/ and is reported as the total diversion for each month in acre-feet.

Blank cells were considered to be zero when calculating the average.



RJH Consultants, Inc.
16134 - South Boulder Creek
Marshallville Ditch Historic Monthly Flows

By:	JNH	Date:	7/28/2020
Checked:	CLS	Date:	7/28/2020
Approved:	ABP	Date:	7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr																	
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified		Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1950							230.09	783.48	87.27				1100.84	AF	Approved	8/14/2001 18:04		1100.84	0	
1951							208.27	813.24	874.72	97.19			1993.42	AF	Approved	8/14/2001 18:04		1993.42	0	
1952								666.46	529.59	35.7			1231.75	AF	Approved	8/14/2001 18:04		1231.75	0	
1953							370.91	892.58	159.67	13.88			1437.05	AF	Approved	8/14/2001 18:04		1437.04	-0.01	
1954							200.33						200.33	AF	Approved	8/14/2001 18:04		200.33	0	
1955							386.78	860.84	119.01				1366.63	AF	Approved	8/14/2001 18:04		1366.63	0	
1956							412.57	751.75	19.84				1184.15	AF	Approved	8/14/2001 18:04		1184.16	0.01	
1957								329.26	900.51	134.88			1364.65	AF	Approved	8/14/2001 18:04		1364.65	0	
1958								501.83	89.26				591.08	AF	Approved	8/14/2001 18:04		591.09	0.01	
1959								825.14	324.3				1149.44	AF	Approved	8/14/2001 18:04		1149.44	0	
1960							107.11	995.72	467.11	19.84			1589.78	AF	Approved	8/14/2001 18:04		1589.78	0	
1961								426.45	359.01				785.47	AF	Approved	8/14/2001 18:04		785.46	-0.01	
1962						5.95	654.56	531.58	368.93	48.6			1609.61	AF	Approved	8/14/2001 18:04		1609.62	0.01	
1963							382.82	351.08					733.9	AF	Approved	8/14/2001 18:04		733.9	0	
1964						17.85	462.16	424.47	238.02				1142.5	AF	Approved	8/14/2001 18:04		1142.5	0	
1965							89.26	430.42	654.56	63.47			1237.7	AF	Approved	8/14/2001 18:04		1237.71	0.01	
1966							230.09	591.08	21.82				842.99	AF	Approved	8/14/2001 18:04		842.99	0	
1967							259.84	190.42					450.25	AF	Approved	8/14/2001 18:04		450.26	0.01	
1968							105.13	793.4	539.51	67.44			1505.48	AF	Approved	8/14/2001 18:04		1505.48	0	
1969								380.83	450.25				831.09	AF	Approved	8/14/2001 18:04		831.08	-0.01	
1970							329.26	307.44	271.74				908.44	AF	Approved	8/14/2001 18:04		908.44	0	
1971								541.5	648.6				1190.1	AF	Approved	8/14/2001 18:04		1190.1	0	
1972							394.72	414.55	148.76				958.03	AF	Approved	8/14/2001 18:04		958.03	0	
1973							71.41	307.44	472.07	25.79			876.71	AF	Approved	8/14/2001 18:04		876.71	0	
1974							567.28	412.57	801.33	7.93			1789.12	AF	Approved	8/14/2001 18:04		1789.11	-0.01	
1975							412.57	422.49	692.24	47.6			1574.9	AF	Approved	8/14/2001 18:04		1574.9	0	
1976							670.42	795.38	91.24	105.13			1662.17	AF	Approved	8/14/2001 18:04		1662.17	0	
1977						47.6	485.96	509.76					1043.32	AF	Approved	8/14/2001 18:04		1043.32	0	
1978						51.57	327.28	702.16	545.46				1626.47	AF	Approved	8/14/2001 18:04		1626.47	0	
1979							238.02	261.82	557.36	61.49			1118.69	AF	Approved	8/14/2001 18:04		1118.69	0	
1980							35.7	676.37	541.5				1253.57	AF	Approved	8/14/2001 18:04		1253.57	0	
1981						103.14	192.4	119.01					414.55	AF	Approved	8/14/2001 18:04		414.55	0	
1982							232.07	723.98	366.95				1322.99	AF	Approved	8/14/2001 18:04		1323	0.01	
1983							33.72		263.81	103.14			400.67	AF	Approved	8/14/2001 18:04		400.67	0	
1984							83.31	301.49	422.49	69.42			876.71	AF	Approved	8/14/2001 18:04		876.71	0	
1985							222.15	351.08					573.23	AF	Approved	8/14/2001 18:04		573.23	0	
1986							156.7	585.13	238.02				979.85	AF	Approved	8/14/2001 18:04		979.85	0	
1987							130.77	577.06					707.83	AF	Approved	8/14/2001 18:04		707.83	0	
1988							502.84	544.27	83.33				1130.44	AF	Approved	8/14/2001 18:04		1130.44	0	
1989						80.65	638.89	201.4	65				985.94	AF	Approved	8/14/2001 18:04		985.94	0	
1990						3.17	308.26	728.74	190.26				1230.42	AF	Approved	8/14/2001 18:04		1230.43	0.01	
1991							316.43	438.16	203.07	18.11			975.76	AF	Approved	8/14/2001 18:04		975.77	0.01	
1992						28.03	457.47	311.15	142	75.59	0	5.95	1020.19	AF	Approved	8/14/2001 18:04		1020.19	0	
1993							144.04	802.88	496.03	8.09			1451.05	AF	Approved	8/14/2001 18:04		1451.04	-0.01	
1994							265.17	877.86		17.67			1160.7	AF	Approved	8/14/2001 18:04		1160.7	0	
1995							145.37	84.72	623.22	247.18			1100.49	AF	Approved	8/14/2001 18:04		1100.49	0	
1996						28.96	921.73	757.7	544.97	11.8		43.24	2308.4	AF	Approved	8/14/2001 18:04		2308.4	0	
1997						6.96	695.77	385.26	284.16	11.27			1383.41	AF	Approved	8/14/2001 18:04		1383.42	0.01	

7/29/2020 CLS

RJH Consultants, Inc.
16134 - South Boulder Creek
Marshallville Ditch Historic Monthly Flows

By: JNH	Date: 7/28/2020	
Checked: CLS	Date: 7/28/2020	
Approved: ABP	Date: 7/29/2020	

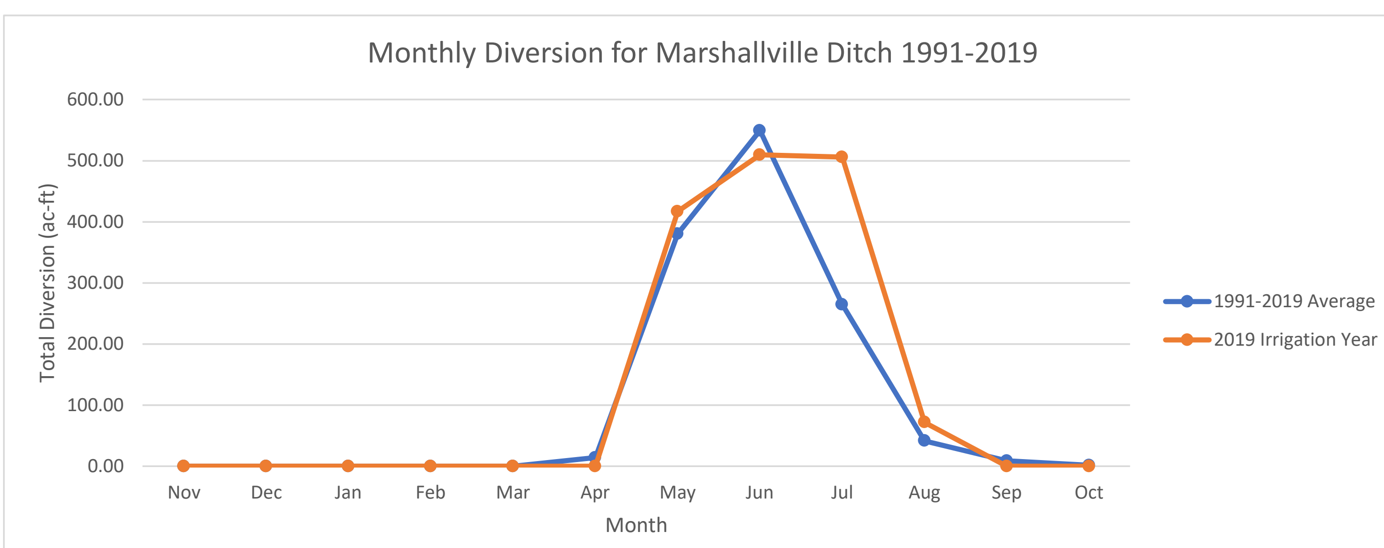
	Previous Calendar Yr		Irrigation Yr = Calendar Yr													
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified
1998							297.43	453.69	278.98	154.73			1184.82	AF	Approved	8/14/2001 18:04
1999							256.15	645.03	245.44	293.3	68.41		1508.33	AF	Approved	8/14/2001 18:04
2000							734.93	610.32	94.91				1440.16	AF	Approved	8/14/2001 18:04
2001							380.34	390.57	54.31				825.22	AF	Approved	5/29/2002 15:57
2002							47.56	206.48					254.05	AF	Approved	8/8/2003 15:15
2003						239.49	932.64	439.19	173.36		168.6		1953.27	AF	Approved	4/20/2004 17:08
2004						53.12	753.13	804.51	223.52				1834.28	AF	Approved	4/6/2005 11:37
2005							624.47	680.74	238.81				1544.02	AF	Approved	6/22/2006 11:13
2006							417.57	794.79	134.08				1346.44	AF	Approved	3/30/2010 17:34
2007						55.34	799.75	687.08	176.73				1718.9	AF	Approved	3/30/2010 17:34
2008							226.12	731.71	330.05	66.65			1354.53	AF	Approved	3/12/2009 14:40
2009							391.9	471.02	242.15				1105.07	AF	Approved	3/2/2010 7:01
2010							67.3	280.25	145.37				492.92	AF	Approved	3/2/2011 10:51
2011							228.3	828.51	729.73	144.99			1931.53	AF	Approved	5/22/2012 11:31
2012							136.98	238.42	35.5				410.9	AF	Approved	2/26/2013 9:11
2013							461.6	903.82	316.01		17.59		1699.03	AF	Approved	2/24/2014 10:20
2014							411.77	580.19	558.67	84.64			1635.28	AF	Approved	1/28/2015 10:21
2015								115.4	359.81				475.21	AF	Approved	1/28/2016 15:31
2016							69.84	477.55	179.07				726.46	AF	Approved	3/16/2017 7:40
2017							42.43	735.16	348.68				1126.27	AF	Approved	3/9/2018 8:55
2018							392.93	695.02	11.9				1099.85	AF	Approved	2/15/2019 11:25
2019	0	0	0	0	0	0	417.13	509.56	506.19	72	0	0	1504.88	AF	Approved	3/2/2020 15:30
1991-2019 Mean	0.00	0.00	0.00	0.00	0.00	14.20	380.56	549.54	264.71	41.59	8.78	1.70				

Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1184.83	0.01	
1508.33	0	
1440.16	0	
825.22	0	
254.04	-0.01	
1953.28	0.01	
1834.28	0	
1544.02	0	
1346.44	0	
1718.9	0	
1354.53	0	
1105.07	0	
492.92	0	
1931.53	0	
410.9	0	
1699.02	-0.01	
1635.27	-0.01	
475.21	0	
726.46	0	
1126.27	0	
1099.85	0	
1504.88	0	

Notes:

Blank cells were considered to be zero when calculating the average.

1. Blank cells mean no recorded flow.
2. Data is from Colorado's Decision Support Systems (CDSS) website https://dwr.state.co.us/Tools/Structures/ and is reported as the total diversion for each month in acre-feet.



RJH Consultants, Inc.
16134 - South Boulder Creek
McGinn Ditch Historic Monthly Flows

By:	JNH	Date:	7/28/2020
Checked:	CLS	Date:	7/28/2020
Approved:	ABP	Date:	7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr																
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified	Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1950						107.11	303.48	753.73	222.15	184.47	119.01	101.16	1791.1	AF	Approved	8/14/2001 18:04	1791.11	0.01	
1951	3.97						136.86	618.85	658.52	162.65	99.18	29.75	1709.78	AF	Approved	8/14/2001 18:04	1709.78	0	
1952								630.75	398.68	184.47	75.37		1289.28	AF	Approved	8/14/2001 18:04	1289.27	-0.01	
1953							174.55	841	321.33	99.18			1436.05	AF	Approved	8/14/2001 18:04	1436.06	0.01	
1954						99.18	259.84	178.52	184.47	138.85	41.65		902.49	AF	Approved	8/14/2001 18:04	902.51	0.02	
1955						35.7	511.74	799.35	271.74	184.47	140.83	7.93	1951.76	AF	Approved	8/14/2001 18:04	1951.76	0	
1956							464.14	725.96	184.47	184.47	21.82		1580.85	AF	Approved	8/14/2001 18:04	1580.86	0.01	
1957							11.9	398.68	721.99	184.47	142.81	107.11	1566.97	AF	Approved	8/14/2001 18:04	1566.96	-0.01	
1958								533.56	209.26	184.47	178.52	158.68	1264.48	AF	Approved	8/14/2001 18:04	1264.49	0.01	
1959							67.44	620.84	337.2	130.91	31.74		1188.12	AF	Approved	8/14/2001 18:04	1188.13	0.01	
1960						23.8	204.3	602.98	533.56	184.47	158.68	71.41	1779.2	AF	Approved	8/14/2001 18:04	1779.2	0	
1961							41.65	343.15	440.34	184.47	79.34	0	1088.94	AF	Approved	8/14/2001 18:04	1088.95	0.01	
1962						43.64	769.6	856.87	601	184.47	109.09	17.85	2582.52	AF	Approved	8/14/2001 18:04	2582.52	0	
1963						95.21	436.37	364.96	184.47	184.47	138.85	115.04	1519.36	AF	Approved	8/14/2001 18:04	1519.37	0.01	
1964	0					11.9	472.07	610.92	295.54	146.78			1537.21	AF	Approved	8/14/2001 18:04	1537.21	0	
1965	55.54					1.98	283.64	763.65	672.41	168.6	101.16		2046.97	AF	Approved	8/14/2001 18:04	2046.98	0.01	
1966							398.68	680.34	184.47	138.85	136.86	41.65	1580.85	AF	Approved	8/14/2001 18:04	1580.85	0	
1967						115.04	267.77	263.81	99.18	156.7	109.09	59.51	1071.09	AF	Approved	8/14/2001 18:04	1071.1	0.01	
1968							200.33	739.85	597.03	146.78	91.24	25.79	1801.02	AF	Approved	8/14/2001 18:04	1801.02	0	
1969						13.88	99.18	184.47	493.89	170.58	156.7	35.7	1154.4	AF	Approved	8/14/2001 18:04	1154.4	0	
1970							353.06	412.57	384.8	182.48	164.63	27.77	1525.31	AF	Approved	8/14/2001 18:04	1525.31	0	
1971						29.75	105.13	664.47	698.19	184.47	89.26		1771.27	AF	Approved	8/14/2001 18:04	1771.27	0	
1972						17.85	456.21	472.07	309.43	184.47	67.44	87.27	1594.73	AF	Approved	8/14/2001 18:04	1594.74	0.01	
1973							41.65	424.47	700.18	212.23	113.06		1491.59	AF	Approved	8/14/2001 18:04	1491.59	0	
1974							485.96	593.07	565.3	186.45	126.94		1957.71	AF	Approved	8/14/2001 18:04	1957.72	0.01	
1975							277.69	400.67	702.16	218.19	156.7	71.41	1826.8	AF	Approved	8/14/2001 18:04	1826.82	0.02	
1976							299.51	454.22	273.72	216.2	93.22		1336.88	AF	Approved	8/14/2001 18:04	1336.87	-0.01	
1977							347.11	495.88	198.35	212.23	103.14	77.36	1434.07	AF	Approved	8/14/2001 18:04	1434.07	0	
1978						57.52	43.64	287.61	720.01	170.58	222.15	15.87	1517.38	AF	Approved	8/14/2001 18:04	1517.38	0	
1979							63.47	206.28	801.33	168.6	168.6	39.67	1447.96	AF	Approved	8/14/2001 18:04	1447.95	-0.01	
1980							13.88	414.55	406.62	196.37	156.7	85.29	1273.41	AF	Approved	8/14/2001 18:04	1273.41	0	
1981						93.22	222.15	212.23	184.47	164.63	164.63	91.24	1132.58	AF	Approved	8/14/2001 18:04	1132.57	-0.01	
1982						29.75	273.72	454.22	238.02	224.14	144.8	99.18	1463.82	AF	Approved	8/14/2001 18:04	1463.83	0.01	
1983								192.4	380.83	347.11	164.63	124.96	1209.94	AF	Approved	8/14/2001 18:04	1209.93	-0.01	
1984	103.14					59.51	392.73	432.4	860.84	351.08	138.85	71.41	2409.95	AF	Approved	8/14/2001 18:04	2409.96	0.01	
1985						39.67	241.99	456.21	291.57	251.11	154.51	162.65	1597.71	AF	Approved	8/14/2001 18:04	1597.71	0	
1986						27.77	198.35	557.36	366.95	188.43	134.88	0	1473.74	AF	Approved	8/14/2001 18:04	1473.74	0	
1987							459.18	365.92	195.08	246.87	105.17		1372.21	AF	Approved	8/14/2001 18:04	1372.22	0.01	
1988							161.87	297.17	278.86	175.78			913.68	AF	Approved	8/14/2001 18:04	913.68	0	
1989						64.13	429.51	634.32	265.43	169.71	78.15		1641.25	AF	Approved	8/14/2001 18:04	1641.25	0	
1990							85.69	306.51	220.51	123.77	159.49	47.62	943.59	AF	Approved	8/14/2001 18:04	943.59	0	
1991						58.31	308.04	498.31	324.28	114.37	116.39	35.98	1455.69	AF	Approved	8/14/2001 18:04	1455.68	-0.01	
1992						32.45	490.52	224.27	160.39	137.44	102.82	21.42	1169.31	AF	Approved	8/14/2001 18:04	1169.31	0	
1993						154.67	168.68	358.72	395.51	136.46	92.83	18.94	1325.81	AF	Approved	8/14/2001 18:04	1325.81	0	
1994						33.03	316.96	471.2	195.57	184.47	15.47		1216.7	AF	Approved	8/14/2001 18:04	1216.7	0	
1995						67.9	109.31	122.44	342	323.97	134.62	10.51	1110.74	AF	Approved	8/14/2001 18:04	1110.75	0.01	
1996						118.65	303.18	472.87	381.23	179.72	69.72	83.88	1609.25	AF	Approved	8/14/2001 18:04	1609.25	0	
1997						110.2	496.45	310.22	314.09	349.65	173.75	56.83	1811.19	AF	Approved	8/14/2001 18:04	1811.19	0	

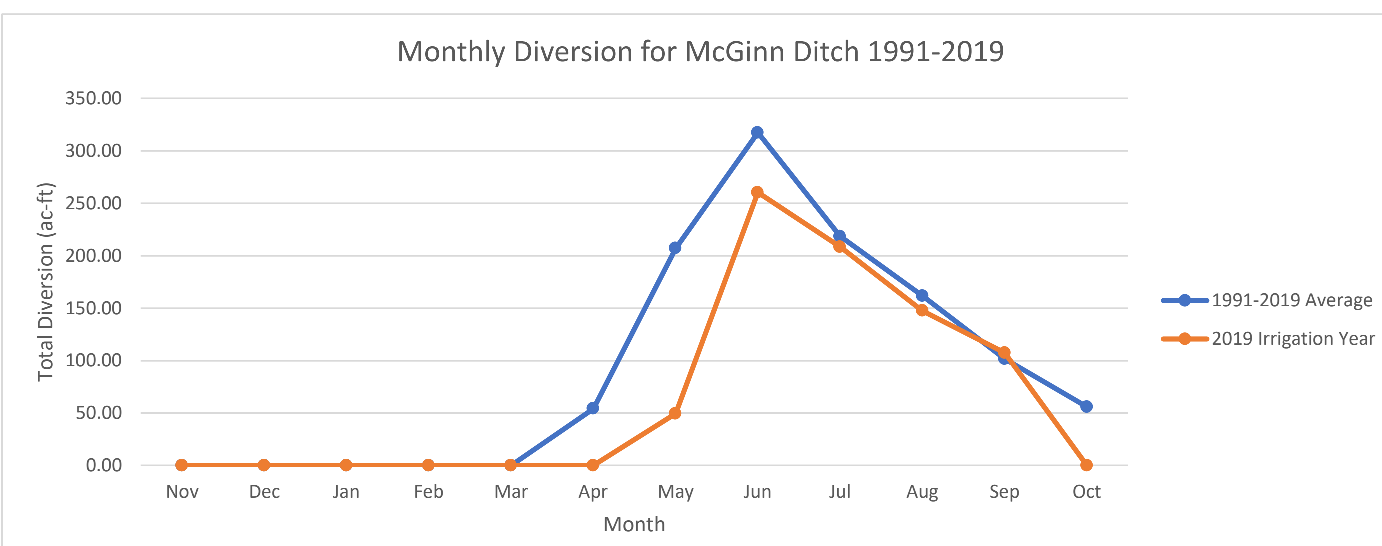
RJH Consultants, Inc.
16134 - South Boulder Creek
McGinn Ditch Historic Monthly Flows

By:	JNH
Date:	7/28/2020
Checked:	CLS
Date:	7/28/2020
Approved:	ABP
Date:	7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr													
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified
1998						94.32	186.65	399.44	204.8	230.36	210.91	181.75	1508.21	AF	Approved	8/14/2001 18:04
1999						52.01	109.53	368.36	198.47	126.51	119.01	115.04	1088.92	AF	Approved	8/14/2001 18:04
2000						46.67	452.95	309.7	187.8	112.35	170.01	116.43	1395.91	AF	Approved	8/14/2001 18:04
2001						18.41	133.61	473.56	191.01	98.74	116.19	52.72	1084.24	AF	Approved	5/29/2002 15:57
2002						134.96	119.21	188.29	123.53	22.02	58.83	83.41	730.25	AF	Approved	8/8/2003 15:15
2003						118.16	248.67	222.77	214.28	185.5	103.06	88.4	1180.84	AF	Approved	4/20/2004 17:08
2004						87.79	163.28	288.6	265.19	161.97	129.46	114.79	1211.09	AF	Approved	4/6/2005 11:37
2005							145.03	266.98	197.7	149.24	19.28	46.77	825	AF	Approved	6/22/2006 11:13
2006						125.16	362.76	468.15	163.84	138.59	88.62	117.76	1464.87	AF	Approved	4/2/2007 13:37
2007	0					23.66	189.11	364.37	183.16	193.47	128.25	0.48	1082.5	AF	Approved	2/12/2009 12:13
2008						41.47	173.93	346.91	179.55	288.6	129.6	113.14	1273.21	AF	Approved	3/12/2009 14:40
2009							192.74	121.87	210.73	155.29	92.31	163.74	936.67	AF	Approved	3/2/2010 7:01
2010							46.41	449.62	217.27	146.82	39.59		899.72	AF	Approved	3/2/2011 10:51
2011						50.84	103.99	322.28	265.51	204.66	141.34	120.02	1208.65	AF	Approved	5/22/2012 11:31
2012							190.22	227.55	154.69	146.54	88.21	41.89	849.1	AF	Approved	2/26/2013 9:11
2013							182.34	486.63	182.34	146.96	52.15		1050.42	AF	Approved	2/24/2014 10:20
2014						66.03	263.79	458.59	291.38	216.76	141.74		1438.28	AF	Approved	1/28/2015 10:21
2015						54.09	20.67	0	39.21		85.29		199.26	AF	Approved	1/28/2016 15:31
2016							129.84	164.39	205.75	138.43	76.29		714.69	AF	Approved	3/16/2017 7:40
2017						82.41	178.46	331.88	212	150.51	112.54	35.31	1103.1	AF	Approved	3/9/2018 8:55
2018							171	229.23	125.5	103.96	29.53		659.22	AF	Approved	2/15/2019 11:25
2019	0	0	0	0	0	0	49.47	260.24	208.47	147.57	107.51	0	773.25	AF	Approved	3/2/2020 15:30
1991-2019 Mean	0.00	0.00	0.00	0.00	0.00	54.18	207.13	317.50	218.46	161.76	101.56	55.83				

Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1508.23	0.02	
1088.93	0.01	
1395.91	0	
1084.24	0	
730.25	0	
1180.84	0	
1211.08	-0.01	
825	0	
1464.88	0.01	
1082.5	0	
1273.2	-0.01	
936.68	0.01	
899.71	-0.01	
1208.64	-0.01	
849.1	0	
1050.42	0	
1438.29	0.01	
199.26	0	
714.7	0.01	
1103.11	0.01	
659.22	0	
773.26	0.01	

Notes:
1. Blank cells mean no recorded flow. Blank cells were considered to be zero when calculating the average.
2. Data is from Colorado's Decision Support Systems (CDSS) website https://dwr.state.co.us/Tools/Structures/ and is reported as the total diversion for each month in acre-feet.



RJH Consultants, Inc.
16134 - South Boulder Creek
New Dry Creek Carrier Ditch Historic Monthly Flows

By:	JNH
Date:	7/28/2020
Checked:	CLS
Date:	7/28/2020
Approved:	ABP
Date:	7/29/2020

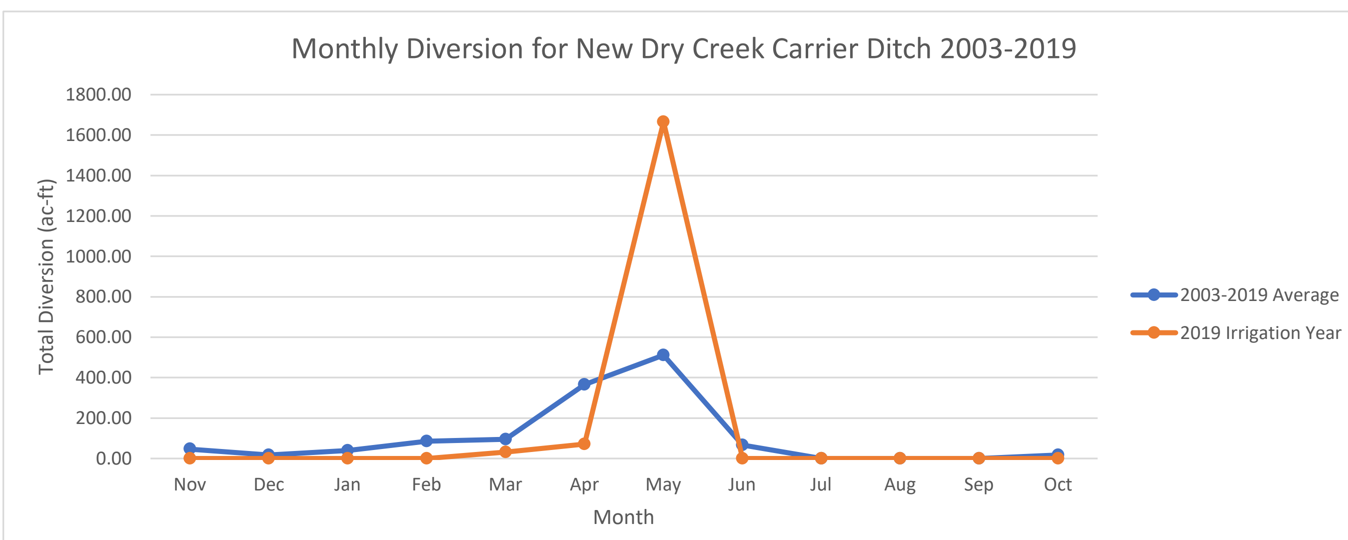
	Previous Calendar Yr		Irrigation Yr = Calendar Yr													
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified
2003	0.34		7.34	36.66	111.1	1285.13	169.67						1610.23	AF	Approved	4/20/2004 17:08
2004						471.22	29.73						500.95	AF	Approved	4/6/2005 11:37
2005			13.92	485.66	863.44	486.75							1849.77	AF	Approved	6/22/2006 11:13
2007				19.8		608.6						58.28	686.67	AF	Approved	4/4/2008 12:41
2008	0		55.58	219.38									274.95	AF	Approved	3/12/2009 14:40
2009	4.7			14.38	16.13	90.69	799.35						925.24	AF	Approved	3/2/2010 7:01
2010					42.47	758.61							801.08	AF	Approved	3/2/2011 10:51
2011	737.68	265.41				39.37	0						1042.47	AF	Approved	5/22/2012 11:31
2012				26.38								218.42	244.8	AF	Approved	2/26/2013 9:11
2013							976.3						976.3	AF	Approved	2/24/2014 10:20
2014							2398.86	477.05					2875.92	AF	Approved	1/28/2015 10:21
2015			465.33	476.04	243.57	406.02							1590.97	AF	Approved	1/28/2016 15:31
2016			83.31		156.36	1463.07	5.95	81.32					1790.01	AF	Approved	3/16/2017 7:40
2017					5.3	27.93	1436.05	493.1					1962.38	AF	Approved	3/9/2018 8:55
2018				92.29	38	140.43	684.31						955.04	AF	Approved	2/15/2019 11:25
2019	0	0	0	0	31.72	70.51	1666.14	0	0	0	0	0	1768.37	AF	Approved	3/2/2020 15:30
2003-2019 Mean	46.42	16.59	39.09	85.66	94.26	365.52	510.40	65.72	0.00	0.00	0.00	17.29				

Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1610.24	0.01	
500.95	0	
1849.77	0	
686.68	0.01	
274.96	0.01	
925.25	0.01	
801.08	0	
1042.46	-0.01	
244.8	0	
976.3	0	
2875.91	-0.01	
1590.96	-0.01	
1790.01	0	
1962.38	0	
955.03	-0.01	
1768.37	0	

Notes:

Blank cells were considered to be zero when calculating the average.

1. Blank cells mean no recorded flow.
2. Data is from Colorado's Decision Support Systems (CDSS) website https://dwr.state.co.us/Tools/Structures/ and is reported as the total diversion for each month in acre-feet.



7/29/2020 CLS

RJH Consultants, Inc.
16134 - South Boulder Creek
South Boulder Bear Creek Ditch Historic Monthly Flows

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/28/2020
Approved: ABP Date: 7/29/2020

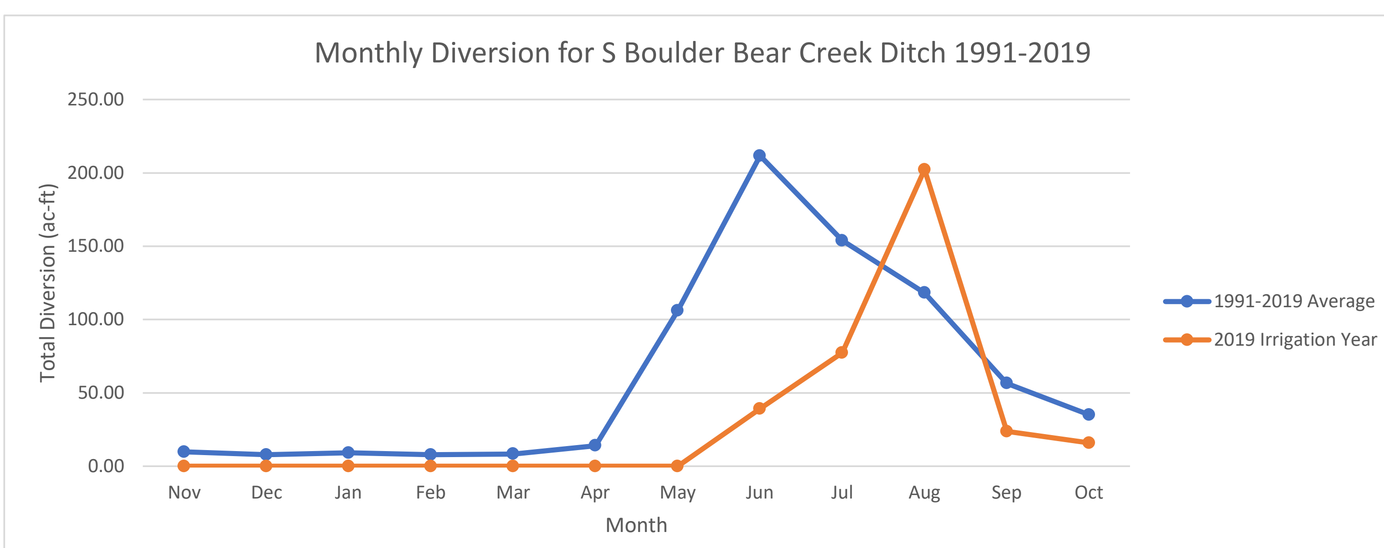
	Previous Calendar Yr		Irrigation Yr = Calendar Yr																	
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified		Irr Year Su	Irr Year Sum - Annual Amounts	Notes
1950						39.67	113.06	444.3	499.84	120.99			1217.87	AF	Approved	8/14/2001 18:04		1217.86	-0.01	
1951							103.14	259.84	291.57	339.18	53.55		1047.29	AF	Approved	8/14/2001 18:04		1047.28	-0.01	
1952								347.11	321.33	243.97	162.65		1075.06	AF	Approved	8/14/2001 18:04		1075.06	0	
1953							134.88	682.32	404.63	176.53			1398.37	AF	Approved	8/14/2001 18:04		1398.36	-0.01	
1954						65.46	345.13	551.41	491.91				1453.91	AF	Approved	8/14/2001 18:04		1453.91	0	
1955						57.52	337.2	319.34	682.32	291.57	63.47		1751.43	AF	Approved	8/14/2001 18:04		1751.42	-0.01	
1956							243.97	577.2	339.18	331.24			1491.59	AF	Approved	8/14/2001 18:04		1491.59	0	
1957								89.26	581.17	521.66	202.32	71.41	1465.81	AF	Approved	8/14/2001 18:04		1465.82	0.01	
1958								234.05	299.51	77.36			610.92	AF	Approved	8/14/2001 18:04		610.92	0	
1959							53.55	412.57	454.22	202.32			1122.66	AF	Approved	8/14/2001 18:04		1122.66	0	
1960						124.96	158.68	420.5	563.31	253.89			1521.34	AF	Approved	8/14/2001 18:04		1521.34	0	
1961							17.85	305.46	372.9	440.34	47.6		1184.15	AF	Approved	8/14/2001 18:04		1184.15	0	
1962						69.42	388.77	341.16	489.92	152.73			1442	AF	Approved	8/14/2001 18:04		1442	0	
1963						170.58	485.96	351.08	335.21	351.08	232.07	81.32	2007.3	AF	Approved	8/14/2001 18:04		2007.3	0	
1964						29.75	291.57	487.94	333.23	240			1382.5	AF	Approved	8/14/2001 18:04		1382.49	-0.01	
1965						17.85	245.95	212.23	466.12	359.01	148.76	71.41	1521.34	AF	Approved	8/14/2001 18:04		1521.33	-0.01	
1966						99.18	299.51	353.06	154.71	95.21			1001.67	AF	Approved	8/14/2001 18:04		1001.67	0	
1967						109.09	154.71	119.01	164.63	188.43			735.88	AF	Approved	8/14/2001 18:04		735.87	-0.01	
1968							120.99	222.15	253.89	198.35	79.34		874.72	AF	Approved	8/14/2001 18:04		874.72	0	
1969						11.9	166.61	166.61	438.35	204.3	23.8	23.8	1035.39	AF	Approved	8/14/2001 18:04		1035.37	-0.02	
1970							247.94	210.25	448.27	321.33	27.77		1255.56	AF	Approved	8/14/2001 18:04		1255.56	0	
1971							103.14	460.17	456.21	212.23	122.98		1354.73	AF	Approved	8/14/2001 18:04		1354.73	0	
1972						91.24	392.73	390.75	394.72	136.86	158.68	188.43	1753.41	AF	Approved	8/14/2001 18:04		1753.41	0	
1973							103.14	481.99	563.31	309.43	240	29.75	1727.63	AF	Approved	8/14/2001 18:04		1727.62	-0.01	
1974							214.22	410.58	428.44	243.97			1297.21	AF	Approved	8/14/2001 18:04		1297.21	0	
1975							240	323.31	474.06	438.35	47.6		1523.33	AF	Approved	8/14/2001 18:04		1523.32	-0.01	
1976							517.69	444.3	424.47	353.06	55.54		1795.07	AF	Approved	8/14/2001 18:04		1795.06	-0.01	
1977							309.43	347.11	357.03	279.67	5.95		1299.19	AF	Approved	8/14/2001 18:04		1299.19	0	
1978							73.39	279.67	402.65	263.81			1019.52	AF	Approved	8/14/2001 18:04		1019.52	0	
1979								321.33	394.72	295.54	327.28		1338.86	AF	Approved	8/14/2001 18:04		1338.87	0.01	
1980							23.8	283.64	168.6	162.65			638.69	AF	Approved	8/14/2001 18:04		638.69	0	
1981						19.84	230.09	154.71	101.16				505.79	AF	Approved	8/14/2001 18:04		505.8	0.01	
1982							109.09	124.96	178.52	101.16	89.26		602.98	AF	Approved	8/14/2001 18:04		602.99	0.01	
1983									190.42	267.77	184.47	49.59	692.24	AF	Approved	8/14/2001 18:04		692.25	0.01	
1984							7.93	130.91	164.63	103.14			406.62	AF	Approved	8/14/2001 18:04		406.61	-0.01	
1985						66.65	131.27	149.93	161.06	128.91	60.12	18.63	716.56	AF	Approved	8/14/2001 18:04		716.57	0.01	
1986	104.35	173.6	162.85	176.29	126.41	12.48	434.13	326.31	282.97	36.3	4.05	38.3	1878.02	AF	Approved	8/14/2001 18:04		1878.04	0.02	
1987	61.91	135.67	139.52	125.36	136.05	27.99	120.68	289.39	266.56	33.96	2.08	62.9	1402.06	AF	Approved	8/14/2001 18:04		1402.07	0.01	
1988	132.7	197.1	202.59	188.35	219.02	185.66	145.47	236.33	220.17	106.97	12.95	20.89	1868.2	AF	Approved	8/14/2001 18:04		1868.2	0	
1989	104.59	135.93	125.48	111.89	132.78	136.98	252.54	272.95	331.18	127.24	12.34	34.43	1778.33	AF	Approved	8/14/2001 18:04		1778.33	0	
1990	55.6	93.18	122.7	59.33	88.01	103.02	256.11	298.97	243.4	69.16	89.48	50.86	1529.81	AF	Approved	8/14/2001 18:04		1529.82	0.01	
1991	97.55	65.06	108.76	90.8	68.61	126.79	203.92	128.17	287.17	148.86	21.4	20.71	1367.8	AF	Approved	8/14/2001 18:04		1367.8	0	
1992	112.56	65.28	72.44	51.06	29	12.65	219.89	214.81	266.88	166.16	66.69	19.3	1296.71	AF	Approved	8/14/2001 18:04		1296.72	0.01	
1993	20.49	42.67	44.01	25.94	29.95	21.44	135.55	282.61	178.97	26.62	19.54	25.37	853.16	AF	Approved	8/14/2001 18:04		853.16	0	
1994	12.08	12.24	2.08	8.63	49.37	67.58	164.35	327.16	128.21	36.56	22.89	21.26	852.41	AF	Approved	8/14/2001 18:04		852.41	0	
1995	23.25	27.05	25.35	24.83	44.63	30.35	3.53		187.5	328.67	156.3	91.42	942.88	AF	Approved	8/14/2001 18:04		942.88	0	
1996	17.12	18.07	15.85	27.95	22.14	20.35	211.7	237.44	189.09	188.27	75.41	23.8	1047.19	AF	Approved	8/14/2001 18:04		1047.19	0	
1997							138.85	238.02	146.78	245.95	206.28	178.52	1154.4	AF	Approved	8/14/2001 18:04		1154.4	0	

RJH Consultants, Inc.
16134 - South Boulder Creek
South Boulder Bear Creek Ditch Historic Monthly Flows

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/28/2020
Approved: ABP Date: 7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr																
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified	Irr Year Su	Irr Year Sum - Annual Amounts	Notes
1998							93.22	248.14	168.58	248.1	107.94		865.98	AF	Approved	8/14/2001 18:04	865.98	0	
1999						121.27	130.91	238.02	249.48	238.16	229.09	34.77	1241.71	AF	Approved	8/14/2001 18:04	1241.7	-0.01	
2000							173.62	254.56	223.86		17.85		669.89	AF	Approved	8/14/2001 18:04	669.89	0	
2001							90.65	219	234.05	67.44			611.14	AF	Approved	5/29/2002 15:57	611.14	0	
2002						7.93	234.05	238.02	121.39		5.95	6.94	614.29	AF	Approved	8/8/2003 15:15	614.28	-0.01	
2003							130.91	247.03	69.48	86.84	177.36	7.93	719.55	AF	Approved	4/20/2004 17:08	719.55	0	
2004							95.74	233.85	236.73	221.46	79.34	122.98	990.1	AF	Approved	4/6/2005 11:37	990.1	0	
2005							88.38	238.02	245.95	228.3	7.93	75.37	883.97	AF	Approved	6/22/2006 11:13	883.95	-0.02	
2006							87.27	332.04	208.64	48.36	15.87	54.55	746.73	AF	Approved	4/2/2007 13:37	746.73	0	
2007	0						145.25	251.13	230.62	62.68	15.87		705.55	AF	Approved	2/12/2009 12:13	705.55	0	
2008							126.01	258.65	148.64	113.16	69.42	3.97	719.85	AF	Approved	3/12/2009 14:40	719.85	0	
2009							108.34	287.98	91.97	41.18	20.83	65.46	615.76	AF	Approved	3/2/2010 7:01	615.76	0	
2010								238.63	73.25	127.82			439.7	AF	Approved	3/2/2011 10:51	439.7	0	
2011							166.93	230.26	63.23	176.33	144.66	44.93	826.35	AF	Approved	5/22/2012 11:31	826.34	-0.01	
2012							230.3	186.15	90.35	42.92	18.84		568.57	AF	Approved	2/26/2013 9:11	568.56	-0.01	
2013							82.04	255.95	157.19	66.21	40.48		601.87	AF	Approved	2/24/2014 10:20	601.87	0	
2014							4.24	218.64	83.21	0		119.01	425.1	AF	Approved	1/28/2015 10:21	425.1	0	
2015										49.59	41.65	47.64	138.88	AF	Approved	1/28/2016 15:31	138.88	0	
2016								138.85	121.83	31.64	7.93	15.87	316.11	AF	Approved	3/16/2017 7:40	316.12	0.01	
2017								194.38	99.18	165.23		7.93	466.72	AF	Approved	3/9/2018 8:55	466.72	0	
2018							11.31	164.59	83.31	71.41	47.6	14.28	392.49	AF	Approved	2/15/2019 11:25	392.5	0.01	
2019	0	0	0	0	0	0	0	39.19	77.4	202.32	23.8	15.87	358.58	AF	Approved	3/2/2020 15:30	358.58	0	
1991-2019 Mean	9.76	7.94	9.26	7.90	8.40	14.08	106.10	211.77	153.89	118.28	56.58	35.10							

Notes:
1. Blank cells mean no recorded flow.
Blank cells were considered to be zero when calculating the average.
2. Data is from Colorado's Decision Support Systems (CDSS) website https://dwr.state.co.us/Tools/Structures/ and is reported as the total diversion for each month in acre-feet.



RJH Consultants, Inc.
16134 - South Boulder Creek
South Boulder Canon Ditch Historic Monthly Flows

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/28/2020
Approved: ABP Date: 7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr																
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified	Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1950							737.86	1783.17	12.89			95.21	2629.13	AF	Approved	8/14/2001 18:04	2629.13	0	
1951							436.37	1729.61	1402.33	7.93	6.94		3583.19	AF	Approved	8/14/2001 18:04	3583.18	-0.01	
1952							773.57	1586.8	555.38				2915.75	AF	Approved	8/14/2001 18:04	2915.75	0	
1953							860.84	1753.41	129.28	84.24	81.52	84.24	2993.54	AF	Approved	8/14/2001 18:04	2993.53	-0.01	
1955						93.22	206.28	1844.66		59.51	119.01	19.84	2342.51	AF	Approved	8/14/2001 18:04	2342.52	0.01	
1956						150.75	1499.53	2005.32	9.92				3665.51	AF	Approved	8/14/2001 18:04	3665.52	0.01	
1957							9.92	1321.01	1328.95	67.44	142.81	245.95	3116.08	AF	Approved	8/14/2001 18:04	3116.08	0	
1958								1049.27	74.38	35.7	11.9		1171.26	AF	Approved	8/14/2001 18:04	1171.25	-0.01	
1959							517.69	1172.25	303.48	0			1993.42	AF	Approved	8/14/2001 18:04	1993.42	0	
1960						353.06	739.85	1188.12	511.74	44.63			2837.4	AF	Approved	8/14/2001 18:04	2837.4	0	
1961							19.84	628.77	86.28				734.89	AF	Approved	8/14/2001 18:04	734.89	0	
1962						29.75	1626.47	591.08	370.91	43.64			2661.86	AF	Approved	8/14/2001 18:04	2661.85	-0.01	
1963							212.23	666.46					878.69	AF	Approved	8/14/2001 18:04	878.69	0	
1964						61.49	591.08	1836.72	18.84				2508.14	AF	Approved	8/14/2001 18:04	2508.13	-0.01	
1965						402.65	1033.4	852.91	940.18	101.16			3330.3	AF	Approved	8/14/2001 18:04	3330.3	0	
1966							345.13	243.97	17.85				606.95	AF	Approved	8/14/2001 18:04	606.95	0	
1967						59.51	602.98	523.64	51.57				1237.7	AF	Approved	8/14/2001 18:04	1237.7	0	
1968							932.25	1035.39	170.58	19.84			2158.05	AF	Approved	8/14/2001 18:04	2158.06	0.01	
1969						178.52	610.92	543.48	422.49				1755.4	AF	Approved	8/14/2001 18:04	1755.41	0.01	
1970							710.09	775.55	380.83	3.97			1870.44	AF	Approved	8/14/2001 18:04	1870.44	0	
1971								1065.14	920.34				1985.48	AF	Approved	8/14/2001 18:04	1985.48	0	
1972							727.94	1422.17	107.11				2257.22	AF	Approved	8/14/2001 18:04	2257.22	0	
1973								529.59	349.1				878.69	AF	Approved	8/14/2001 18:04	878.69	0	
1974							1406.3	1069.11	398.68				2874.09	AF	Approved	8/14/2001 18:04	2874.09	0	
1975							555.38	789.43	1202				2546.81	AF	Approved	8/14/2001 18:04	2546.81	0	
1976							793.4	1271.42	11.9	182.48			2259.21	AF	Approved	8/14/2001 18:04	2259.2	-0.01	
1977							674.39	1283.32					1957.71	AF	Approved	8/14/2001 18:04	1957.71	0	
1978								846.95	444.3				1291.26	AF	Approved	8/14/2001 18:04	1291.25	-0.01	
1979							119.01	232.07	662.49				1013.57	AF	Approved	8/14/2001 18:04	1013.57	0	
1980								848.94	178.52				1027.45	AF	Approved	8/14/2001 18:04	1027.46	0.01	
1981							579.18	368.93					948.11	AF	Approved	8/14/2001 18:04	948.11	0	
1982							400.67	819.19	438.35				1658.21	AF	Approved	8/14/2001 18:04	1658.21	0	
1983								43.64	682.32	315.38			1041.34	AF	Approved	8/14/2001 18:04	1041.34	0	
1984							245.95	1039.35	985.8	158.68			2429.79	AF	Approved	8/14/2001 18:04	2429.78	-0.01	
1985						321.33	1010.89	148.76			97.19	319.34	1897.52	AF	Approved	8/14/2001 18:04	1897.51	-0.01	
1986							800.64	751.75	355.05		23.8	119.01	2050.24	AF	Approved	8/14/2001 18:04	2050.25	0.01	
1987							1230.29	929.37	2.06				2161.72	AF	Approved	8/14/2001 18:04	2161.72	0	
1988							1345.41	1131.61	230.48		58.18		2765.67	AF	Approved	8/14/2001 18:04	2765.68	0.01	
1989	198.35					147.37	1107.94	1178.34	24.2		98.58		2754.78	AF	Approved	8/14/2001 18:04	2754.78	0	
1990	78.74		78.23			205.43	656.8	1208.86	69.4			277.59	2575.06	AF	Approved	8/14/2001 18:04	2575.05	-0.01	
1991						165.42	1276.38	1184.67	247.96		110.96	71.41	3056.79	AF	Approved	8/14/2001 18:04	3056.8	0.01	
1992					282.57	198.33	1145.45	454.92	155.27	73.39			2309.92	AF	Approved	8/14/2001 18:04	2309.93	0.01	
1993						234.69	961.52	803.06	822.06		248.45		3069.78	AF	Approved	8/14/2001 18:04	3069.78	0	
1994						118.79	1080.57	1244.88					2444.25	AF	Approved	8/14/2001 18:04	2444.24	-0.01	
1995							780.94	397.87	827.93	108.32		357.01	2472.08	AF	Approved	8/14/2001 18:04	2472.07	-0.01	
1996						19.84	1006.03	348.74	592.05		252.1	203.19	2421.95	AF	Approved	8/14/2001 18:04	2421.95	0	
1997						29.91	1168.62	506.03	520.67		144.4		2369.63	AF	Approved	8/14/2001 18:04	2369.63	0	
1998							783.44	1075.63	641.72	306.81		347.53	3155.13	AF	Approved	8/14/2001 18:04	3155.13	0	

7/29/2020 CLS

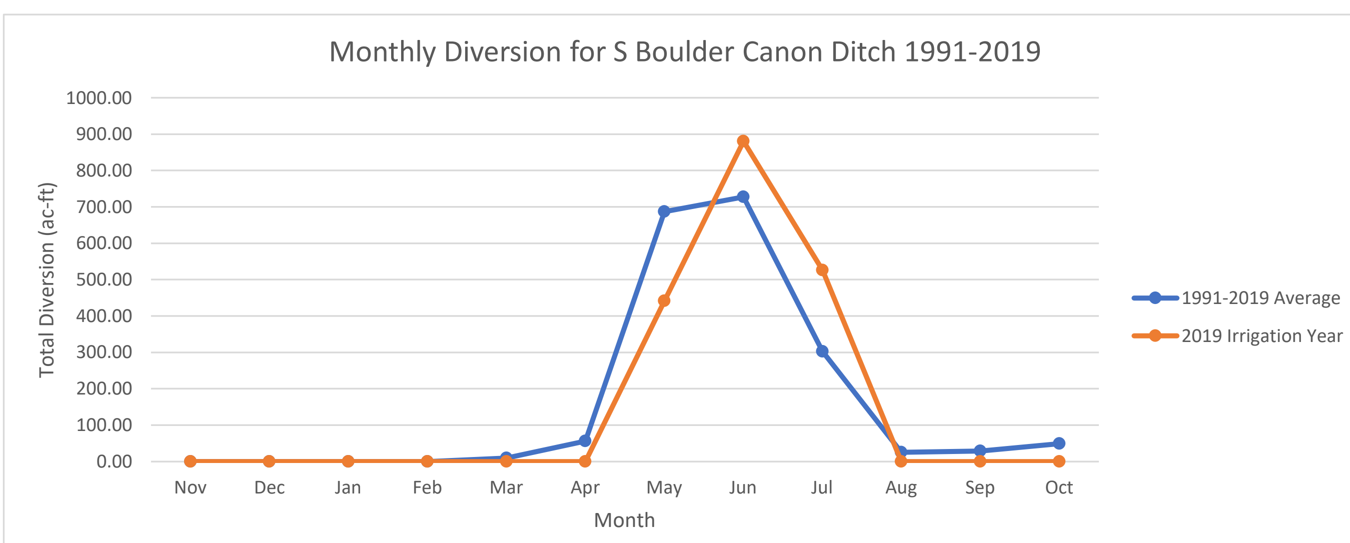
RJH Consultants, Inc.
16134 - South Boulder Creek
South Boulder Canon Ditch Historic Monthly Flows

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/28/2020
Approved: ABP Date: 7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr													
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified
1999							73.63	803.5	397	165.32			1439.45	AF	Approved	8/14/2001 18:04
2000							1296.97	725.05	24.85		77.63	429.39	2553.9	AF	Approved	8/14/2001 18:04
2001							560.72	824.66	54.7				1440.08	AF	Approved	5/29/2002 15:57
2002								302.52					302.52	AF	Approved	8/8/2003 15:15
2003						290.38	1012.97	1170.27	336.8				2810.42	AF	Approved	4/20/2004 17:08
2004						46.61	947.32	948.91	79.4				2022.24	AF	Approved	4/6/2005 11:37
2005						171.02	609.93	559.55	33.32				1373.81	AF	Approved	6/22/2006 11:13
2006							683.99	803.48					1487.47	AF	Approved	3/30/2010 17:40
2007							1151.42	533.76					1685.18	AF	Approved	3/30/2010 17:41
2008							195.18	1341.24	706.72	64.34			2307.48	AF	Approved	3/12/2009 14:40
2009							450.75	794.59	460.57				1705.91	AF	Approved	3/2/2010 7:01
2010							740.64	931.25	355.03				2026.92	AF	Approved	3/2/2011 10:51
2011						36.69	742.03	736.37	496.21	6.94			2018.25	AF	Approved	5/22/2012 11:31
2012						140.63	100.37	96.91	51.17				389.08	AF	Approved	2/26/2013 9:11
2013							756.71	1246.09	0				2002.8	AF	Approved	2/24/2014 10:20
2014							436.77	594.93	638.55				1670.25	AF	Approved	1/28/2015 10:21
2015								275.47	440.04				715.51	AF	Approved	1/28/2016 15:31
2016							379.15	593.38	225.25				1197.78	AF	Approved	3/16/2017 7:40
2017						178.81	613.83	361.61	139.14				1293.4	AF	Approved	3/9/2018 8:55
2018							519.5	563.35					1082.85	AF	Approved	2/15/2019 11:25
2019	0	0	0	0	0	0	441.13	880.67	526.22	0	0	0	1848.03	AF	Approved	3/2/2020 15:30
1991-2019 Mean	0.00	0.00	0.00	0.00	9.74	56.25	686.76	727.70	302.50	25.00	28.74	48.57				

Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1439.45	0	
2553.89	-0.01	
1440.08	0	
302.52	0	
2810.42	0	
2022.24	0	
1373.82	0.01	
1487.47	0	
1685.18	0	
2307.48	0	
1705.91	0	
2026.92	0	
2018.24	-0.01	
389.08	0	
2002.8	0	
1670.25	0	
715.51	0	
1197.78	0	
1293.39	-0.01	
1082.85	0	
1848.02	-0.01	

Notes:
1. Blank cells mean no recorded flow.
Blank cells were considered to be zero when calculating the average.
2. Data is from Colorado's Decision Support Systems (CDSS) website https://dwr.state.co.us/Tools/Structures/ and is reported as the total diversion for each month in acre-feet.



RJH Consultants, Inc.
16134 - South Boulder Creek
Schearer Ditch Historic Monthly Flows

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/28/2020
Approved: ABP Date: 7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr																
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified	Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1950							200.33	204.3	206.28	154.71	0		765.63	AF	Approved	8/14/2001 18:04	765.62	-0.01	
1951							79.34	176.53	138.85	142.81	122.98		660.51	AF	Approved	8/14/2001 18:04	660.51	0	
1952							43.64	390.75	198.35	347.11	45.62		1025.47	AF	Approved	8/14/2001 18:04	1025.47	0	
1953							277.69	285.62	190.42	299.51	71.41		1124.64	AF	Approved	8/14/2001 18:04	1124.65	0.01	
1954						198.35	208.27	513.73	263.81	261.82	0		1445.97	AF	Approved	8/14/2001 18:04	1445.98	0.01	
1955						134.88	364.96	285.62	311.41	359.01	140.83	99.18	1695.89	AF	Approved	8/14/2001 18:04	1695.89	0	
1956							257.86	676.37	267.77	208.27	63.47		1473.74	AF	Approved	8/14/2001 18:04	1473.74	0	
1957								408.6	77.36	513.73	67.44	3.97	1071.09	AF	Approved	8/14/2001 18:04	1071.1	0.01	
1958								511.74	89.26	481.99	113.06	5.95	1202	AF	Approved	8/14/2001 18:04	1202	0	
1959							41.65	487.94	186.45	329.26	49.59		1094.89	AF	Approved	8/14/2001 18:04	1094.89	0	
1960							51.57	876.71	23.8	678.36	226.12		1856.56	AF	Approved	8/14/2001 18:04	1856.56	0	
1961							253.89	384.8	65.46	523.64	31.74		1259.52	AF	Approved	8/14/2001 18:04	1259.53	0.01	
1962							462.16	616.87	31.74	597.03	47.6		1755.4	AF	Approved	8/14/2001 18:04	1755.4	0	
1963						15.87	569.26	335.21	361	361	283.64	23.8	1949.78	AF	Approved	8/14/2001 18:04	1949.78	0	
1964							386.78	450.25	152.73	378.85			1368.62	AF	Approved	8/14/2001 18:04	1368.61	-0.01	
1965						57.52	571.25	723.98	5.95	172.56	222.15		1753.41	AF	Approved	8/14/2001 18:04	1753.41	0	
1966							868.77	860.84	202.32	361	323.31	107.11	2723.35	AF	Approved	8/14/2001 18:04	2723.35	0	
1967						83.31	684.31	313.39		480.01	259.84	158.68	1979.53	AF	Approved	8/14/2001 18:04	1979.54	0.01	
1968							589.1	876.71	59.51	864.81	390.75		2780.87	AF	Approved	8/14/2001 18:04	2780.88	0.01	
1969								801.33	525.63	311.41	452.24		2090.61	AF	Approved	8/14/2001 18:04	2090.61	0	
1970							355.05	636.7	115.04	174.55	236.04		1517.38	AF	Approved	8/14/2001 18:04	1517.38	0	
1971								1406.3	323.31	353.06	249.92		2332.6	AF	Approved	8/14/2001 18:04	2332.59	-0.01	
1972							400.67	593.07	164.63	339.18	275.71		1773.25	AF	Approved	8/14/2001 18:04	1773.26	0.01	
1973								1013.57	668.44	249.92	293.56		2225.49	AF	Approved	8/14/2001 18:04	2225.49	0	
1974							444.3	1057.21	293.56	279.67	368.93	7.93	2451.61	AF	Approved	8/14/2001 18:04	2451.6	-0.01	
1975								904.48	563.31	29.75	347.11		1844.66	AF	Approved	8/14/2001 18:04	1844.65	-0.01	
1976							35.7	781.5	864.81	160.66	422.49		2265.16	AF	Approved	8/14/2001 18:04	2265.16	0	
1977							815.22	771.58	279.67	67.44	279.67	307.44	2521.03	AF	Approved	8/14/2001 18:04	2521.02	-0.01	
1978								938.2	468.11	172.56	309.43		1888.29	AF	Approved	8/14/2001 18:04	1888.3	0.01	
1979								805.3	176.53	755.71	416.54		2154.08	AF	Approved	8/14/2001 18:04	2154.08	0	
1980								1090.93	434.39	224.14	509.76	126.94	2386.15	AF	Approved	8/14/2001 18:04	2386.16	0.01	
1981							178.52	852.91	236.04	218.19	172.56		1658.21	AF	Approved	8/14/2001 18:04	1658.22	0.01	
1982							87.27	833.07	464.14	109.09	238.02		1731.6	AF	Approved	8/14/2001 18:04	1731.59	-0.01	
1983								424.47	317.36	9.92	204.3	13.88	969.93	AF	Approved	8/14/2001 18:04	969.93	0	
1984							49.59	850.92	23.8	622.82	485.96		2033.09	AF	Approved	8/14/2001 18:04	2033.09	0	
1985							107.11	0					107.11	AF	Approved	8/14/2001 18:04	107.11	0	
1986							45.62	700.18	1.98	271.74	523.64	47.6	1590.77	AF	Approved	8/14/2001 18:04	1590.76	-0.01	
1987								223.84	174.81	111.91			510.55	AF	Approved	8/14/2001 18:04	510.56	0.01	
1988							240.6	439.42	124.82	221.72			1026.56	AF	Approved	8/14/2001 18:04	1026.56	0	
1989							254.34	203.92	145.03	194.32			797.62	AF	Approved	8/14/2001 18:04	797.61	-0.01	
1990							104.53	848.2		132.85	123.61		1209.2	AF	Approved	8/14/2001 18:04	1209.19	-0.01	
1991							44.63	332.16	213.07	0	64.01		653.86	AF	Approved	8/14/2001 18:04	653.87	0.01	
1992							247.54	284.63	0	196.51	47.07		775.75	AF	Approved	8/14/2001 18:04	775.75	0	
1993							222.35	547.27	675.38	445.3			1890.3	AF	Approved	8/14/2001 18:04	1890.3	0	
1994							257.86	193.39	185.18	143.98			780.41	AF	Approved	8/14/2001 18:04	780.41	0	
1995									14.88	667.51	124.88		807.26	AF	Approved	8/14/2001 18:04	807.27	0.01	
1996							280.07	250.32		314.94	67.28		912.61	AF	Approved	8/14/2001 18:04	912.61	0	
1997							75.37	223.98	14.88	268.45	118.16		700.83	AF	Approved	8/14/2001 18:04	700.84	0.01	

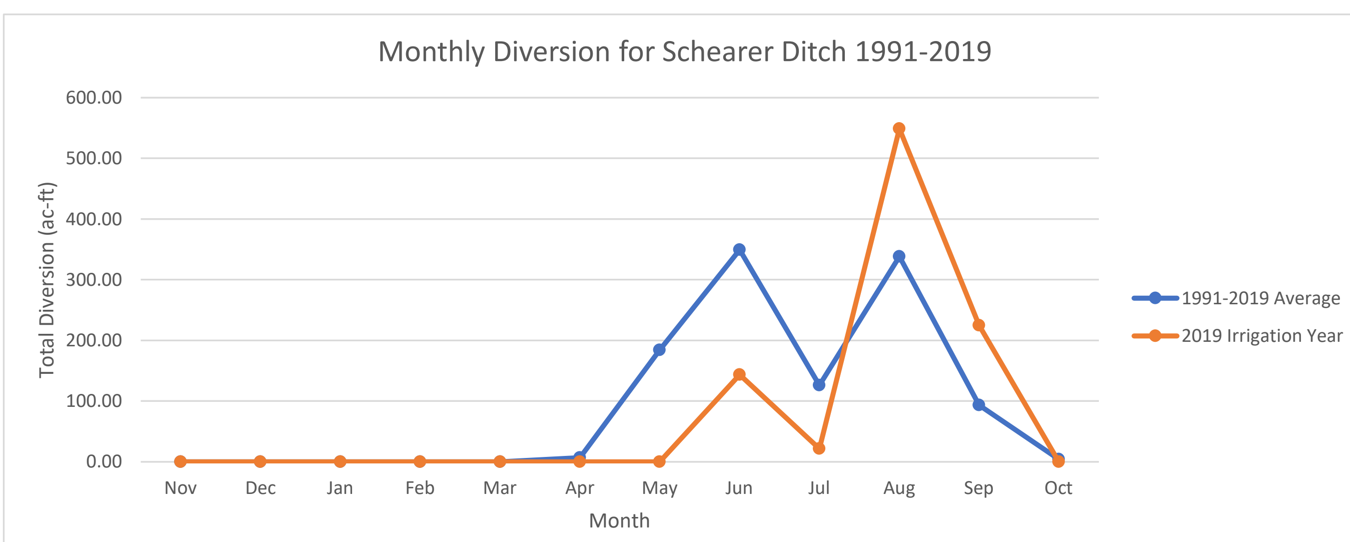
RJH Consultants, Inc.
16134 - South Boulder Creek
Schearer Ditch Historic Monthly Flows

By: JNH Date: 7/28/2020
Checked: CLS Date: 7/28/2020
Approved: ABP Date: 7/29/2020

	Previous Calendar Yr		Irrigation Yr = Calendar Yr																	
Irr Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Amount	Units	Data Status	Modified		Irr Year Sum	Irr Year Sum - Annual Amounts	Notes
1998							174.03	550.02	291.46	403.76	10.73		1430	AF	Approved	8/14/2001 18:04		1430	0	
1999								600.45	355.54	198.91	189.72		1344.61	AF	Approved	8/14/2001 18:04		1344.62	0.01	
2000							232.62	882.6	66.72	135.41	281.68		1599.04	AF	Approved	8/14/2001 18:04		1599.03	-0.01	
2001						29	459.76	105.64	368.81	461.76			1424.97	AF	Approved	5/29/2002 15:57		1424.97	0	
2002						169.89	343.5	347.61		28.88	142.67	89.32	1121.87	AF	Approved	8/8/2003 15:15		1121.87	0	
2003							206.48	174.94	437.76	287.61			1106.79	AF	Approved	4/20/2004 17:08		1106.79	0	
2004							215.8	320.34		38.48	500.04	5.91	1080.57	AF	Approved	4/6/2005 11:37		1080.57	0	
2005							190.22	245.56	376.47	515.71			1327.95	AF	Approved	6/22/2006 11:13		1327.96	0.01	
2006							708.9	208.07		504.8			1421.77	AF	Approved	3/30/2010 17:39		1421.77	0	
2007							354.45	588.7	219.97	437.96			1601.08	AF	Approved	3/30/2010 17:39		1601.08	0	
2008							479.21	262.62	119.8	489.13	50.98		1401.74	AF	Approved	3/12/2009 14:40		1401.74	0	
2009							387.58	38.12	118.02	375.28	53.59	27.65	1000.24	AF	Approved	3/2/2010 7:01		1000.24	0	
2010								192		612.9	43.82		848.72	AF	Approved	3/2/2011 10:51		848.72	0	
2011								706.72	98.58	528.6	131.11		1465.01	AF	Approved	5/22/2012 11:31		1465.01	0	
2012							378.85	416.54	4.56	488.73	58.71		1347.39	AF	Approved	2/26/2013 9:11		1347.39	0	
2013							74.38	610.72	6.53	373.24	144.93		1209.8	AF	Approved	2/24/2014 10:20		1209.8	0	
2014								581.6					581.6	AF	Approved	1/28/2015 10:21		581.6	0	
2015										306.37	128		434.37	AF	Approved	1/28/2016 15:31		434.37	0	
2016								366.21	61.49	457.55	15.87		901.12	AF	Approved	3/16/2017 7:40		901.12	0	
2017								682.46	0	98.78	204.9		986.14	AF	Approved	3/9/2018 8:55		986.14	0	
2018								278.64		476.24	100.37		855.25	AF	Approved	2/15/2019 11:25		855.25	0	
2019	0	0	0	0	0	0	0	143.21	21.42	548.64	224.53	0	937.8	AF	Approved	3/2/2020 15:30		937.8	0	
1991-2019 Mean	0.00	0.00	0.00	0.00	0.00	6.86	183.92	349.47	125.88	338.12	93.21	4.24								

Notes:
1. Blank cells mean no recorded flow.
2. Data is from Colorado's Decision Support Systems (CDSS) website https://dwr.state.co.us/Tools/Structures/ and is reported as the total diversion for each month in acre-feet.

Blank cells were considered to be zero when calculating the average.



APPENDIX D

BEDROCK SURFACE DEVELOPMENT

CONSULTANTS, INC.

Project	16134	Page	1/10
Date	9/9/2020	By	ATMerook
Checked	9/10/2020	By	JNH
Approved	9/11/20	By	ABP

Client City of Boulder

Subject Bedrock Surface Generation

Purpose: Document development of the bedrock surface for the South Boulder Creek Regional Detention Project Groundwater Vistas 7 (GWV7) transient groundwater model:

Approach:

1. A representative surface defining the top of bedrock (TOR) throughout the groundwater model extents was generating using kriging interpolation techniques within the Visual MODFLOW Flex 6.1 computer program. The data used to develop this surface are summarized on pages 2-9 and consisted of the following:
   a. Nine CDOT borings and 11 CDSS wells. Additional information about these borings and wells is presented in the Phase I Geotechnical Report.
   b. 26 borings performed by RJH during the Phase I geotechnical investigation. Additional information about these borings is presented in the Phase I Geotechnical Report.
   c. 358 manually-created points (z100 through z379 and gis0 through gis79). These points were developed by RJH based on our geologic interpretation of the shape of bedrock throughout the model area. These points were primarily added on CU South Campus and along the western portion of the modeled extents in areas where topography was variable and existing borehole and well data were lacking. The purpose of these points was to prevent the contoured ground surface from extending above the ground surface topography. The top of bedrock at these points was generally assigned 2 to 3 feet below the ground surface.
2. The TOR surface generated using VMOD was exported in XYZ format with 62,500 points on a uniform rectilinear grid. An excerpt of the exported data is shown on page 10.
3. The gridded TOR XYZ data was imported into GWV7. The TOR surface was regenerated in GWV7 using Nearest Neighbor interpolation.

9/10/2020 JNH

1/3/20 JNH

ABP 8/7/2020

16134 - SBC Groundwater Model

Bedrock Data Object Points - Bedrock layers

Date: 11/15/2019 By: JNH
Addended: 12/19/2019 By: ATMerook
Checked: 1/3/20 By: JNH

For model

points added by ATMerook to constrain the top of bedrock surface were spot checked.

General Notes:
1. Data from Fill_forModel and Qal_forModel sheets, combined so Boring_ID in order for Table 3.1, edited for model input.
2. Supplemental points below alluvium added to constrain top of bedrock contours: see z-### IDs.
3. Supplemental points below fill added define interpreted top of bedrock contours georeferenced in GIS; see gis## IDs.
4. Ground elevations (Elev_GND) extracted from CAD surface at point locations.

Tables 2.1, 2.2, 3.1					JNH ADDED			
Boring_ID	Y	X	Elev_GND	Depth_to_Bedrock	Elev_TOR	Elev_TOR-12	Elev_TOR-30	Point Notes:
BCB-KA-1	1235950	3078026	5370.7	22	5348.7	5336.7 ✓	5318.7 ✓	Here through B-128 previously checked; only Elev_TOR-12 & Elev_TOR-30 checked 1/3/20
BCB-KA-2	1235953	3078081	5356.4	8	5348.4	5336.4	5318.4	
SN-KA-1	1237349	3075543	5353.9	25.5	5328.4	5316.4	5298.4	
SN-KA-2	1236688	3076675	5358.8	20.5	5338.3	5326.3	5308.3	
SN-KA-3	1235991	3077793	5367.2	20	5347.2	5335.2	5317.2	
YA-SBC1	1235875	3078009	5372	23	5349	5337.0	5319.0	
Lord 1	1237725	3075056	5344.3	26	5318.3	5306.3	5288.3	
S-0084(5)	1227931	3074702	5460.3	9.9	5450.5	5438.5	5420.5	
SU-0157(01)	1240513	3075157	5310.9	17.4	5293.4	5281.4	5263.4	
CDSS-28	1239778	3077134	5300	10	5290.0	5278.0	5260.0	
CDSS-29	1242879	3073977	5296.6	19.5	5277.1	5265.1	5247.1	
CDSS-33	1242347	3075805	5293.8	15	5278.8	5266.8	5248.8	
CDSS-34	1238489	3077139	5335.2	14	5321.2	5309.2	5291.2	
CDSS-37	1242878	3072917	5306.7	12	5294.7	5282.7 ✓	5264.7 ✓	
CDSS-42	1232516	3074380	5415.1	8	5407.1	5395.1	5377.1	
CDSS-43	1227989	3074501	5464.8	18	5446.8	5434.8	5416.8	
CDSS-44	1231908	3074510	5419.2	19	5400.2	5388.2	5370.2	
CDSS-45	1229295	3074503	5449.4	25	5424.4	5412.4	5394.4	
CDSS-48	1231251	3073847	5440.9	16	5424.9	5412.9	5394.9	
CDSS-50	1229956	3075163	5439.0	16	5423.0	5411.0	5393.0	
B-101(P)	1230674.8	3073924.4	5443.2	6	5437.2	5425.2	5407.2	
B-102(P)	1228131.3	3073807.7	5467.4	18.5	5448.9	5436.9	5418.9	
B-103(P)	1231354.6	3074840.8	5421.7	19.5	5402.2	5390.2	5372.2	
B-105(P)	1242628.5	3078265.5	5289.2	17.9	5271.3	5259.3	5241.3	
B-106(P)	1243075.3	3079484.2	5280.8	8.8	5272.0	5260.0	5242.0	
B-107(P)	1237625.7	3077970.0	5340.6	13.9	5326.7	5314.7	5296.7	
B-108(P)	1237577.0	3076822.7	5343.3	11.5	5331.8	5319.8	5301.8	
B-109(P)	1235749.6	3077992.0	5358.8	10	5348.8	5336.8	5318.8	
B-110(P)	1236469.0	3076834.6	5357.8	13	5344.8	5332.8	5314.8	
B-111(P)	1236839.5	3075674.9	5353.8	18	5335.8	5323.8	5305.8	
B-112(P)	1237180.0	3074651.4	5349.7	13	5336.7	5324.7	5306.7	
B-113(P)	1236993.6	3074126.8	5351.9	13.9	5338.0	5326.0	5308.0	
B-114(P)	1235984.4	3074145.7	5376.2	22.8	5353.4	5341.4	5323.4	
B-115(P)	1235617.7	3075564.2	5358.7	4.5	5354.2	5342.2 ✓	5324.2 ✓	
B-116(P)	1234858.2	3077455.4	5370.7	10	5360.7	5348.7	5330.7	
B-117(P)	1233771.2	3076622.6	5377.8	10.8	5367.0	5355.0	5337.0	
B-118(P)	1233989.6	3074955.0	5383.6	12.7	5370.9	5358.9	5340.9	
B-119(P)	1232256.2	3074772.0	5413.5	19.1	5394.4	5382.4	5364.4	
B-121(P)	1236336.5	3076102.0	5359.8	16	5343.8	5331.8	5313.8	
B-122(P)	1236181.5	3076787.9	5361.3	12	5349.3	5337.3	5319.3	
B-123(P)	1235521.5	3077340.3	5364.0	10.8	5353.2	5341.2	5323.2	

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B-124(P)	1237205.9	3076716.7	5347.0	12.8	5334.2	5322.2	5304.2	
B-125(P)	1236932.8	3077105.0	5349.5	7.5	5342.0	5330.0	5312.0	
B-126(P)	1236597.6	3077694.7	5350.6	9.3	5341.3	5329.3	5311.3	
B-127	1235154.4	3076599.6	5377.3	20.1	5357.2	5345.2	5327.2	
B-128	1234185.9	3077028.3	5385.2	15.3	5369.9	5357.9	5339.9	
z100	1227754.0	3074510.4	5464.0		5452.6	5440.6	5422.6	ATMerook ADDED z100 through z130 previously checked 12/12/19 by JNH
z101	1231443.2	3076591.2	5409.9		5394.4	5382.4	5364.4	
z102	1233320.0	3077491.4	5381.9		5367.0	5355.0	5337.0	
z103	1234767.7	3077746.6	5365.0		5360.7	5348.7	5330.7	
z104	1235393.8	3077969.9	5359.0		5353.2	5341.2	5323.2	
z105	1235847.9	3078118.5	5354.1		5351.6	5339.6	5321.6	
z106	1237163.0	3078132.5	5342.0		5326.6	5314.6	5296.6	
z107	1242996.0	3079713.6	5273.9		5270.8	5258.8	5240.8	
z108	1242987.4	3072809.0	5306.9		5304.9	5292.9	5274.9	
z109	1241174.3	3074504.3	5308.7		5306.7	5294.7	5276.7	
z110	1238910.1	3074355.8	5331.9		5329.9	5317.9	5299.9	
z111	1238219.6	3074089.8	5345.0		5343.0	5331.0	5313.0	
z113	1236989.5	3074259.6	5352.0		5337.6	5325.6	5307.6	
z114	1229286.8	3072047.1	5474.8		5472.8	5460.8	5442.8	
z115	1228669.5	3073008.8	5474.2		5472.2	5460.2	5442.2	
z116	1229105.0	3071304.2	5487.3		5485.3	5473.3	5455.3	
z117	1230112.2	3072179.5	5480.5		5478.5	5466.5	5448.5	
z118	1231676.2	3072030.3	5480.0		5478.0	5466.0	5448.0	
z119	1232468.8	3073548.1	5482.2		5480.2	5468.2	5450.2	
z120	1236005.8	3074075.7	5364.0		5353.8	5341.8	5323.8	
z121	1234043.2	3074648.2	5398.1		5396.1	5384.1	5366.1	
z122	1235336.9	3072890.5	5387.4		5385.4	5373.4	5355.4	
z123	1236461.4	3072811.5	5389.2		5387.2	5375.2	5357.2	
z124	1233532.0	3076657.7	5394.4		5367.0	5355.0	5337.0	
z125	1235129.1	3076675.1	5377.1		5357.5	5345.5	5327.5	
z127	1235377.5	3075938.8	5373.5		5355.5	5343.5	5325.5	
z128	1236268.5	3075936.1	5362.6		5343.3	5331.3	5313.3	
z129	1237218.5	3073727.1	5356.8		5354.8	5342.8	5324.8	
z130	1236548.9	3075284.2	5356.0		5340.3	5328.3	5310.3	
z131	1231589.2	3072229.0	5468.0		5465.0	5453.0	5435.0	Bedrock set 3 feet below existing ground at this point to eliminte pinchout.
z132	1231463.7	3072438.0	5465.3		5463.3	5451.3	5433.3	
z133	1231388.6	3072445.2	5468.0		5466.0	5454.0	5436.0	
z134	1231278.1	3072451.8	5476.0		5474.0	5462.0	5444.0	
z135	1231256.1	3072455.2	5478.0		5476.0	5464.0	5446.0	
z136	1231185.2	3072456.6	5478.0		5476.0	5464.0	5446.0	
z137	1230993.9	3072463.7	5474.0		5472.0	5460.0	5442.0	
z138	1230831.2	3072444.4	5474.0		5472.0	5460.0	5442.0	
z139	1230651.4	3072431.6	5474.0		5472.0	5460.0	5442.0	
z140	1230549.3	3072393.6	5476.0		5474.0	5462.0	5444.0	
z141	1230422.5	3072333.5	5476.0		5473.0	5461.0	5443.0	Bedrock set 3 feet below existing ground at this point to eliminate pinchout.
z142	1230229.2	3072241.6	5478.0		5476.0	5464.0	5446.0	
z143	1229763.8	3071915.3	5480.0		5478.0	5466.0	5448.0	
z144	1229646.7	3071747.8	5482.0		5480.0	5468.0	5450.0	
z145	1229558.5	3071605.3	5486.0		5484.0	5472.0	5454.0	
z146	1229391.1	3071378.9	5488.0		5486.0	5474.0	5456.0	
z147	1229283.8	3071310.7	5488.0		5486.0	5474.0	5456.0	
z148	1229027.0	3071358.9	5488.0		5486.0	5474.0	5456.0	
z149	1228957.5	3071517.6	5484.0		5482.0	5470.0	5452.0	

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z150	1229172.6	3071897.1	5476.0		5474.0	5462.0	5444.0	
z151	1229390.1	3072202.2	5474.0		5472.0	5460.0	5442.0	
z152	1229418.1	3072318.9	5480.0		5478.0	5466.0	5448.0	
z153	1229423.4	3072520.7	5476.0		5474.0	5462.0	5444.0	
z154	1229407.1	3072685.6	5476.7		5474.7	5462.7	5444.7	
z155	1229215.2	3072918.6	5476.3		5474.3	5462.3	5444.3	
z156	1228920.5	3073068.2	5478.0		5476.0	5464.0	5446.0	
z157	1232239.6	3072485.4	5498.0		5496.0	5484.0	5466.0	
z158	1232064.9	3072171.8	5490.0		5488.0	5476.0	5458.0	
z159	1231950.3	3072060.7	5488.0		5486.0	5474.0	5456.0	
z160	1232390.5	3073284.0	5488.0		5486.0	5474.0	5456.0	
z161	1231787.6	3072602.4	5450.0		5448.0	5436.0	5418.0	
z162	1229139.1	3071460.6	5482.0		5480.0	5468.0	5450.0	
z163	1229224.0	3071530.6	5480.0		5478.0	5466.0	5448.0	
z164	1229303.5	3071616.1	5478.0		5476.0	5464.0	5446.0	
z165	1229361.1	3071672.9	5476.0		5474.0	5462.0	5444.0	
z166	1229391.8	3071840.1	5474.0		5472.0	5460.0	5442.0	
z167	1229471.5	3071886.0	5472.0		5470.0	5458.0	5440.0	
z168	1229501.2	3071956.9	5470.0		5468.0	5456.0	5438.0	
z169	1229590.4	3072110.2	5468.0		5466.0	5454.0	5436.0	
z170	1229702.0	3072203.8	5466.0		5464.0	5452.0	5434.0	
z171	1229774.2	3072330.8	5464.0		5462.0	5450.0	5432.0	
z172	1229945.3	3072485.4	5462.0		5460.0	5448.0	5430.0	
z173	1230058.2	3072608.7	5460.0		5458.0	5446.0	5428.0	
z174	1230254.3	3072668.3	5458.0		5456.0	5444.0	5426.0	
z175	1230342.7	3072759.1	5456.0		5454.0	5442.0	5424.0	
z176	1230515.4	3072821.8	5454.0		5452.0	5440.0	5422.0	
z177	1230766.8	3072894.8	5452.0		5450.0	5438.0	5420.0	
z178	1230866.5	3073065.8	5450.0		5448.0	5436.0	5418.0	
z179	1230943.2	3073247.2	5448.0		5446.0	5434.0	5416.0	
z180	1231007.9	3073372.3	5446.0		5444.0	5432.0	5414.0	
z181	1231319.1	3073446.5	5444.0		5442.0	5430.0	5412.0	
z182	1231417.5	3073488.7	5442.0		5440.0	5428.0	5410.0	
z183	1231486.0	3073505.8	5440.0		5438.0	5426.0	5408.0	
z184	1231590.8	3073512.0	5438.0		5436.0	5424.0	5406.0	
z185	1231739.7	3073488.8	5438.0		5436.0	5424.0	5406.0	
z186	1231764.5	3073270.2	5436.0		5434.0	5422.0	5404.0	
z187	1231822.7	3073118.4	5438.0		5436.0	5424.0	5406.0	
z188	1231847.4	3072999.3	5440.0		5438.0	5426.0	5408.0	
z189	1231852.1	3072879.7	5442.0		5440.0	5428.0	5410.0	
z190	1231881.1	3072805.2	5444.0		5442.0	5430.0	5412.0	
z191	1231876.9	3072741.2	5446.0		5444.0	5432.0	5414.0	
z192	1231932.1	3072678.4	5448.0		5446.0	5434.0	5416.0	
z193	1231853.8	3072603.0	5450.0		5448.0	5436.0	5418.0	
z194	1231995.6	3072302.3	5470.0		5468.0	5456.0	5438.0	
z195	1231787.5	3072098.1	5472.0		5470.0	5458.0	5440.0	
z196	1232131.5	3072578.3	5468.0		5465.0	5453.0	5435.0	Bedrock set 3 feet below existing ground at this point to eliminate pinchout area.
z197	1232206.4	3072936.4	5464.0		5462.0	5450.0	5432.0	
z198	1232239.1	3073243.4	5460.0		5458.0	5446.0	5428.0	
z199	1232342.4	3073543.9	5452.0		5450.0	5438.0	5420.0	
z200	1232118.7	3073238.6	5444.0		5442.0	5430.0	5412.0	
z201	1231399.8	3073092.1	5452.0		5450.0	5438.0	5420.0	
z202	1229546.9	3072321.3	5476.0		5474.0	5462.0	5444.0	

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z203	1229245.2	3073502.6	5456.0		5454.0	5442.0	5424.0	
z204	1229001.7	3073442.2	5458.0		5456.0	5444.0	5426.0	
z205	1228872.6	3073436.2	5460.0		5458.0	5446.0	5428.0	
z206	1229346.6	3073409.0	5458.0		5456.0	5444.0	5426.0	
z207	1229549.5	3073486.3	5454.0		5452.0	5440.0	5422.0	
z208	1229123.0	3073333.2	5462.0		5460.0	5448.0	5430.0	
z209	1229902.1	3073830.8	5446.0		5444.0	5432.0	5414.0	
z210	1229339.4	3071922.6	5472.0		5470.0	5458.0	5440.0	
z211	1229441.4	3072044.9	5470.0		5468.0	5456.0	5438.0	
z212	1229238.1	3071854.1	5474.0		5472.0	5460.0	5442.0	
z213	1229161.9	3071403.0	5484.0		5482.0	5470.0	5452.0	
z214	1229272.8	3071506.7	5480.0		5478.0	5466.0	5448.0	
z215	1229305.1	3071558.8	5478.0		5476.0	5464.0	5446.0	
z216	1229511.0	3071811.7	5476.0		5474.0	5462.0	5444.0	
z217	1229664.4	3072045.4	5470.0		5468.0	5456.0	5438.0	
z218	1229882.0	3072190.6	5470.0		5468.0	5456.0	5438.0	
z219	1229992.3	3072307.7	5468.0		5466.0	5454.0	5436.0	
z220	1230088.4	3072455.7	5464.0		5462.0	5450.0	5432.0	
z221	1230239.9	3072534.2	5462.0		5460.0	5448.0	5430.0	
z222	1230413.6	3072623.1	5458.0		5456.0	5444.0	5426.0	
z223	1230565.4	3072649.4	5458.0		5456.0	5444.0	5426.0	
z224	1230663.9	3072709.5	5456.0		5454.0	5442.0	5424.0	
z225	1230736.3	3072743.3	5454.0		5452.0	5440.0	5422.0	
z226	1230870.6	3072774.7	5454.0		5452.0	5440.0	5422.0	
z227	1230963.1	3073012.2	5452.0		5450.0	5438.0	5420.0	
z228	1231155.2	3072953.6	5454.0		5452.0	5440.0	5422.0	
z229	1231243.0	3073175.4	5450.0		5448.0	5436.0	5418.0	
z230	1231564.4	3073293.8	5438.0		5436.0	5424.0	5406.0	
z231	1231603.3	3073178.2	5438.0		5436.0	5424.0	5406.0	
z232	1231607.2	3073022.9	5440.0		5438.0	5426.0	5408.0	
z233	1231599.7	3072902.2	5442.0		5440.0	5428.0	5410.0	
z234	1231602.7	3072816.2	5444.0		5442.0	5430.0	5412.0	
z235	1231583.6	3072749.8	5446.0		5444.0	5432.0	5414.0	
z236	1231622.4	3072688.3	5448.0		5446.0	5434.0	5416.0	
z237	1231649.1	3072557.1	5452.0		5450.0	5438.0	5420.0	
z238	1231625.0	3072464.7	5456.0		5454.0	5442.0	5424.0	
z239	1231471.9	3072939.6	5446.0		5444.0	5432.0	5414.0	
z240	1231424.1	3072892.7	5450.0		5448.0	5436.0	5418.0	
z241	1232059.0	3073161.1	5440.0		5438.0	5426.0	5408.0	
z242	1232036.2	3073009.7	5442.0		5440.0	5428.0	5410.0	
z243	1232032.7	3072887.7	5446.0		5444.0	5432.0	5414.0	
z244	1232020.4	3072741.5	5448.0		5446.0	5434.0	5416.0	
z245	1232013.5	3072627.6	5452.0		5450.0	5438.0	5420.0	
z246	1231869.1	3072419.5	5456.0		5454.0	5442.0	5424.0	
z247	1231905.3	3072338.9	5460.0		5458.0	5446.0	5428.0	
z248	1231791.3	3072309.4	5460.0		5458.0	5446.0	5428.0	
z249	1231781.1	3072259.0	5462.0		5460.0	5448.0	5430.0	
z250	1231722.9	3072210.9	5464.0		5462.0	5450.0	5432.0	
z251	1232081.1	3073414.3	5438.0		5436.0	5424.0	5406.0	
z252	1232169.6	3073532.8	5438.0		5436.0	5424.0	5406.0	
z253	1232044.8	3073582.2	5432.0		5430.0	5418.0	5400.0	
z254	1231952.9	3073396.2	5434.0		5432.0	5420.0	5402.0	
z255	1231915.5	3073627.8	5436.0		5434.0	5422.0	5404.0	

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z256	1231892.4	3073867.2	5432.0		5430.0	5418.0	5400.0	
z257	1231772.7	3073806.8	5434.0		5432.0	5420.0	5402.0	
z258	1229490.3	3072255.4	5474.0		5472.0	5460.0	5442.0	
z259	1229547.3	3072244.2	5470.0		5468.0	5456.0	5438.0	
z260	1229569.7	3072295.2	5470.0		5468.0	5456.0	5438.0	
z261	1229596.2	3072314.5	5470.0		5468.0	5456.0	5438.0	
z262	1229571.9	3072326.0	5472.0		5470.0	5458.0	5440.0	
z263	1229601.0	3072381.7	5472.0		5470.0	5458.0	5440.0	
z264	1229629.6	3072409.5	5470.0		5468.0	5456.0	5438.0	
z265	1229715.2	3072507.0	5470.0		5468.0	5456.0	5438.0	
z266	1229771.6	3072579.3	5470.0		5468.0	5456.0	5438.0	
z267	1230973.4	3072667.5	5460.0		5458.0	5446.0	5428.0	
z268	1230988.8	3072832.3	5454.0		5452.0	5440.0	5422.0	
z269	1231177.7	3072889.4	5456.0		5454.0	5442.0	5424.0	
z270	1231191.0	3072843.5	5458.0		5456.0	5444.0	5426.0	
z271	1231194.1	3072795.9	5460.0		5458.0	5446.0	5428.0	
z272	1231209.9	3072758.8	5462.0		5460.0	5448.0	5430.0	
z273	1231214.6	3072715.9	5464.0		5462.0	5450.0	5432.0	
z274	1231216.6	3072671.3	5466.0		5464.0	5452.0	5434.0	
z275	1231226.4 ✓	3072633.4 ✓	5468.0 ✓		5466.0 ✓	5454.0 ✓	5436.0 ✓	
z276	1230852.6	3072685.7	5458.0		5456.0	5444.0	5426.0	
z277	1230911.8	3072580.0	5464.0		5462.0	5450.0	5432.0	
z278	1231072.3	3072785.0	5458.0		5456.0	5444.0	5426.0	
z279	1231076.5	3072680.7	5462.0		5460.0	5448.0	5430.0	
z280	1231083.0	3072607.0	5466.0		5464.0	5452.0	5434.0	
z281	1231970.3	3072570.4	5452.0		5450.0	5438.0	5420.0	
z282	1232021.4	3072510.1	5460.0		5457.5	5445.5	5427.5	Bedrock set 2.5 feet below existing gorund surface at this point to elimnate pinchout. ✓
z283	1232076.8	3072482.4	5468.0		5466.0	5454.0	5436.0	
z284	1232112.8	3072410.9	5478.0		5476.0	5464.0	5446.0	
z285	1231763.7	3072893.5	5442.0		5440.0	5428.0	5410.0	
z286	1231712.9	3073016.4	5440.0		5438.0	5426.0	5408.0	
z287	1231946.9 ✓	3073121.3 ✓	5438.0 ✓		5436.0 ✓	5424.0 ✓	5406.0 ✓	
z288	1231846.6	3073449.7	5436.0		5434.0	5422.0	5404.0	
z289	1231798.7	3072548.3	5452.0		5450.0	5438.0	5420.0	
z290	1232279.5	3072867.9	5480.0		5478.0	5466.0	5448.0	
z291	1232185.5	3072845.5	5464.0		5462.0	5450.0	5432.0	
z292	1232139.5	3073135.0	5448.0		5446.0	5434.0	5416.0	
z293	1232304.8	3073164.8	5484.0		5482.0	5470.0	5452.0	
z294	1232226.0	3073463.3	5446.0		5444.0	5432.0	5414.0	
z295	1232496.2	3073651.5	5452.0		5450.0	5438.0	5420.0	
z296	1232454.1	3073663.1	5450.0		5448.0	5436.0	5418.0	
z297	1232423.5	3073668.7	5450.0		5448.0	5436.0	5418.0	
z298	1232373.6	3073662.8	5448.0		5446.0	5434.0	5416.0	
z299	1232539.4	3073879.2	5436.0		5434.0	5422.0	5404.0	
z300	1228752.6 ✓	3073080.9 ✓	5470.0 ✓		5468.0 ✓	5456.0 ✓	5438.0 ✓	
z301	1228832.4	3073126.5	5470.0		5468.0	5456.0	5438.0	
z302	1228963.1	3073213.5	5468.0		5466.0	5454.0	5436.0	
z303	1229083.1	3073295.4	5464.0		5462.0	5450.0	5432.0	
z304	1228470.4	3073600.1	5458.0		5456.0	5444.0	5426.0	
z305	1228482.4	3073519.5	5460.0		5458.0	5446.0	5428.0	
z306	1228830.0 ✓	3073646.8 ✓	5456.0 ✓		5453.0 ✓	5441.0 ✓	5423.0 ✓	Bedrock set ~~2~~ 3 feet below existing ground at this point to eliminate pinchout areas. ✓
z307	1230951.5	3074858.1	5426.0		5424.0	5412.0	5394.0	
z308	1231831.0	3072103.7	5472.0		5470.0	5458.0	5440.0	

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z309	1231897.0	3072145.9	5472.0		5470.0	5458.0	5440.0	
z310	1231866.5	3072148.2	5470.0		5468.0	5456.0	5438.0	
z311	1231943.5	3072215.4	5470.0		5468.0	5456.0	5438.0	
z312	1231919.9	3072257.7	5466.0		5464.0	5452.0	5434.0	
z313	1232045.8	3072403.5	5470.0		5468.0	5456.0	5438.0	
z314	1231944.3	3072505.1	5454.0		5452.0	5440.0	5422.0	
z315	1232127.9	3072681.7	5464.0		5462.0	5450.0	5432.0	
z316	1232147.8	3072754.4	5464.0		5462.0	5450.0	5432.0	
z317	1232101.0	3072814.4	5454.0		5452.0	5440.0	5422.0	
z318	1232108.1	3072983.0	5448.0		5446.0	5434.0	5416.0	
z319	1232157.2	3073076.9	5452.0		5450.0	5438.0	5420.0	
z320	1232196.7	3073114.0	5460.0		5458.0	5446.0	5428.0	
z321	1232221.6	3073138.7	5462.0		5460.0	5448.0	5430.0	
z322	1232281.5	3073381.5	5456.0		5454.0	5442.0	5424.0	
z323	1232289.5	3073481.8	5452.0		5450.0	5438.0	5420.0	
z324	1232161.5	3073398.8	5444.0		5442.0	5430.0	5412.0	
z325	1232386.1	3073647.8	5450.0		5448.0	5436.0	5418.0	
z326	1232428.0	3073742.1	5448.0		5446.0	5434.0	5416.0	
z327	1229683.2	3072448.6	5468.0		5466.0	5454.0	5436.0	
z328	1229641.4	3072331.4	5466.0		5464.0	5452.0	5434.0	
z329	1229710.4	3072434.4	5466.0		5464.0	5452.0	5434.0	
z330	1229794.7	3072514.8	5466.0		5464.0	5452.0	5434.0	
z331	1229871.8	3072600.9	5466.0		5464.0	5452.0	5434.0	
z332	1230005.1	3072791.4	5462.0		5460.0	5448.0	5430.0	
z333	1229860.4	3072355.2	5464.0		5462.0	5450.0	5432.0	
z334	1229856.2	3072538.2	5464.0		5462.0	5450.0	5432.0	
z335	1230182.5	3072366.2	5470.0		5468.0	5456.0	5438.0	
z336	1230313.6	3072456.8	5464.0		5462.0	5450.0	5432.0	
z337	1230505.6	3072500.6	5464.0		5462.0	5450.0	5432.0	
z338	1230607.0	3072516.8	5466.0		5464.0	5452.0	5434.0	
z339	1230740.2	3072620.6	5460.0		5458.0	5446.0	5428.0	
z340	1230775.6	3072510.0	5468.0		5466.0	5454.0	5436.0	
z341	1230859.4	3072542.5	5466.0		5464.0	5452.0	5434.0	
z342	1235551.5	3072961.6	5380.0		5378.0	5366.0	5348.0	
z343	1235412.7	3072994.0	5380.0		5378.0	5366.0	5348.0	
z344	1235616.3	3073031.5	5376.0		5374.0	5362.0	5344.0	
z345	1232378.7	3073870.5	5436.0		5434.0	5422.0	5404.0	
z346	1232425.1	3073941.1	5434.0		5432.0	5420.0	5402.0	
z347	1232322.5	3073904.3	5434.0		5432.0	5420.0	5402.0	
z348	1232470.9	3073866.8	5436.0		5434.0	5422.0	5404.0	
z349	1232544.1	3073812.9	5444.0		5442.0	5430.0	5412.0	
z350	1230454.7	3074090.1	5434.0		5432.0	5420.0	5402.0	
z351	1229568.8	3071943.0	5470.0		5468.0	5456.0	5438.0	
z352	1229575.5	3071891.8	5472.0		5470.0	5458.0	5440.0	
z353	1229577.9	3071820.7	5476.0		5474.0	5462.0	5444.0	
z354	1229414.9	3071803.9	5474.0		5472.0	5460.0	5442.0	
z355	1229613.0	3071969.5	5470.0		5468.0	5456.0	5438.0	
z356	1229644.1	3071878.7	5474.0		5472.0	5460.0	5442.0	
z357	1229695.1	3071978.3	5474.0		5472.0	5460.0	5442.0	
z358	1229763.6	3072014.7	5476.0		5474.0	5462.0	5444.0	
z359	1229014.5	3071670.2	5478.0		5476.0	5464.0	5446.0	
z360	1228891.3	3073233.0	5464.0		5462.0	5450.0	5432.0	
z361	1228859.1	3073186.4	5470.0		5468.0	5456.0	5438.0	

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z362	1232099.0	3073905.5	5430.0		5428.0	5416.0	5398.0	
z363	1232008.6	3073988.8	5430.0		5428.0	5416.0	5398.0	
z364	1232244.3	3073917.1	5430.0		5428.0	5416.0	5398.0	
z365	1235887.0	3073073.7	5368.0		5366.0	5354.0	5336.0	
z366	1235999.2	3073423.8	5364.0		5362.0	5350.0	5332.0	
z367	1235886.6	3073021.3	5370.0		5368.0	5356.0	5338.0	
z368	1235897.1	3072950.7	5372.0		5370.0	5358.0	5340.0	
z369	1235907.7	3072880.4	5374.0		5372.0	5360.0	5342.0	
z370	1235750.4	3072802.2	5382.0		5380.0	5368.0	5350.0	
z371	1235725.0	3072568.2	5388.0		5386.0	5374.0	5356.0	
z372	1238044.2	3074111.4	5344.0		5342.0	5330.0	5312.0	
z373	1235440.8	3072818.7	5384.0		5382.0	5370.0	5352.0	
z374	1235615.8	3072728.1	5384.0		5382.0	5370.0	5352.0	
z375	1235585.1	3072627.8	5386.0		5384.0	5372.0	5354.0	
z376	1235529.0	3072876.9	5380.0		5378.0	5366.0	5348.0	
z377	1235520.6	3072782.1	5382.0		5380.0	5368.0	5350.0	
z378	1238762.6	3074339.8	5332.0		5330.0	5318.0	5300.0	
z379	1238672.8	3074276.7	5332.0		5330.0	5318.0	5300.0	
gis0	1235049.1	3075090.7	5367.18		5361	5349	5331	**ATMerook ADDED**
gis1	1235024.7	3075885.9	5361.55		5359.5	5347.5	5329.5	Northern Deepe Pit XS bedrock reported above existing ground surface; lowered 2 feet below existing ground.
gis2	1232944.9	3074493.5	5406.73		5390	5378	5360	
gis3	1232937.9	3075597.7	5401.56		5382	5370	5352	
gis4	1232943.2	3076275.5	5394.06		5385	5373	5355	
gis5	1232631.7	3075378.5	5408.02		5390	5378	5360	
gis6	1232099.1	3074873.3	5415.60		5395	5383	5365	
gis7	1232307.4	3074628.5	5414.00		5395	5383	5365	
gis8	1232547.0	3074472.3	5413.94		5395	5383	5365	
gis9	1232854.3	3074373.3	5415.78		5395	5383	5365	
gis10	1233312.7	3074435.8	5412.64		5395	5383	5365	
gis11	1233135.6	3074493.1	5406.18		5390	5378	5360	
gis12	1232880.4	3074675.4	5396.00		5390	5378	5360	
gis13	1233010.6	3075045.2	5391.97		5385	5373	5355	
gis14	1233307.4	3074899.3	5390.13		5380	5368	5350	
gis15	1233625.2	3075019.1	5385.59		5375	5363	5345	
gis16	1233458.5	3076112.9	5380.00		5370	5358	5340	
gis17	1234677.2	3076684.1	5369.18		5365	5353	5335	
gis18	1235411.6	3074222.3	5365.81		5360	5348	5330	
gis19	1235328.3	3074550.4	5366.81		5360	5348	5330	
gis20	1235234.5	3075638.9	5363.68		5360	5348	5330	
gis21	1234828.3	3075123.3	5369.00		5365	5353	5335	
gis22	1234797.0	3074836.8	5369.02		5365	5353	5335	
gis23	1234838.7	3076382.0	5367.85		5365	5353	5335	
gis24	1233317.9	3076300.4	5381.32		5370	5358	5340	
gis25	1233234.5	3075982.7	5380.98		5375	5363	5345	
gis26	1233359.5	3075415.0	5385.92		5375	5363	5345	
gis27	1233500.2	3075170.2	5385.33		5375	5363	5345	
gis28	1233823.1	3074899.3	5385.77		5375	5363	5345	
gis29	1233675.5	3074781.3	5388.97		5380	5368	5350	
gis30	1233460.2	3074611.1	5395.15		5385	5373	5355	
gis31	1233710.2	3074635.5	5400.02		5390	5378	5360	
gis32	1237344.8	3074101.2	5352.93		5335	5323	5305	
gis33	1237314.4	3074227.0	5344.29		5335	5323	5305	
gis34	1237279.7	3074387.6	5341.74		5335	5323	5305	

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gis35	1237279.7	3074795.6	5344.90		5335	5323	5305	
gis36	1237260.1	3074596.0	5344.93		5335	5323	5305	
gis37	1236727.1	3074350.3	5351.42		5340	5328	5310	
gis38	1236702.8	3074503.1	5353.00		5340	5328	5310	
gis39	1236657.7	3074652.4	5353.98		5340	5328	5310	
gis40	1236633.4	3074850.3	5354.97		5340	5328	5310	
gis41	1236748.0	3074239.2	5350.80		5340	5328	5310	
gis42	1236612.6	3074992.7	5354.97		5340	5328	5310	
gis43	1236296.6	3074659.3	5357.15		5345	5333	5315	
gis44	1236369.5	3074371.1	5357.32		5345	5333	5315	
gis45	1236435.5	3074159.3	5352.26		5345	5333	5315	
gis46	1236251.5	3074940.6	5359.00		5345	5333	5315	
gis47	1236234.1	3075207.9	5355.85		5345	5333	5315	
gis48	1236227.1	3075339.9	5353.19		5345	5333	5315	
gis49	1236185.5	3075517.0	5350.60		5345	5333	5315	
gis50	1236150.8	3075843.4	5352.11		5345	5333	5315	
gis51	1236029.2	3074565.6	5359.03		5350	5338	5320	
gis52	1235970.2	3074808.6	5360.69		5350	5338	5320	
gis53	1235909.4	3075517.0	5355.28		5350	5338	5320	
gis54	1235933.7	3075030.9	5360.54		5350	5338	5320	
gis55	1235902.5	3075280.9	5357.68		5350	5338	5320	
gis56	1235902.5	3075756.5	5350.88		5350	5338	5320	
gis57	1235781.0	3074128.1	5371.64		5355	5343	5325	
gis58	1235728.9	3074312.1	5363.00		5355	5343	5325	
gis59	1235718.5	3074433.6	5362.97		5355	5343	5325	
gis60	1235652.5	3074631.5	5363.00		5355	5343	5325	
gis61	1235590.0	3074930.2	5361.59		5355	5343	5325	
gis62	1235527.5	3075228.8	5359.76		5355	5343	5325	
gis63	1235496.2	3075419.7	5361.30		5355	5343	5325	
gis64	1235204.6	3075072.5	5365.02		5360	5348	5330	
gis65	1235225.4	3075353.8	5366.00		5360	5348	5330	
gis66	1235253.2	3074791.3	5367.20		5360	5348	5330	
gis67	1234267.1	3074937.1	5380.09		5370	5358	5340	
gis68	1233986.7	3075120.3	5380.86		5370	5358	5340	
gis69	1233676.4	3075816.9	5379.89		5370	5358	5340	
gis70	1233800.6	3075601.7	5380.18		5370	5358	5340	
gis71	1235010.4	3076085.6	5357.96		5355.5	5343.5	5325.5	Bedrock point added to force bedrock surface below existing ground where channel likely exists based on Northern Deepe Pit XS information
gis72	1235337.2	3075781.6	5355.48		5353.5	5341.5	5323.5	Bedrock point added to force bedrock surface below existing ground where channel likely exists based on Northern Deepe Pit XS information
gis73	1235137.4	3075928.8	5356.69		5355.0	5343.0	5325.0	Bedrock point added to force bedrock surface below existing ground where channel likely exists based on Northern Deepe Pit XS information
gis74	1235686.6	3075744.2	5352.04		5348.5	5336.5	5318.5	Bedrock point added to force bedrock surface below existing ground where channel likely exists based on Northern Deepe Pit XS information
gis75	1235230.9	3075824.5	5356.00		5354.0	5342.0	5324.0	Bedrock point added to force bedrock surface below existing ground where channel likely exists based on Northern Deepe Pit XS information
gis76	1234983.5	3076338.8	5359.00		5358.0	5346.0	5328.0	Bedrock point added to force bedrock surface below existing ground where channel likely exists based on Northern Deepe Pit XS information
gis77	1234847.2	3076778.3	5363.00		5358.5	5346.5	5328.5	Bedrock point added to force bedrock surface below existing ground where channel likely exists based on Northern Deepe Pit XS information
gis78	1235060.4	3075980.3	5357.00		5355.0	5343.0	5325.0	Bedrock point added to force bedrock surface below existing ground where channel likely exists based on Northern Deepe Pit XS information
gis79	1232833.9	3075107.5	5386.91		5384.00	5372.0	5354.0	Bedrock set 2.91 feet below existing ground (to nearest foot) to eliminate pinchout area.

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Excerpt of 62,500 data points for TOR surface exported from VMOD

X	Y	Z
3071278	1227727	5482.234
3071312	1227727	5481.778
3071347	1227727	5481.646
3071381	1227727	5482.711
3071415	1227727	5482.709
3071449	1227727	5482.576
3071484	1227727	5482.598
3071518	1227727	5481.877
3071552	1227727	5481.737
3071586	1227727	5481.584
3071621	1227727	5481.428
3071655	1227727	5481.273
3071689	1227727	5481.114
3071723	1227727	5480.959
3071758	1227727	5479.937
3071792	1227727	5479.762
3071826	1227727	5479.586
3071860	1227727	5478.725
3071895	1227727	5478.553
3071929	1227727	5478.779
3071963	1227727	5478.604
3071997	1227727	5478.431
3072032	1227727	5477.575
3072066	1227727	5477.439
3072100	1227727	5477.302
3072135	1227727	5477.167
3072169	1227727	5477.031
3072203	1227727	5476.896
3072237	1227727	5476.762
3072272	1227727	5476.627
3072306	1227727	5476.494
3072340	1227727	5476.361
3072374	1227727	5476.229
3072409	1227727	5476.097
3072443	1227727	5475.965
3072477	1227727	5475.834
3072511	1227727	5471.555
3072546	1227727	5471.299
3072580	1227727	5471.037
3072614	1227727	5470.769
3072648	1227727	5470.496
3072683	1227727	5468.746
3072717	1227727	5467.739
3072751	1227727	5467.5
3072785	1227727	5467.255
3072820	1227727	5466.412

APPENDIX E

MATERIAL PROPERTY REFERENCE DATA

Anisotropy Ratio

Permeability (k_V) of Embankment Core Materials (k_V inversely related to % fines)

Unified Soil Classification	k_V Range (ft/yr or $x10^{-6}$ cm/s)*
GM-SM	0.0 to 10.0
GM or GC	0.0 to 10.0
SP-SM	0.0 to 10.0
SM	0.0 to 10.0
SM-SC	0.0 to 3.0
SM-ML	0.0 to 10.0
SC	0.0 to 3.0
ML	0.0 to 10.0
ML-CL	0.0 to 1.0
CL	0.0 to 1.0
MH	0.0 to 0.1

References: [31-32], [34], [44-45]
* Based primarily on Reclamation laboratory test data

Permeability (k_V) of Embankment Shell Materials (k_V inversely related to % fines)

Unified Soil Classification	k_V Range (ft/yr or $x10^{-6}$ cm/s)
GP	2,000 to 1,000,000
GW	1,000 to 100,000
GP-SP	1,000 to 50,000
GW-SW	500 to 5,000
GM	10 to 500
SP (medium to coarse)	10,000 to 20,000
SP (fine to medium)	5,000 to 10,000
SP (very fine to fine)	500 to 5,000
SW	300 to 5,000
SP-SM	10 to 1,000
SM	10 to 500

References: [18], [26], [33], [36], [44-45]

Permeability (k_V) of Washed Embankment Drain Materials (k_V increases with grain size)

Material	k_V Range (ft/yr or $x10^{-6}$ cm/s)
Coarse sand and gravel	150,000 to 500,000
Medium to coarse sand	50,000 to 150,000
Fine to medium sand	10,000 to 50,000

References: [18], [26], [33], [36], [45]

Anisotropy (k_H/k_V) of embankment materials (k_H/k_V increases with placement water content)

Material	k_H/k_V Range
Embankment core Reclamation standard placement	4 to 9
Nonstandard placement	9 to 36
Hydraulic fill	64 to 225
Embankment shell Reclamation standard	4 to 9
Embankment drains Reclamation standard	1 to 4

Fill - assume 10 (clayey sand)

References: [3], [17], [21], [31], [37]

Figure 8.3.2.3.3-1. Permeability of various embankment materials.

8.3.2.4 Effect of Degree of Saturation on Permeability

The degree of saturation of a soil has an important influence on permeability, with a decrease in saturation leading to a decrease in permeability. Testing done by Lambe [46] indicates that when the degree of saturation of a soil is less than 85 percent, much of the air would be continuous throughout the soil void space,

U.S. Bureau of Reclamation (Reclamation) (2014). Design Standards No. 13 Embankment Dams, Chapter 8 Seepage, Phase 4 (Final). January.

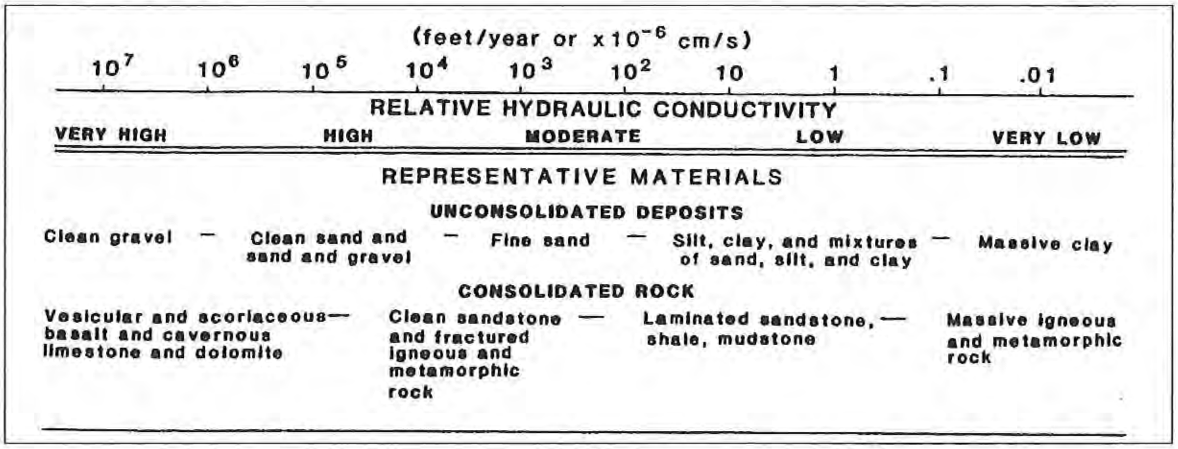


Figure 8.3.2.2-1. Hydraulic conductivities for various classes of geologic materials [15].

8.3.2.3 Variations in Permeability Values Due to Anisotropy

In addition to potentially having a wide range of permeability, most soils can have significant variability in the ratio of horizontal to vertical permeability given the general stratified nature of both natural and, in some cases, man-placed deposits. In this design standard, this difference in horizontal and vertical permeability is defined as anisotropy. Anisotropy is primarily due to the method of deposition or placement but also can be influenced by particle shape and orientation. In rock, the fracture and joint pattern is obviously a key factor.

8.3.2.3.1 Anisotropy in Natural Soil Deposits

Alluvium - Assume ~ 100

Water-deposited soils, which include alluvial/fluvial and lacustrine types of deposition, are typically deposited in horizontal layers and are highly stratified in nature. Such deposits can have horizontal to vertical permeability ratios (k_H/k_V) of more than 100. Fine-grained strata control the vertical permeability, and coarse-grained strata control the horizontal permeability. For a given stratified deposit of significant thickness, a single continuous layer of clay will likely control the overall vertical permeability of the entire deposit, while a uniform, open-work, or particularly permeable coarse layer will likely control the horizontal permeability of the deposit. It thus becomes essential to accurately define the stratigraphy of such a soil foundation.

Windblown deposits such as dune sand and loess tend to have low values of k_H/k_V, typically ranging from 0.2 to 2. (For permeability values in loess, reference [16] contains a summary of a significant amount of testing of loessial soils associated with Reclamation facilities.) These types of deposits are often more permeable in the vertical, rather than the horizontal, direction due to the presence of continuous root holes (and the typical lack of horizontal bedding). As stated earlier, a complication with assessing the permeability of windblown soils

U.S. Bureau of Reclamation (Reclamation) (2014). Design Standards No. 13 Embankment Dams, Chapter 8 Seepage, Phase 4 (Final). January.

is that they can be subject to significant collapse upon wetting, which can lead to significant changes in permeability between the in situ condition and post-wetting (post-reservoir) condition.

Figure 8.3.2.3.1-1 shows some typical permeability values referenced from various sources [15-42] for natural soils, as well as the expected range of anisotropy.

Permeability k_H of Unconsolidated Natural Soils (k_H inversely related to % finer grains)

Soil	k_H Range (ft/yr or 10^{-6} cm/s)
Gravel, open-work	>2,000,000
Gravel (GP)	200,000 to 2,000,000
Gravel (GW)	10,000 to 1,000,000
Sand, coarse (SP)	10,000 to 500,000
Sand, medium (SP)	1,000 to 100,000
Sand, fine (SP)	500 to 50,000
Sand (SW)	100 to 50,000
Sand, silty (SM)	100 to 10,000
Sand, clayey (SC)	1 to 1,000
Silt (ML)	1 to 1,000
Clay (CL)	~0 to 3

References: [15], [18], [22-29], [32-36]

Permeability k_H of Unfractured Rock (k_H increases with pore size)

Rock	k_H Range (ft/yr or 10^{-6} cm/s)
Sandstone, medium	100 to 200,000
Sandstone, silty	~0 to 5,000
Limestone	~0 to 15,000
Granite, weathered	200 to 10,000
Schist	~0 to 2,000
Tuff	~0 to 1,000
Gabbro, weathered	50 to 500
Basalt	~0 to 50
Dolomite	~0 to 5
Gneiss	~0 to 2

References: [15], [25], [27-28], [34], [36]

Anisotropy of Natural Soil and Rock

Formation	k_H/k_V	Remarks
Stratified deposits	10 to 1,000	k_H/k_V depends on grain size of substrata
Massive soil or rock	1 to 3	Depends on particle shape and orientation
Fractured rock	0.1 to 10	Depends on aperture arrangement
Eolian soil (loess and dune)	0.02 to 2	Depends on consolidation

References: [3], [15], [17], [19-21], [24], [30-32], [35-42]

Alluvium assume ~100

Figure 8.3.2.3.1-1 Permeability of natural soil and rock.

Pierre Shale assume ~10

8.3.2.3.2 Anisotropy in Bedrock

Permeability in rock is typically defined in terms of primary and secondary permeability. Primary permeability in rock refers to flow through the grain structure of the material. Secondary permeability refers to flow through joints, fractures, or other finite open discontinuities in the rock unit. Primary permeability in unstratified (massive) permeable rock generally has low anisotropy (k_H/k_V equal to 1 or 2). Fractured rock anisotropy, or secondary permeability, is quite complex and governed by factors such as fracture orientation, fracture density, and aperture size. These factors may also govern whether Darcy flow is assumed to apply to bedrock.

U.S. Bureau of Reclamation (Reclamation) (2014). Design Standards No. 13 Embankment Dams, Chapter 8 Seepage, Phase 4 (Final). January.

Specific Storage

Table 5.2 Typical values of specific storage (S_s) (adapted from Domenico, 1972)

	Material	Specific storage (S_s) (m^{-1})
	Plastic clay	$2.0 \times 10^{-2} - 2.6 \times 10^{-3}$
	Stiff clay	$2.6 \times 10^{-3} - 1.3 \times 10^{-3}$
	Medium–hard clay	$1.3 \times 10^{-3} - 9.2 \times 10^{-4}$
	Loose sand	$1.0 \times 10^{-3} - 4.9 \times 10^{-4}$
Fill	Dense sand	$2.0 \times 10^{-4} - 1.3 \times 10^{-4}$
Alluvium	Dense sandy gravel	$1.0 \times 10^{-4} - 4.9 \times 10^{-5}$
	Rock, fissured, jointed	$6.9 \times 10^{-5} - 3.3 \times 10^{-6}$
Pierre Shale	Rock, sound	Less than 3.3×10^{-6}

using Eqn (5.7) or estimated from literature values (Table 5.2). Because storage parameters are typically not well constrained by field data, uncertainty in values of storage is usually evaluated during model calibration.

5.4.1.3 Vertical Leakance, Resistance, and Conductance

Surface water features often are simulated in a groundwater model by head-dependent boundary conditions (Section 4.3) whereby the rate of exchange of water between surface water and groundwater is affected by sediments present at the sediment—water interface. The vertical hydraulic conductivity and thickness of the sediments is used to calculate flow rate through the sediments (Eqn (4.5)), where vertical leakance is the vertical hydraulic conductivity of the sediments divided by their thickness (K_z'/b'); vertical resistance, (b'/K_z'), is the inverse of leakance. Vertical conductance is leakance times the horizontal area of the sediments within the cell (Eqn (4.4b)).

Vertical leakance is difficult to measure in the field; point measurements are strongly affected by local heterogeneity in K_z', which makes upscaling problematic (e.g., Rosenberry et al., 2008). In practice, vertical leakance (or conductance) is estimated during model calibration. Generic guidelines for the relative magnitude of K_z' can be helpful when checking that calibrated values are reasonable for the hydrogeologic setting being simulated. For example, littoral sediments (sediments disturbed by waves and currents) have relatively higher K_z' than finer sediments deposited in deeper and calmer water. In areas where surface water recharges an aquifer, sediments may have lower K_z' than areas where groundwater discharge occurs owing to clogging of pore space by fine-grained sediment suspended in surface water (Lee, 1977; Rose, 1993).

Head-dependent conditions only approximately represent the relevant geometry and flow system around surface water features and fine spatial discretization may be required to represent properties associated with surface water features (Section 5.2). Consequently, adjusting vertical leakance (or conductance) during calibration offsets artifacts introduced by discretization such that calibrated leakance values likely will not agree even with

Anderson, M.P., Woessner, W.W., and Hunt, R.J. (2015). Applied Groundwater Modeling: Simulation of Flow and Advective Transport (Second Edition). Academic Press.

Specific Yield

TABLE 5.—*Properties of sand and gravel*

[Classified by predominant particle size]

Test	Fine			Medium			Coarse		
	Range	Arithmetic mean	Number of analyses	Range	Arithmetic mean	Number of analyses	Range	Arithmetic mean	Number of analyses
Sand									
Permeability, repacked (gpd per sq ft)	0.4 – 400	61	159	2.0 – 1,200	300	255	2.0 –14,000	1,100	158
Permeability, vertical (gpd per sq ft)	.1 – 980	94	164	1 – 1,900	340	112	18.0 – 1,900	680	20
Dry unit weight (g per cc)	1.13– 1.99	1.55	374	1.27– 1.93	1.69	341	1.42– 1.94	1.73	158
Specific gravity of solids	2.54– 2.77	2.67	356	2.60– 2.77	2.66	287	2.52– 2.73	2.65	102
Porosity, undisturbed (percent)	26.0 – 53.3	43	243	28.5 – 48.9	39	127	30.9 – 46.4	39	26
Porosity, repacked (percent)	26.7 – 50.2	32	134	27.2 – 52.3	35	213	37.0 – 42.0	34	132
Centrifuge-moisture equivalent (percent)	.1 – 33.7	4	288	.1 – 8.8	1	295	.1 – 8.2	1	142
Specific retention (percent)	.3 – 43.2	8	264	.1 – 17.8	4	292	.5 – 17.6	5	143
Specific yield (percent)	1.0 – 45.9	33	287	16.2 – 46.2	32	297	18.4 – 42.9	30	143
Gravel									
Permeability, repacked (gpd per sq ft)	960 –66,000	11,000	22	730 –40,000	6,700	11	1,200 – 7,400	3,700	7
Dry unit weight (g per cc)	1.60– 1.99	1.76	41	1.47– 2.09	1.85	24	1.69– 2.08	1.93	15
Specific gravity of solids	2.63– 2.76	2.68	19	2.65– 2.79	2.71	25	2.64– 2.76	2.69	17
Porosity, repacked (percent)	25.1 – 38.5	34	38	23.7 – 44.1	32	22	23.8 – 36.5	28	15
Centrifuge-moisture equivalent (percent)	.01– 8.2	2	33	.1 – 6.8	3	15	.6 – 5.4	3	10
Specific retention (percent)	.06– 16.7	7	33	.6 – 14.9	7	13	3.1 – 13.8	9	10
Specific yield (percent)	12.6 – 39.9	28	33	16.9 – 43.5	24	13	13.2 – 25.2	21	9

Morris, D.A. and Johnson, A.I. (1967). Summary of Hydrologic and Physical Properties of Rock and Soil Materials, as Analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, 1948-60. U.S. Geological Survey, Water-Supply Paper 1839-D. Available at: https://doi.org/10.3133/wsp1839D.

TABLE 6.—*Properties of silt and clay*

Test	Silt			Clay		
	Range	Arithmetic mean	Number of analyses	Range	Arithmetic mean	Number of analyses
Permeability, vertical (gpd per sq ft)	0.0002–15	0.6	39	0.00003–0.01	0.002	19
Permeability, horizontal (gpd per sq ft)	.0004–23	2	39	.0002 – .03	.005	19
Dry unit weight (g per cc)	1.01 – 1.79	1.38	374	1.18 – 1.72	1.49	91
Specific gravity of solids	2.47 – 2.79	2.62	388	2.51 – 2.77	2.67	104
Porosity, undisturbed (percent)	33.9 –61.1	46	281	34.2 –56.9	42	74
Porosity, repacked (percent)	41.0 –56.0	46	85	39.9 –52.8	48	16
Centrifuge-moisture equivalent (percent)	3.6 –46.5	13	266	15.6 –51.1	30	27
Specific retention (percent)	3.2 –45.0	28	266	24.6 –46.9	38	27
Specific yield (percent)	1.1 –38.6	20	266	1.1 –17.6	6	27

study, however, comparisons were made only on the basis of predominant particle size.

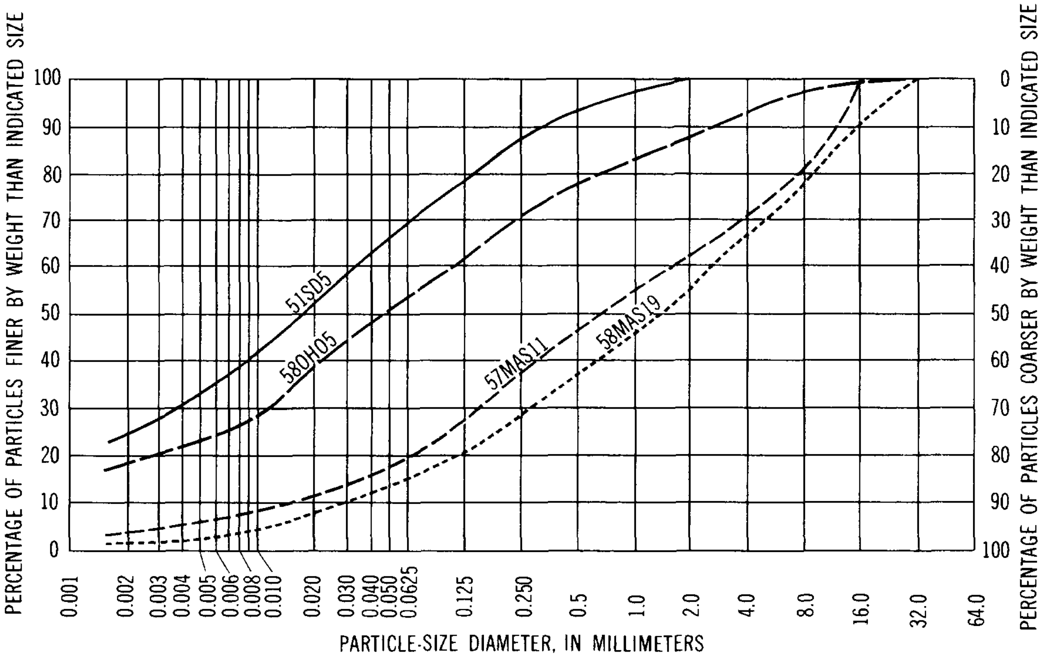
Analysis of individual sample data has indicated that horizontal permeabilities for the same sample are generally higher that the vertical permeabilities, and that repacked permeabilities are higher than either the horizontal or vertical permeabilities, which seems to be a logical relation—especially for stratified sedimentary rocks. Data also indicate that repacked porosity is generally higher than undisturbed porosity and that the dry unit weight of repacked samples is generally lower than that of undisturbed samples.

Silt and clay and their consolidated counterparts—siltstone, claystone, and shale—bear the same relation to one another that the coarse-grained rocks exhibit. Clay is the poorest source of water supply, not because it has low porosity and contains no water, but because the particles of clay and their interstices are very small. So, even though the porosity may be comparatively large, the minute pores hold water tenaciously and release it slowly.

WIND-LAID DEPOSITS

Wind-laid deposits are generally formed from the particles that are derived from weathering of older rocks and are transported by

Morris, D.A. and Johnson, A.I. (1967). Summary of Hydrologic and Physical Properties of Rock and Soil Materials, as Analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, 1948-60. U.S. Geological Survey, Water-Supply Paper 1839-D. Available at: https://doi.org/10.3133/wsp1839D.



PERCENTAGE OF PARTICLES, OF INDICATED SIZE

CLAY <0.004	SILT 0.004-0 0625	SAND Very fine 0 0625-0 125	SAND Fine 0 125-0.25	SAND Medium 0.25-0 5	SAND Coarse 0 5-1	SAND Very coarse 1-2	GRAVEL Very fine 2-4	GRAVEL Fine 4-8	GRAVEL Medium 8-16	GRAVEL Coarse 16-32	GRAVEL Very coarse 32-64
——— 30.5	38.9	9.0	8 8	6.2	3.8	2.8					
— — 21.9	31 7	7.7	9.1	7.4	5.3	4.7	4.9	4.5	2 2	0.6	
– – – 5.4	14.6	6.8	9.3	9.0	8.7	8.0	9.2	10.5	18.5		
-------- 2.1	12.8	5.1	7.6	8.9	9.3	9.2	12.0	10.1	13.1	9.8	

HYDROLOGIC AND PHYSICAL PROPERTIES

Fill

Lab. No.	Location	Depth of sample (feet)	Specific gravity of solids	Dry unit weight (g per cc)	Specific retention (percent of volume)	Total porosity (percent of volume)	Specific yield (percent of volume)	Coefficient of permeab'lity (gpd per sq ft
51SD5	Hand County, S. Dak	97. 0–98. 0	2. 69	1. 62	33. 4	39. 8	6. 4	0. 1
58OHO5	Montgomery County, Ohio	-------	2. 71	1. 78	----------	33. 9	----------	. 08
57MAS11	Middlesex County, Mass	2. 5	2. 72	2. 12	2. 5	22. 1	19. 6	2
58MAS19	Brockton, Mass	-------	2. 73	1. 78	. 6	34. 8	34. 2	97

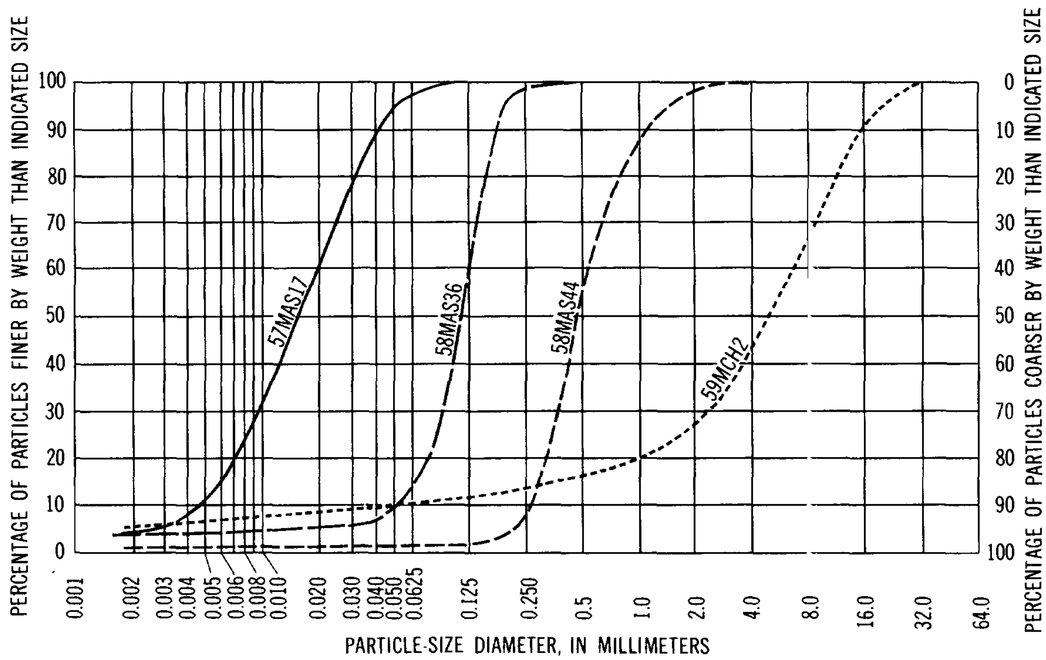
FIGURE 11.—Typical data on particle-size distribution and the hydrologic and physical properties of till.

evaporation in isolated bodies of water. One rock of chemical origin is chert. Although some tests have been made on chert in the laboratory, data are not complete enough to be presented in this report.

Organic origin

Rocks of organic origin may form in many different ways. They may form from precipitation or accumulation of calcium carbonate from water by organisms, or they may form from accumulations of

Morris, D.A. and Johnson, A.I. (1967). Summary of Hydrologic and Physical Properties of Rock and Soil Materials, as Analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, 1948-60. U.S. Geological Survey, Water-Supply Paper 1839-D. Available at: https://doi.org/10.3133/wsp1839D.



PERCENTAGE OF PARTICLES OF INDICATED SIZE	CLAY <0.004	SILT 0.004–0.0625	SAND: Very fine 0.0625–0.125	SAND: Fine 0.125–0.25	SAND: Medium 0.25–0.5	SAND: Coarse 0.5–1	SAND: Very coarse 1–2	GRAVEL: Very fine 2–4	GRAVEL: Fine 4–8	GRAVEL: Medium 8–16	GRAVEL: Coarse 16–32	GRAVEL: Very coarse 32–64
———	7.6	89.0	3.2	0.2								
— — —	3.8	9.4	46.0	39.6	1.2							
– – –	1.2	.0	.4	6.3	46.3	32.1	11.8	1.6	0.3			
-------	6.3	4.0	1.0	2.1	2.3	4.2	7.2	15.4	25.3	22.5	9.7	

HYDROLOGIC AND PHYSICAL PROPERTIES

Lab. No.	Location	Depth of sample (feet)	Specific gravity of solids	Dry unit weight (g per cc)	Specific retention (percent of volume)	Total porosity (percent of volume)	Specific yield (percent of volume)	Coefficient of permeability (gpd per sq ft)
57MAS17	Middlesex County, Mass.	15	2.72	1.12	13.3	58.8	45.5	2
58MAS36	Ipswich River valley, Mass.	2	2.69	1.41	2.8	47.6	44.8	71
58MAS44	do.	2	2.67	1.47	.9	44.9	44.0	1,400
59MCH2	Kalamazoo, Mich.	1–2	2.72	1.78	26.5	34.6	$\boxed{8.1}$	130

Alluvium

FIGURE 12.—Typical data on particle-size distribution and the hydrologic and physical properties of washed drift.

plant and (or) animal life, which decays and produces carbonaceous materials. Limestone, dolomite, and peat are the only materials of organic origin considered in this report.

Limestone, dolomite, and peat.—Limestone is a common and widely distributed calcium carbonate rock. It is fine grained and generally gray and will effervesce freely when tested with cold dilute hydrochloric acid. Dolomite differs from limestone in that it contains magnesium and will effervesce only slightly when tested with cold

Morris, D.A. and Johnson, A.I. (1967). Summary of Hydrologic and Physical Properties of Rock and Soil Materials, as Analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, 1948-60. U.S. Geological Survey, Water-Supply Paper 1839-D. Available at: https://doi.org/10.3133/wsp1839D.

TABLE 9-2 Values of Specific Yield for Various Geologic Materials

Material	Specific yield (%)
Gravel, coarse	23
Gravel, medium	24
Gravel, fine	25
Sand, coarse	27
Sand, medium	28
Sand, fine	23
Silt	8
Pierre Shale → Clay	3
Sandstone, fine-grained	21
Sandstone, medium-grained	27
Limestone	14
Dune sand	38
Loess	18
Peat	44
Schist	26
Siltstone	12
Till, predominantly silt	6
Till, predominantly sand	16
Till, predominantly gravel	16
Tuff	21

Source: Johnson (1967).

(Englund and Sparks, 1988) and GEOPACK (Yates and Yates, 1990), distributed by the USEPA (see Appendix B). Program INTERP, discussed in Chapter 8 for assigning initial conditions to a numerical model, can also be used in processing hydraulic conductivity data. The program contains several interpolation and kriging options. As noted in Chapter 8, an option is provided for conversion of field data to a logarithmic scale prior to interpolation or kriging, and reconversion of the results to an arithmetic scale. This conversion simplifies data processing where the hydraulic conductivity is assumed to follow a lognormal distribution. Further information on this program is provided in Appendix B.

Because of the strong heterogeneity which often characterizes the hydraulic properties of porous media, even a relatively large number of field measurements may not adequately describe the hydraulic conductivity distribution at a given field site. Where this is true, simulation results are necessarily subject to uncertainty. A number of techniques for sensitivity analysis and uncertainty analysis, as discussed in Chapters 10 and 11, can be invoked in these situations.

9.2.2 Storage Coefficient and Specific Yield

Transient flow simulation requires data on : aquifers and specific yield for unconfined aqu yield are illustrated in Table 9-2, compiled Johnson (1967). Where inelastic aquifer co are not present, estimates of storage coefficie properties of water and of the porous frame 1979; Domenico and Schwartz, 1990). For a possible to develop a storage coefficient esti of land subsidence in response to pumpage.

9.3 TRANSPORT PARAMETERS

9.3.1 Porosity

Porosity affects transport calculation in two in determining the seepage velocity, which co it determines the pore volume of a model cell mass. Representative porosity values for certai shown in Table 9-3, based on the sources of Jo Davis (1969) as compiled by Domenico and S

As discussed in Chapters 1 and 2, there is the porosity required to account for the appar solute mass in the field, and the total porosity, to bulk volume, as determined in laborator through the concept of effective porosity, i.e. the porosity consists of interconnected pore s flow, while the balance consists of isolated pore can occur. As discussed previously, this represe more common reality is that, to one degree o flow through the pore space is nonunifor distribution is highly nonuniform—where a occurs in a small fraction of the pore space—th calculation tends to be much smaller than th same time the dispersive transport effect ten distribution becomes more uniform, the po calculation should approach the total porosity

The problem of highly nonuniform flow distr has sometimes been addressed through the dual in fractured rock where both primary and secon In the dual-porosity approach two distinct

Zheng, C. and Bennett, G.D. (1995). Applied Contaminant Transport Modeling: Theory and Practice. Van Nostrand Reinhold.

APPENDIX F

SOUTH BOULDER CREEK SFR BOUNDARY CONDITION DEVELOPMENT

Purpose:

To document South Boulder Creek inflow and diversions as model boundary condition inputs for the South Boulder Creek Regional Detention Project (Project) Groundwater Vistas 7 (GWV7) transient groundwater model.

Available Data:

1. Analysis of monthly ditch irrigation diversion records from Colorado's Decision Support Systems (CDSS) website was completed in a separate appendix to this report "Ditch Diversion Records". (page 28)
2. Available automated stream stage and flow data available through the Mile High Flood District (MHFD) ALERT System and OneRain gauge stations at the Sans Souci and South Boulder Road sites were documented and analyzed in a separate appendix to this report "South Boulder Creek Data". (page 27)
3. Channel roughness values were chosen Open Channel Flow (Chow, 1959). (p. 26)

Approach:

- Flux across the SFR boundary condition is dependent on the head difference between the channel stage and surrounding aquifer and the channel conductance. Channel stage at each SFR boundary cell is computed from Manning's equation using model inputs of cross-sectional area, channel slope, channel roughness, and discharge. Channel conductance is computed from the SFR cell hydraulic conductivity and streambed cell area.
- The SFR boundary condition is divided into segments that characterize representative reaches of South Boulder Creek through the Project area.
- Each SFR segment is defined by a uniform 8-point cross section cut from topographic data. Channel slope and channel roughness are constant between the upstream and downstream segment end cells. The SFR BC allows both inflow rates to the model domain and diversions out of the model domain.
- Inflow to the model domain from upstream is estimated from periodic stage and discharge readings from two MHFD stream gauges on South Boulder Creek near the Project area – the Sans Souci gauge at the upstream end and the South Boulder Road gauge downstream of the Project area. Daily average and maximum flow readings area reported in "South Boulder Creek Data".
- Monthly diversions for each irrigation ditch drawing from South Boulder Creek near the model domain were tabulated in "Ditch Diversion Records". (page 28)

Only data from the Sans Souci stream gauge is used in SFR boundary condition development because the gauge rating relationship for the South Boulder Road stream gauge is currently being calibrated.

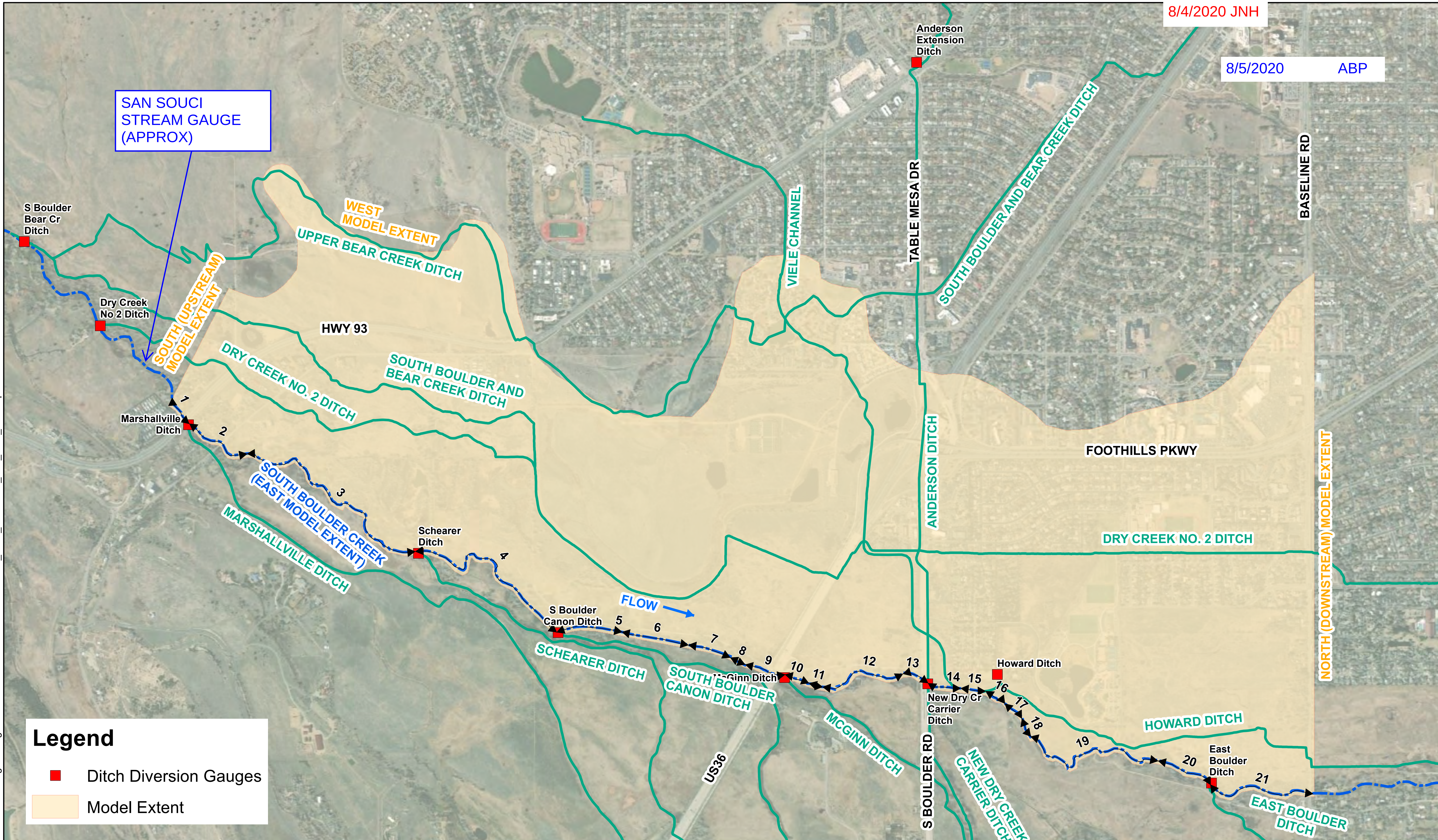
(page 27)

Methods:

1. SFR segment endpoints were assigned at irrigation diversion locations to allow for flow removal from South Boulder Creek. Additional segments were included to allow for a greater number of representative cross sections along South Boulder Creek to improve accuracy of surface water-groundwater interaction computations. There are 21 segments in total for the SFR boundary condition (p.__3__) Segments are labeled 1 through 21 from upstream to downstream on page 3.
2. Representative 8-point cross-sections were cut from LiDAR topographic data along South Boulder Creek for each segment (p.__4-25__). Cross section coordinates input into GWV7 are shown on p. 29-34.
3. A Manning's roughness value of 0.045 was selected for all channel segments as generally representative of South Boulder Creek based on field observations (p.__26__).
4. Elevations at the upstream and downstream end of each SFR segment were extracted from LiDAR topographic data. Segment streambed slopes were linearly approximated by GWV7 between the upstream and downstream endpoint elevations. SFR cell elevations along each segment were computed in GWV7 by linearly interpolating along the segment length.
5. Streambed conductance is a function of hydraulic conductivity, cell area (Wetted perimeter and length), and layer thickness. Values for streambed hydraulic conductivity and streambed thickness were selected such that flux across the SFR BC was not limited by conductance. Input values were not directly supported by field data and were adjusted based on model calibration.
   a. Streambed hydraulic conductivity was set at 207 ft/d (7.3E-2 cm/s) for all segments during the calibration process.
   b. Streambed thickness was ~~assumed~~ considered to be 1 ft.
   c. Stream cell wetted perimeter is computed as a function of stage and input cross-section points within the SFR package from Manning's equation given channel slope, discharge, and roughness.
   d. Stream cell length was assigned as the square cell length dimension.
6. South Boulder Creek inflow to the model domain is input at the furthest-upstream segment (Segment 1). Inflow was computed as the monthly average of average daily flows measurements taken at the Sans Souci MHFD gauge (p.__27__). Flows reported from the Sans Souci gauge were selected due to the greater uncertainty associated with the South Boulder Road gauge. ~~Diversion and~~ irrigation activities in the site area between the Sans Souci and South Boulder Road gauges are sparsely documented, and the South Boulder Road gauge rating relationship is being actively calibrated by the City of Boulder at this stage of analysis. (San Souci gauge is also near U/S end of model (page 3)).

See Note 1, page 28.

7. Monthly irrigation diversions to each ditch within the model domain are subtracted from the inflow amount at the upstream end of the corresponding SFR segment (p.__28__).
8. These flows are input to GWV7 as tabulated segment data (~~p. 29-41~~ (p. 34-40)).
9. Flow inputs and diversions by SFR segment for each stress period are summarized on p. 41.



0 600 1,200 2,400 Feet

REPRODUCE IN COLOR

N

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

SFR SEGMENTS

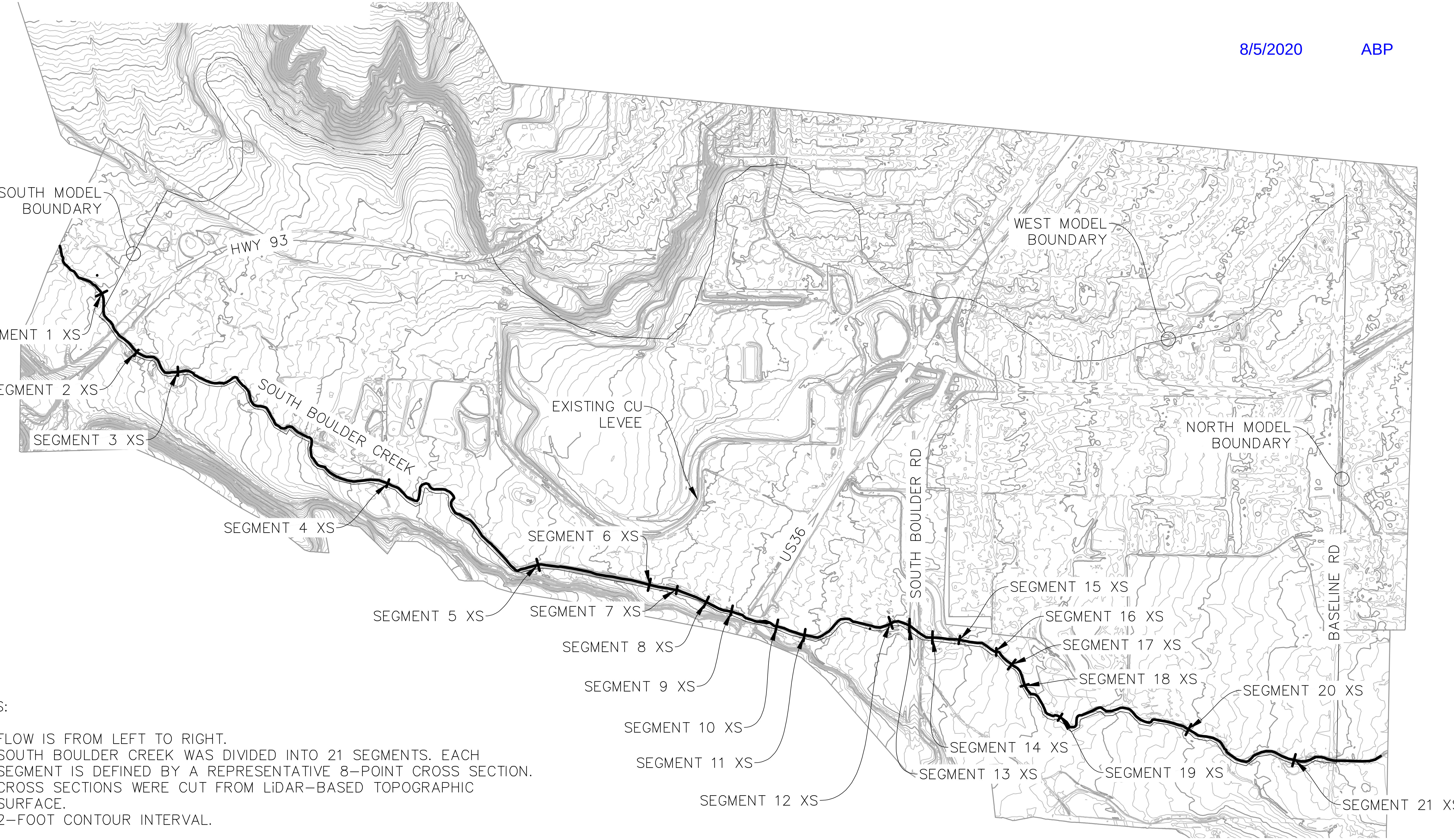
PROJECT NO. 16134

August 2020

Figure 1

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\16134_3004_07242020_GW_SFR_Development.mxd

8/5/2020 ABP



NOTES:

1. FLOW IS FROM LEFT TO RIGHT.
2. SOUTH BOULDER CREEK WAS DIVIDED INTO 21 SEGMENTS. EACH SEGMENT IS DEFINED BY A REPRESENTATIVE 8-POINT CROSS SECTION.
3. CROSS SECTIONS WERE CUT FROM LiDAR-BASED TOPOGRAPHIC SURFACE.
4. 2-FOOT CONTOUR INTERVAL.

0 600 1200 2400 2600

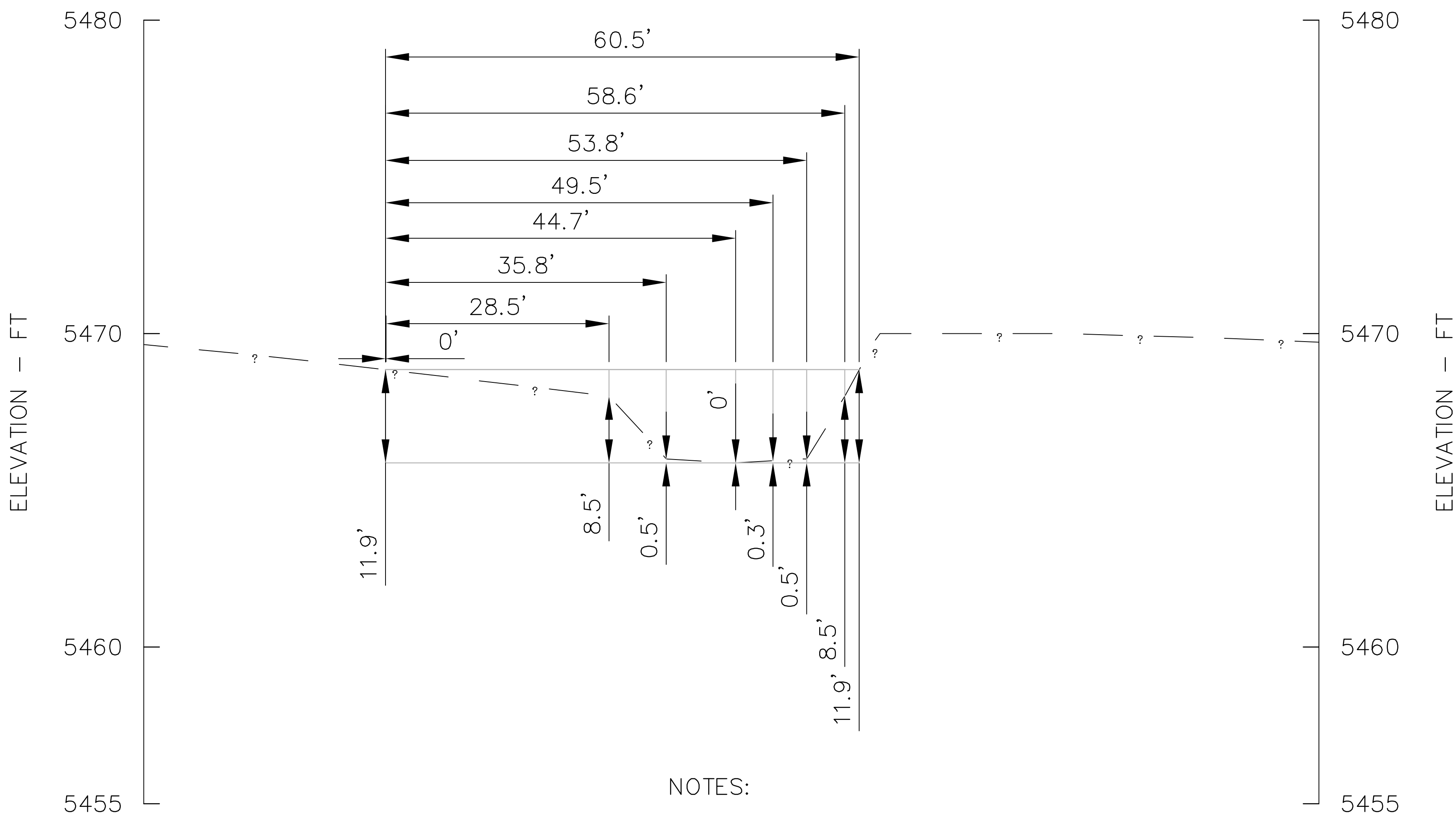
SCALE IN FEET

N

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/26/2020 4:08 PM

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SEGMENTS PLAN
	PROJECT NO. 16134	August 2020 **Figure 2**

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

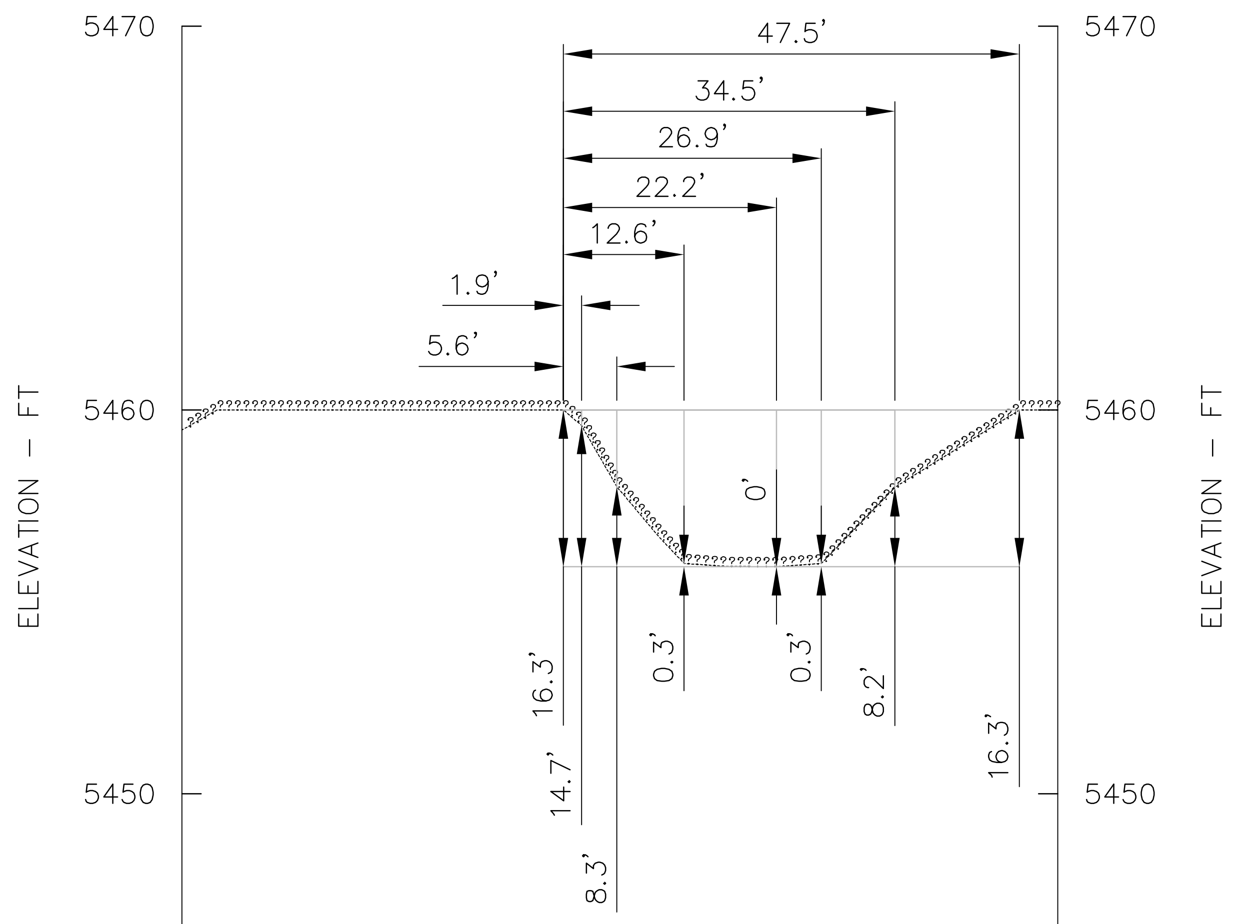
0 10 20 40 60

SCALE IN FEET

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 1	
PROJECT NO. 16134	August 2020	**Figure 3**

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 6:17 PM



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

0 10 20 40 60

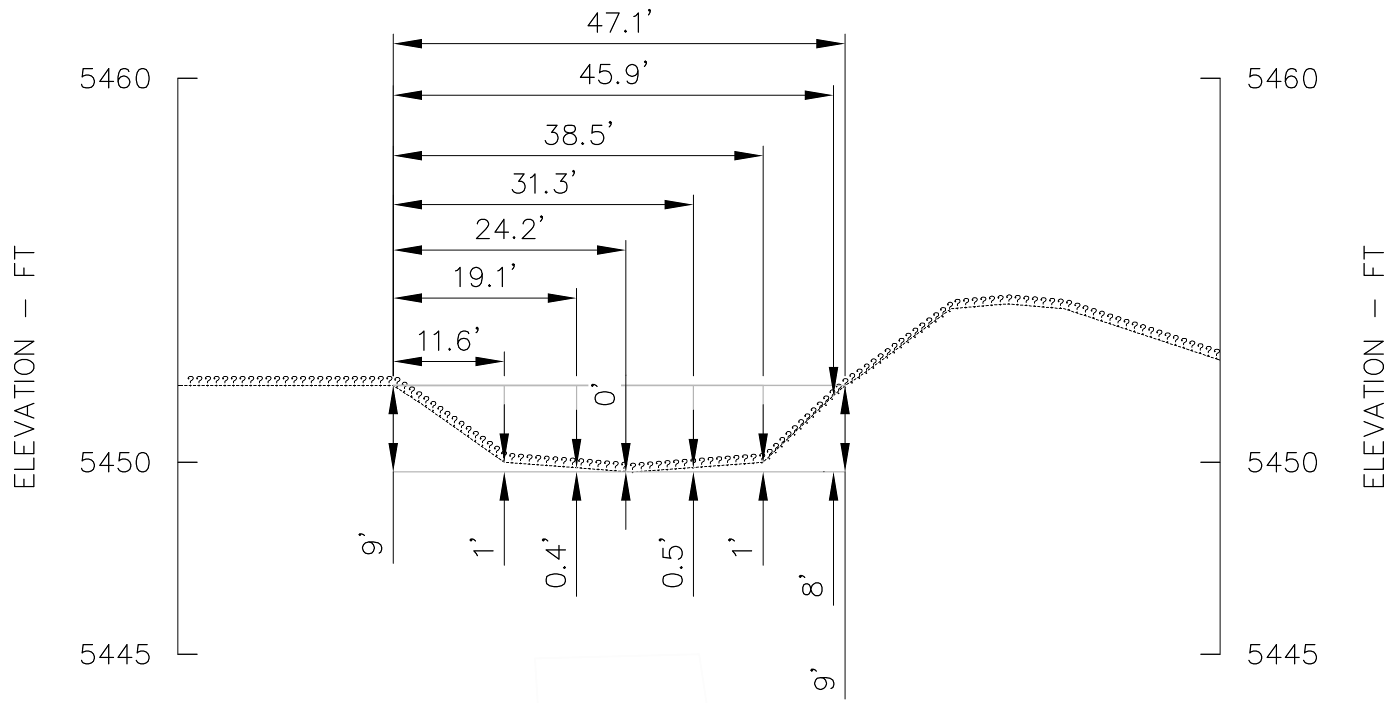
SCALE IN FEET

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 6:40 PM

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 2	
PROJECT NO. 16134	August 2020	**Figure 4**

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

0 10 20 40 60

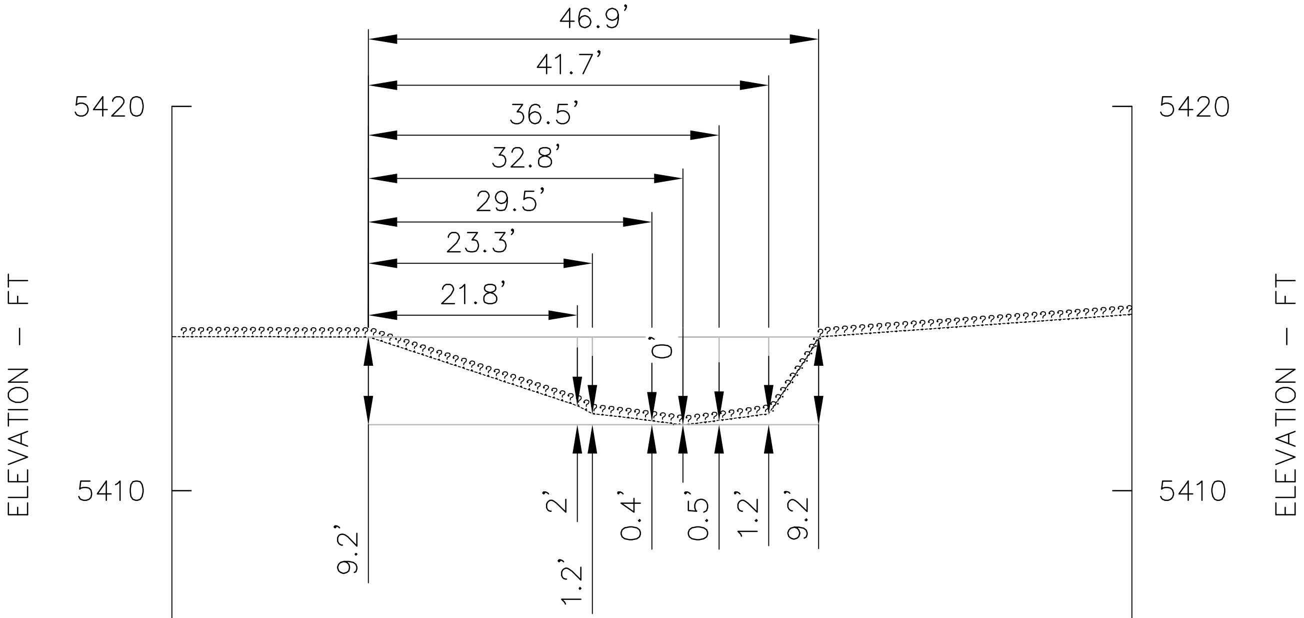
SCALE IN FEET

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 3	
PROJECT NO. 16134	August 2020	**Figure 5**

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 7:16 PM

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

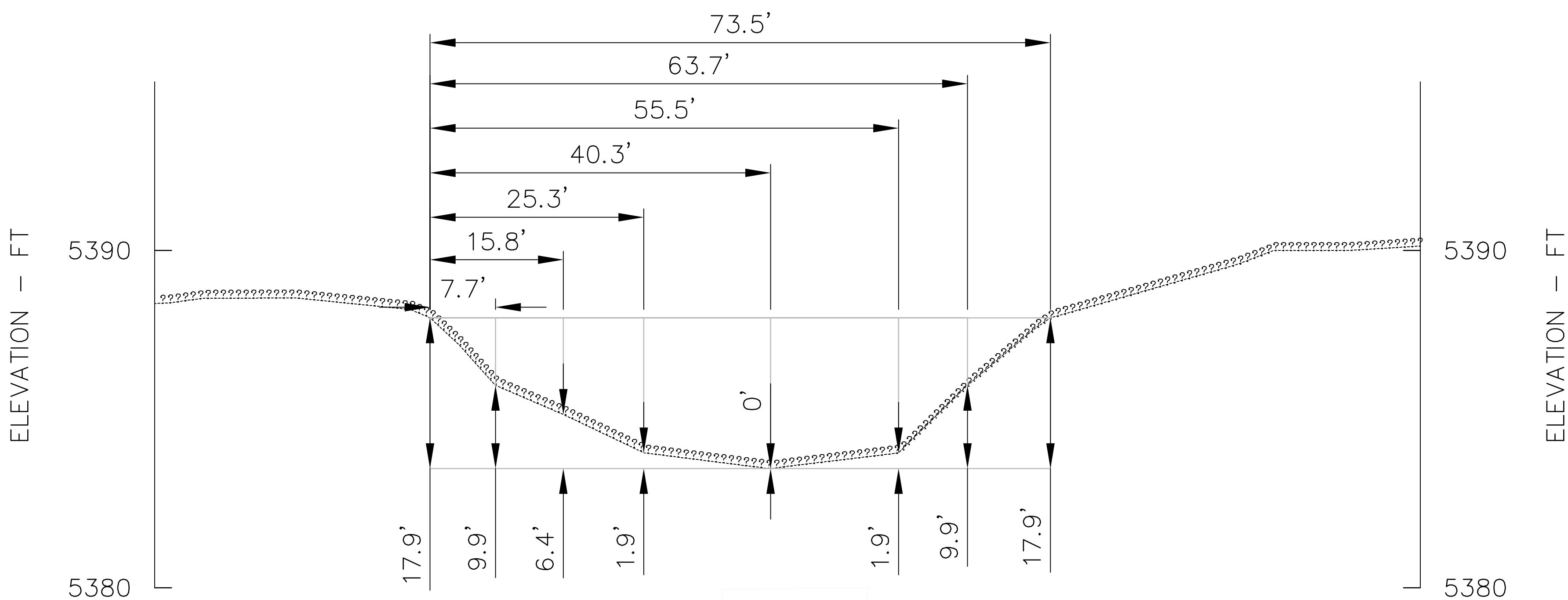
0 10 20 40 60

SCALE IN FEET

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 4	
PROJECT NO. 16134	August 2020	**Figure 6**

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 7:41 PM



NOTES:

1. SECTION LOOKING DOWNSTREAM

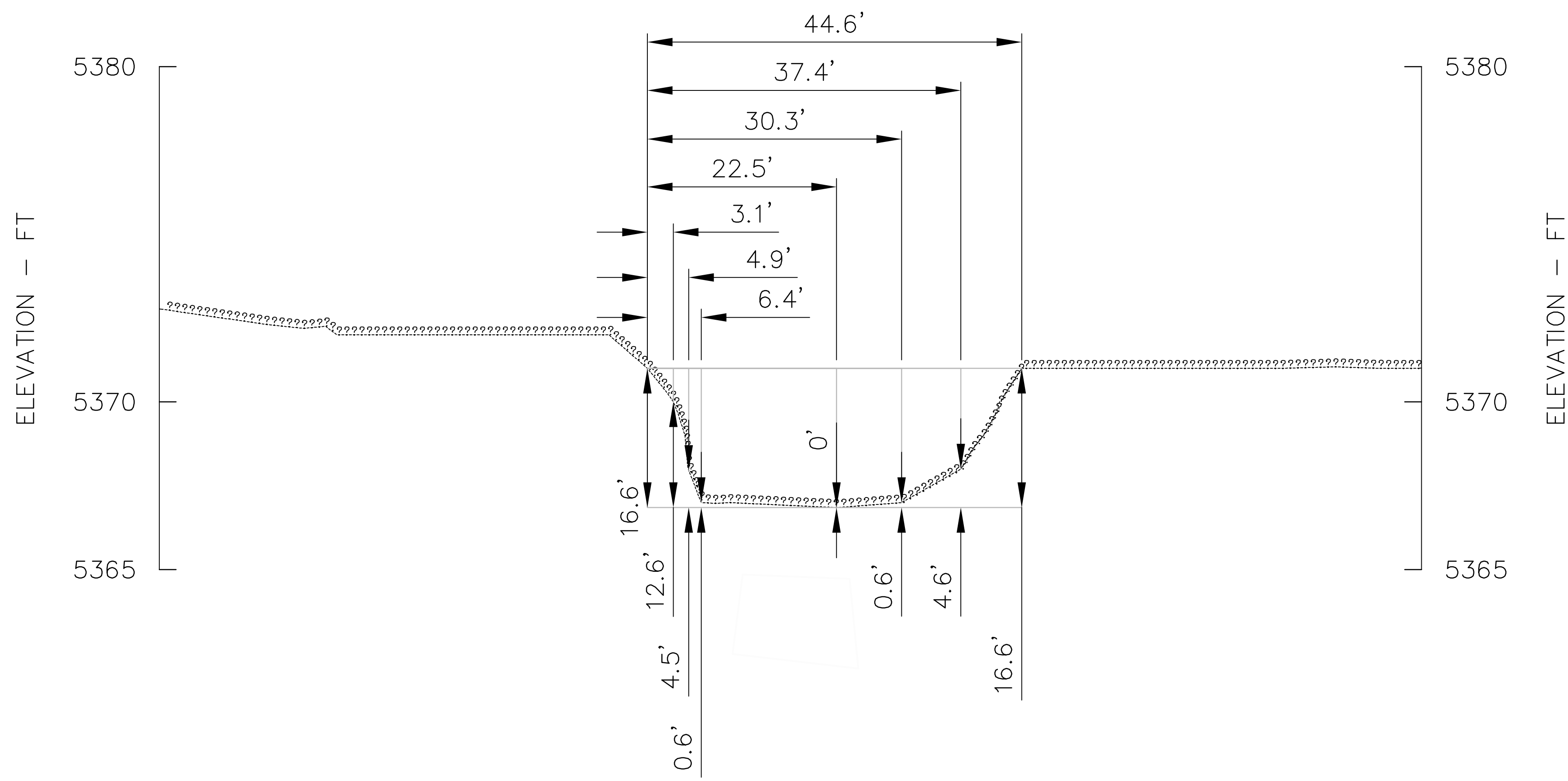
VERTICAL SCALE
0 2.5 5 10 15
SCALE IN FEET

HORIZONTAL SCALE
0 10 20 40 60
SCALE IN FEET

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 8:17 PM

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION- BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 5
	PROJECT NO. 16134	August 2020 **Figure 7**

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

0 10 20 40 60

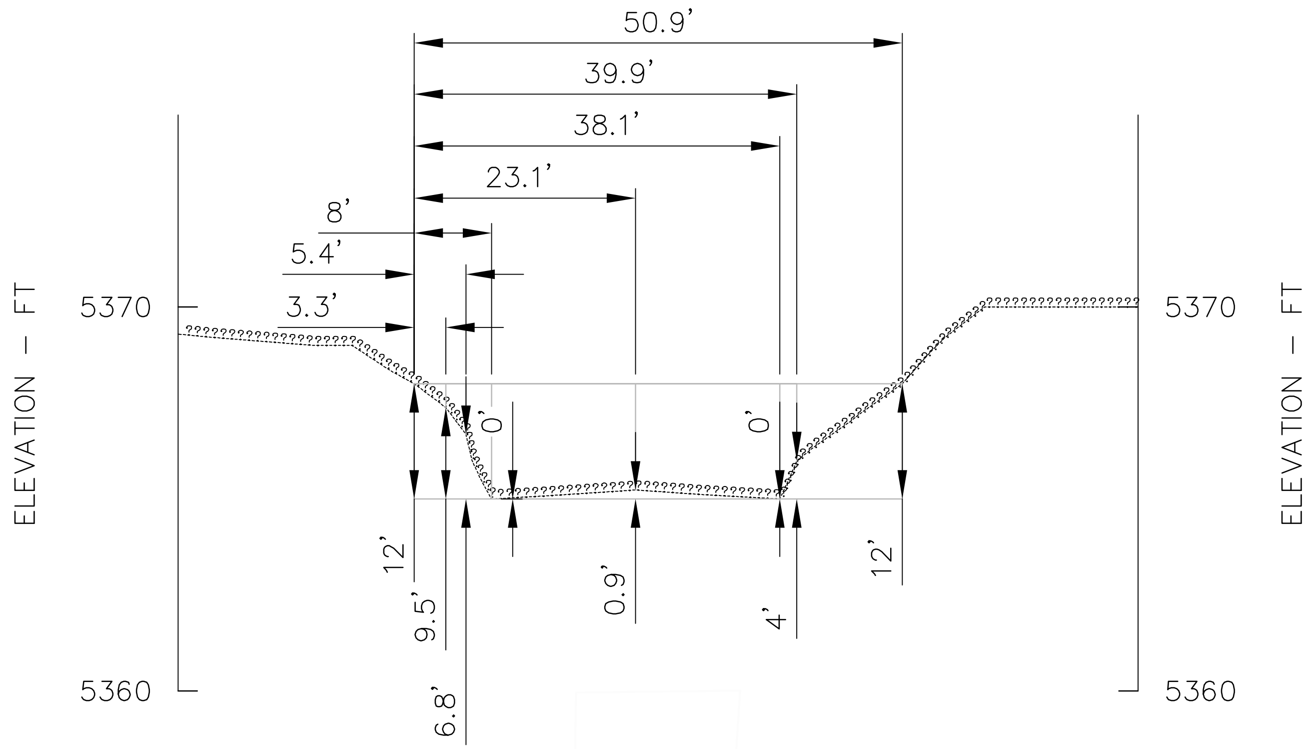
SCALE IN FEET

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 8:42 PM

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 6	
PROJECT NO. 16134	August 2020	**Figure 8**

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

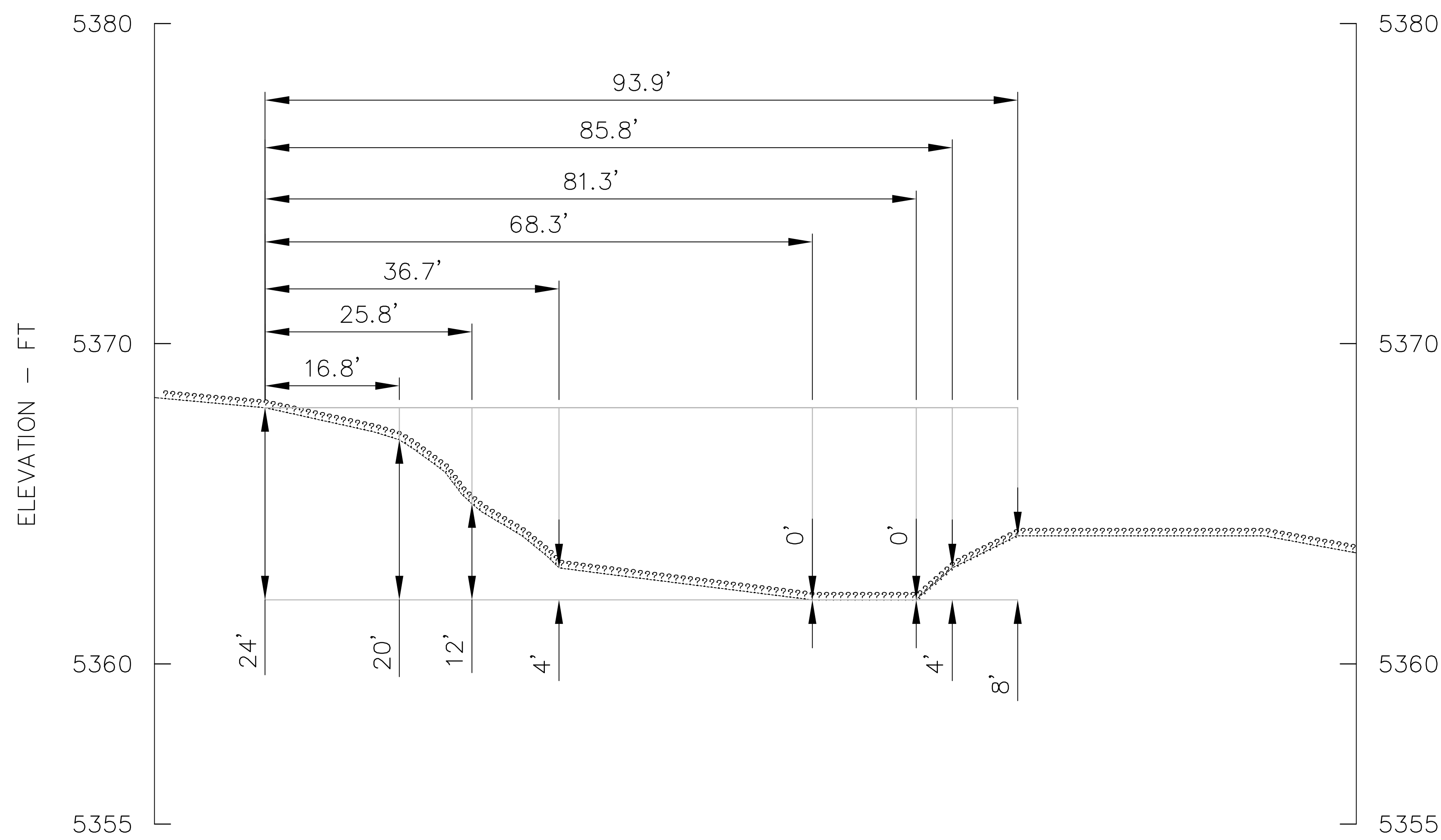
0 10 20 40 60

SCALE IN FEET

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 8:58 PM

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION- BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 7
	PROJECT NO. 16134	August 2020 **Figure 9**

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

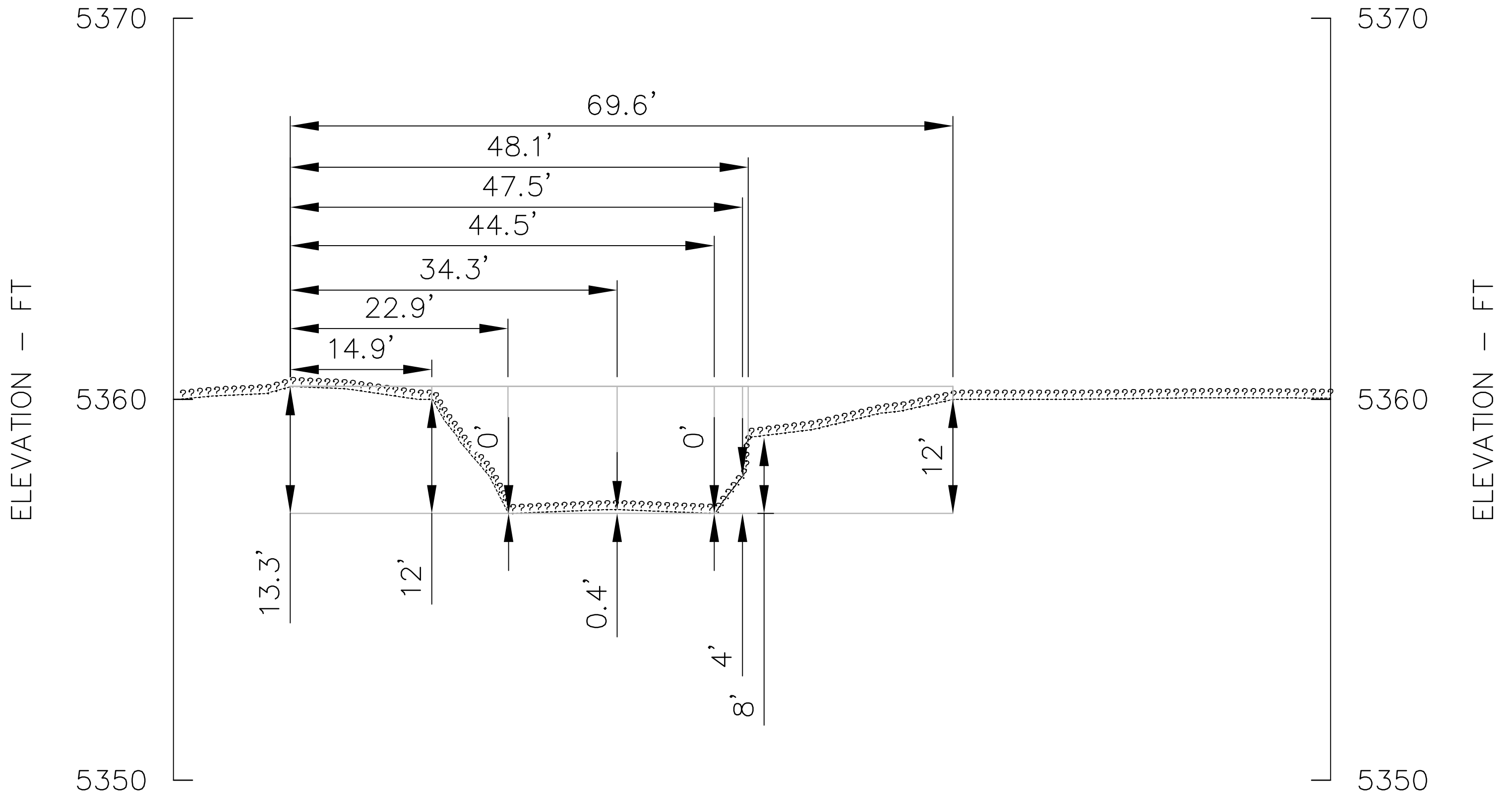
0 10 20 40 60

SCALE IN FEET

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 9:16 PM

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 8
	PROJECT NO. 16134	August 2020 **Figure 10**

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

0 10 20 40 60

SCALE IN FEET

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION- BASELINE GROUNDWATER MODEL REPORT

SBC CROSS SECTIONS SFR SEGMENT 9

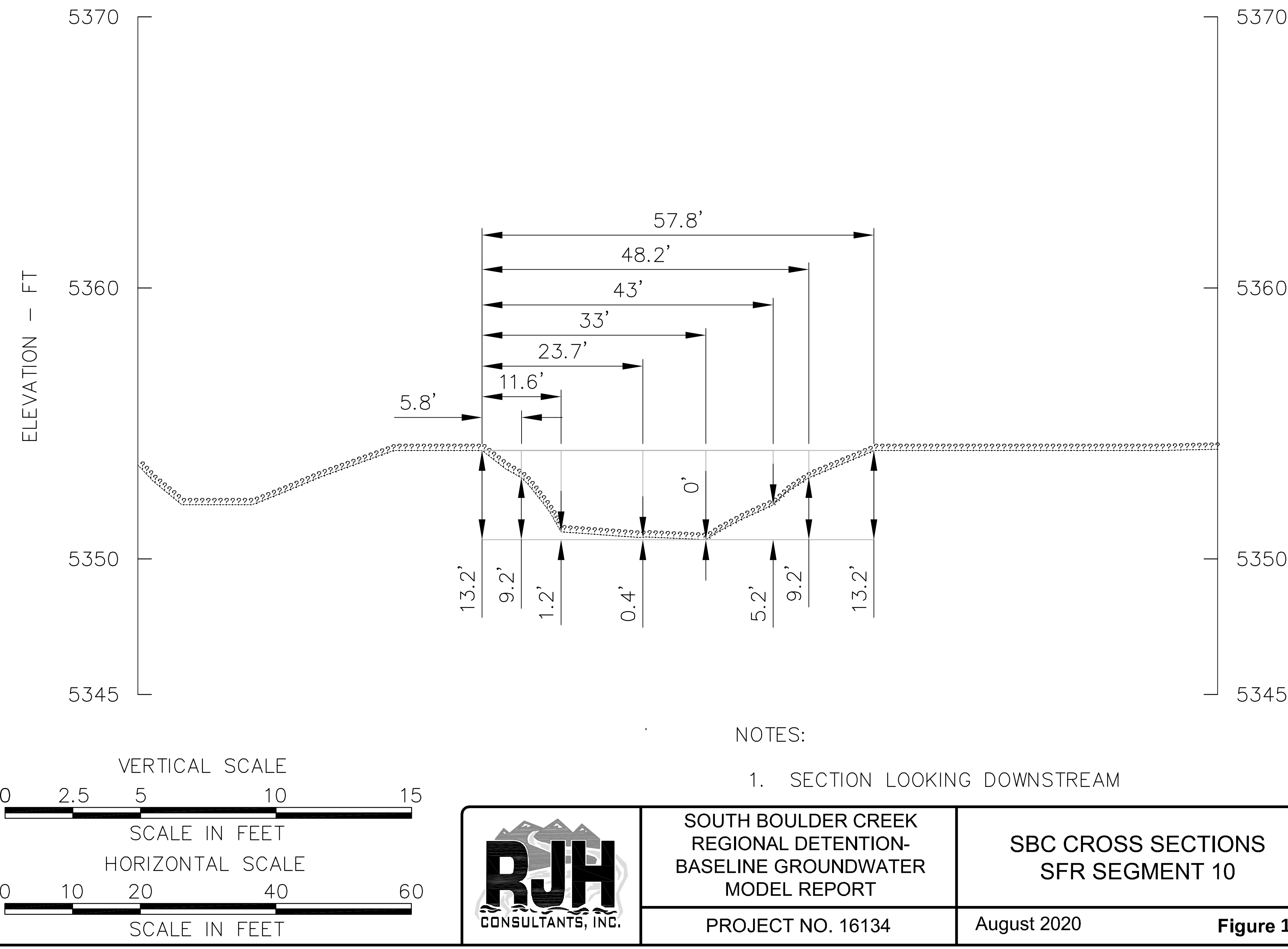
PROJECT NO. 16134

August 2020

Figure 11

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/28/2020 1:07 PM

8/5/2020 ABP

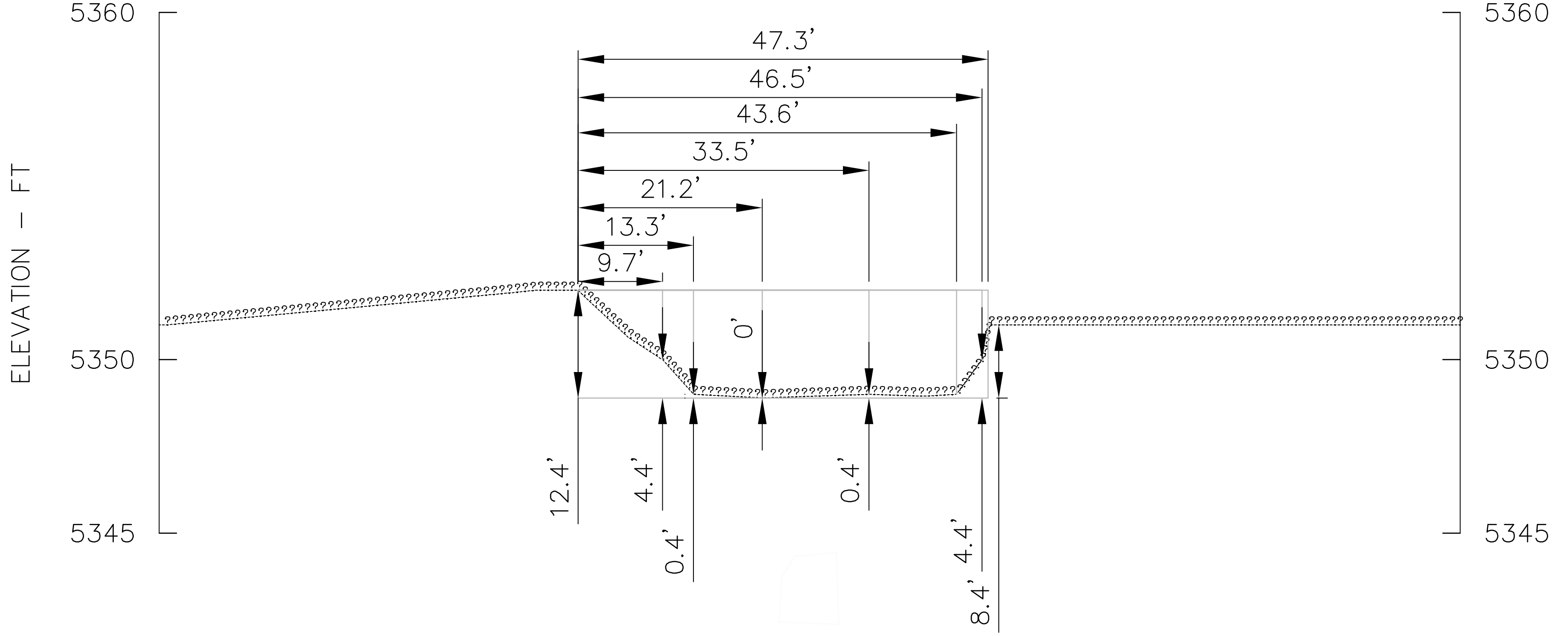


NOTES:

1. SECTION LOOKING DOWNSTREAM

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 10:01 PM

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 10
	PROJECT NO. 16134	August 2020 **Figure 12**



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE
0 2.5 5 10 15
SCALE IN FEET

HORIZONTAL SCALE
0 10 20 40 60
SCALE IN FEET

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT

SBC CROSS SECTIONS SFR SEGMENT 11

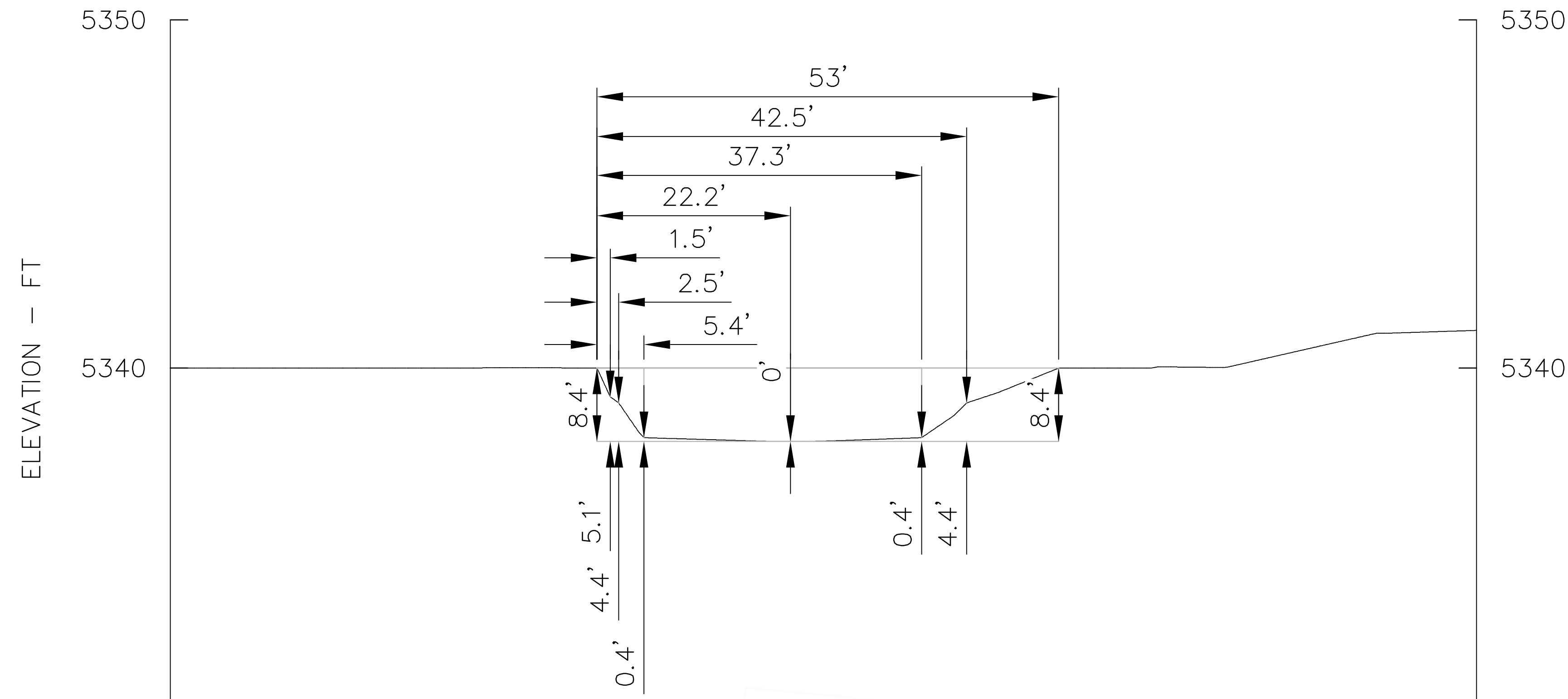
PROJECT NO. 16134

August 2020

Figure 13

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 10:30 PM

8/5/2020 ABP



P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 10:56 PM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

0 10 20 40 60

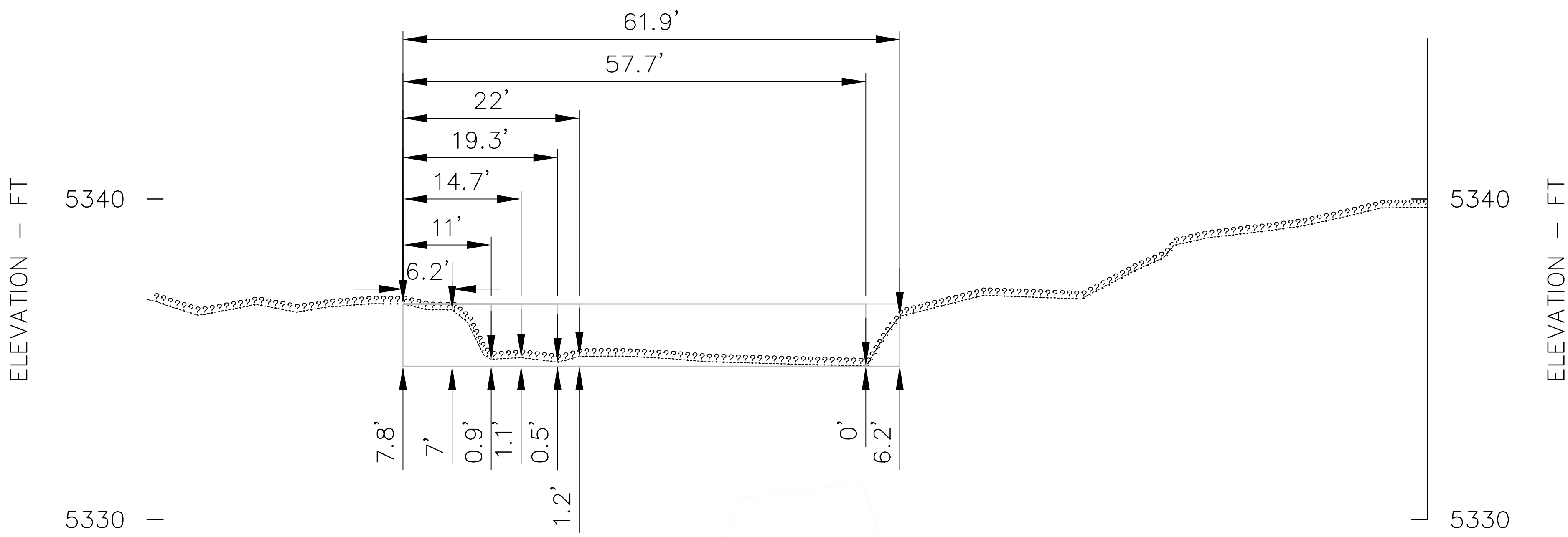
SCALE IN FEET

NOTES:

1. SECTION LOOKING DOWNSTREAM

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 12
	PROJECT NO. 16134	August 2020 **Figure 14**

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

0 10 20 40 60

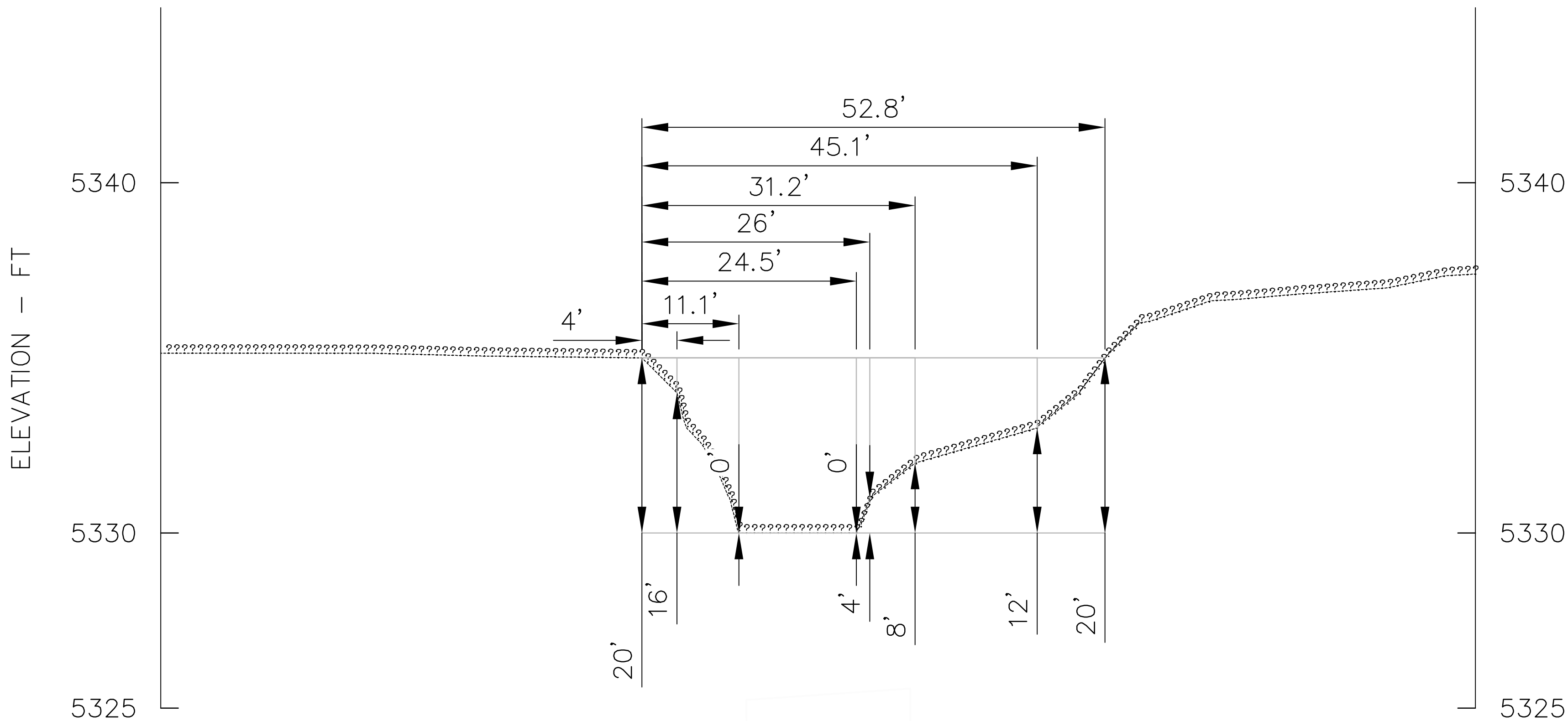
SCALE IN FEET

CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 13	
PROJECT NO. 16134	August 2020	**Figure 15**

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 11:07 PM

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

0 10 20 40 60

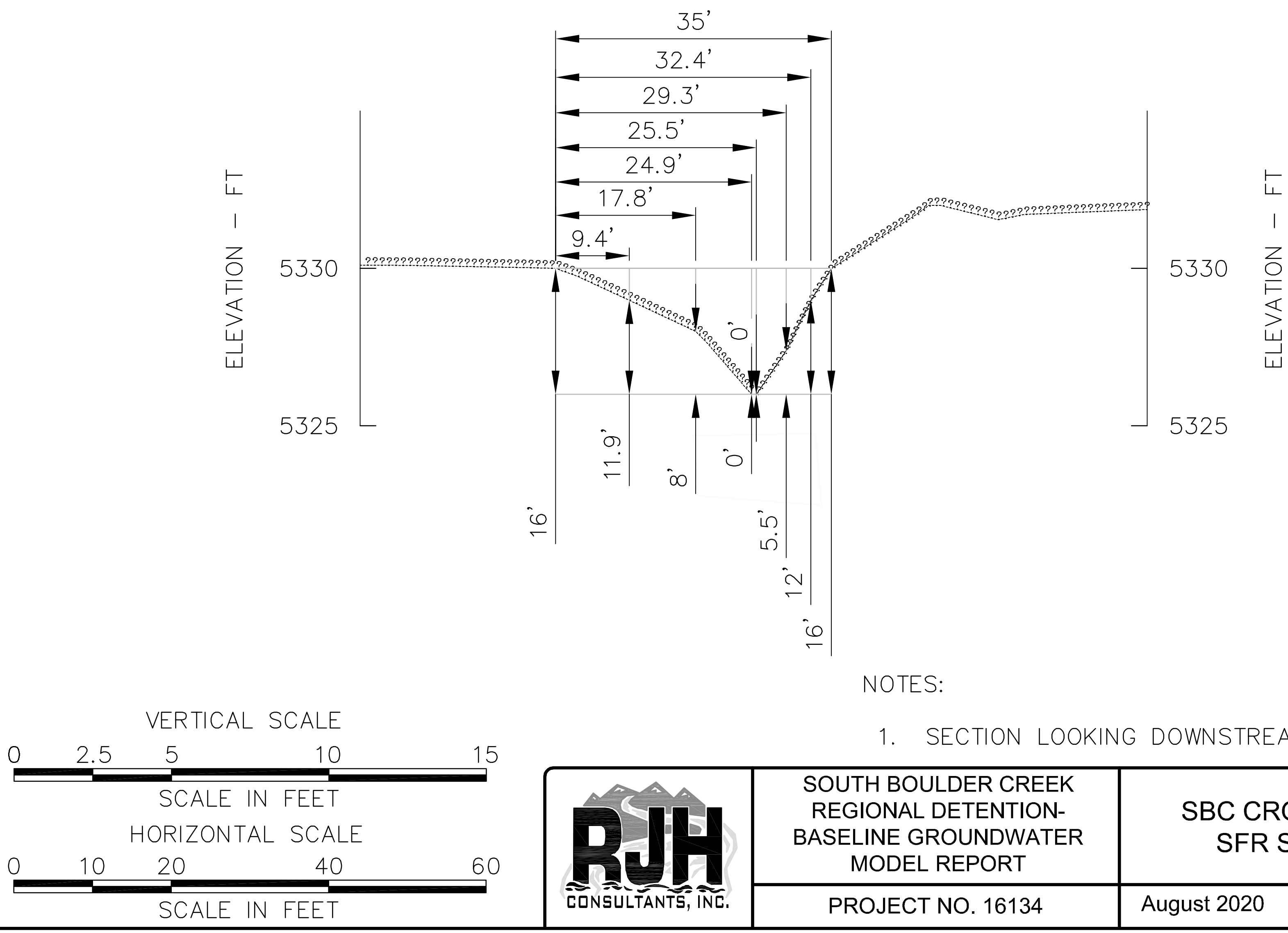
SCALE IN FEET

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 11:24 PM

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 14	
PROJECT NO. 16134	August 2020	**Figure 16**

8/5/2020 ABP



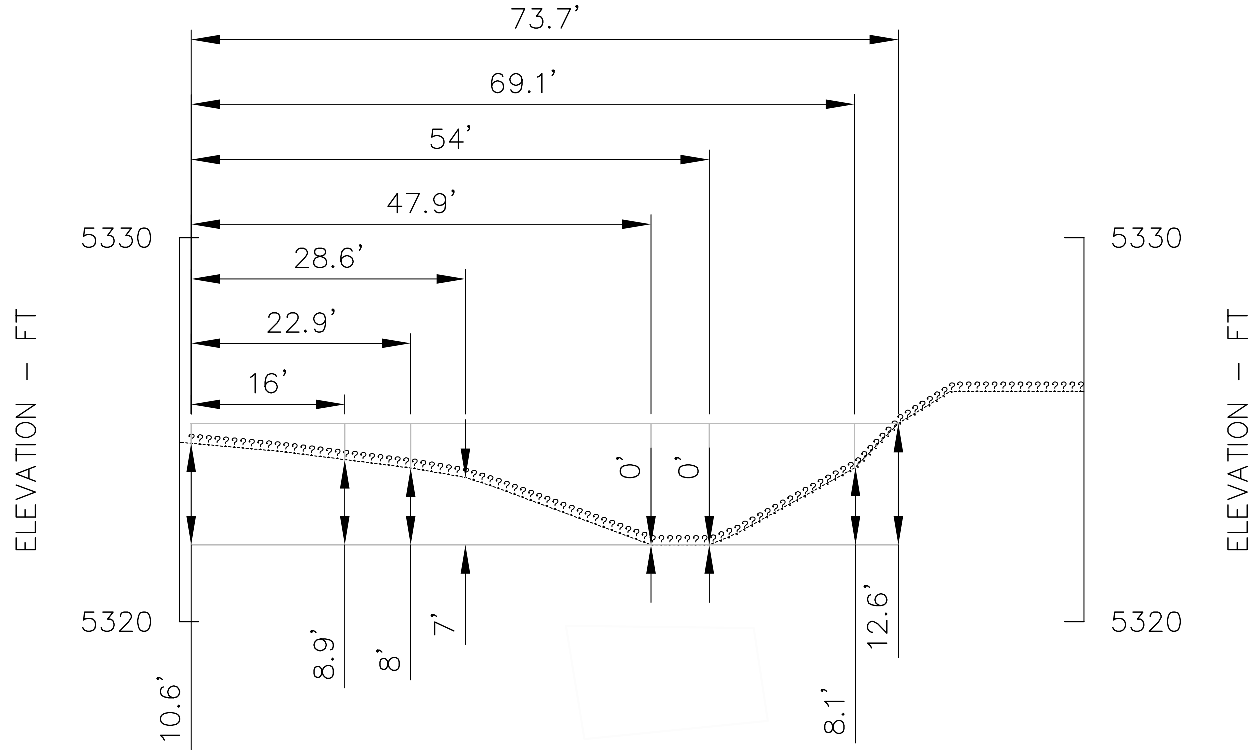
NOTES:

1. SECTION LOOKING DOWNSTREAM

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 11:38 PM

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 15
	PROJECT NO. 16134	August 2020 **Figure 17**

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

0 10 20 40 60

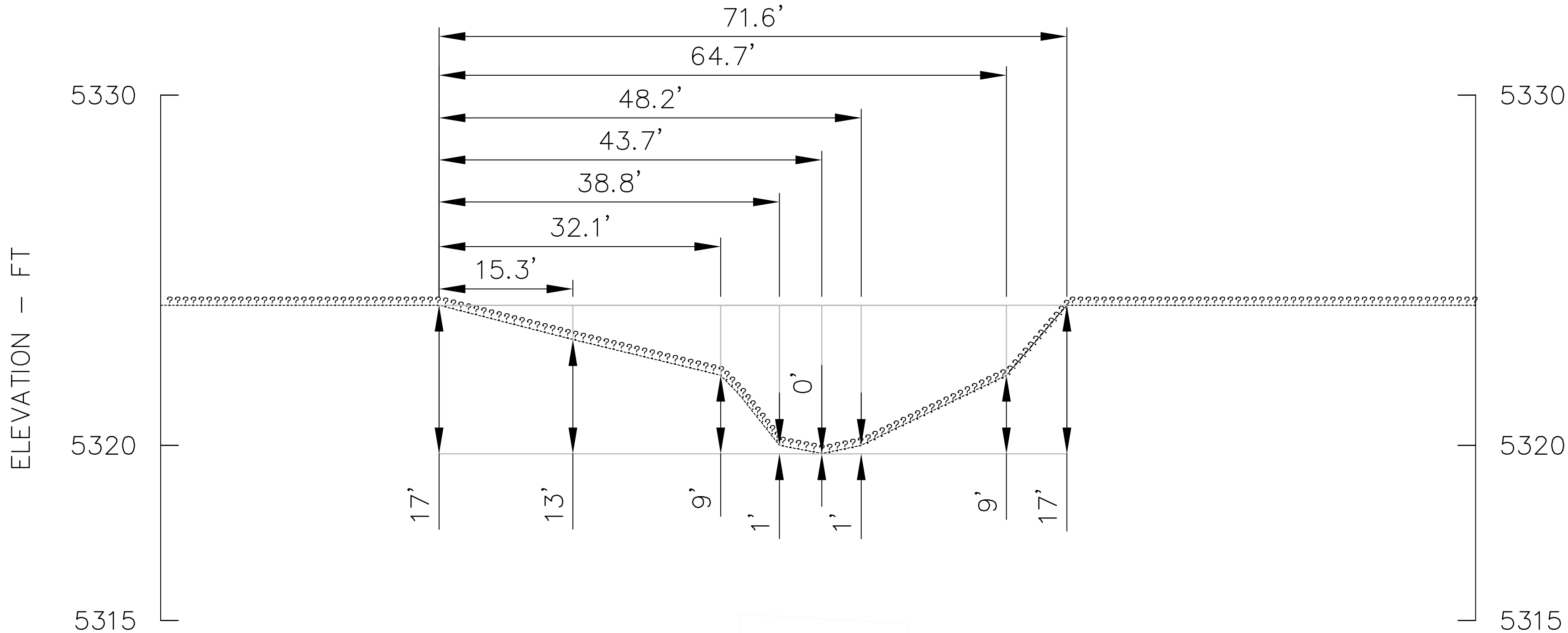
SCALE IN FEET

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION- BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 16	
PROJECT NO. 16134	August 2020	**Figure 18**

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/25/2020 11:55 PM

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

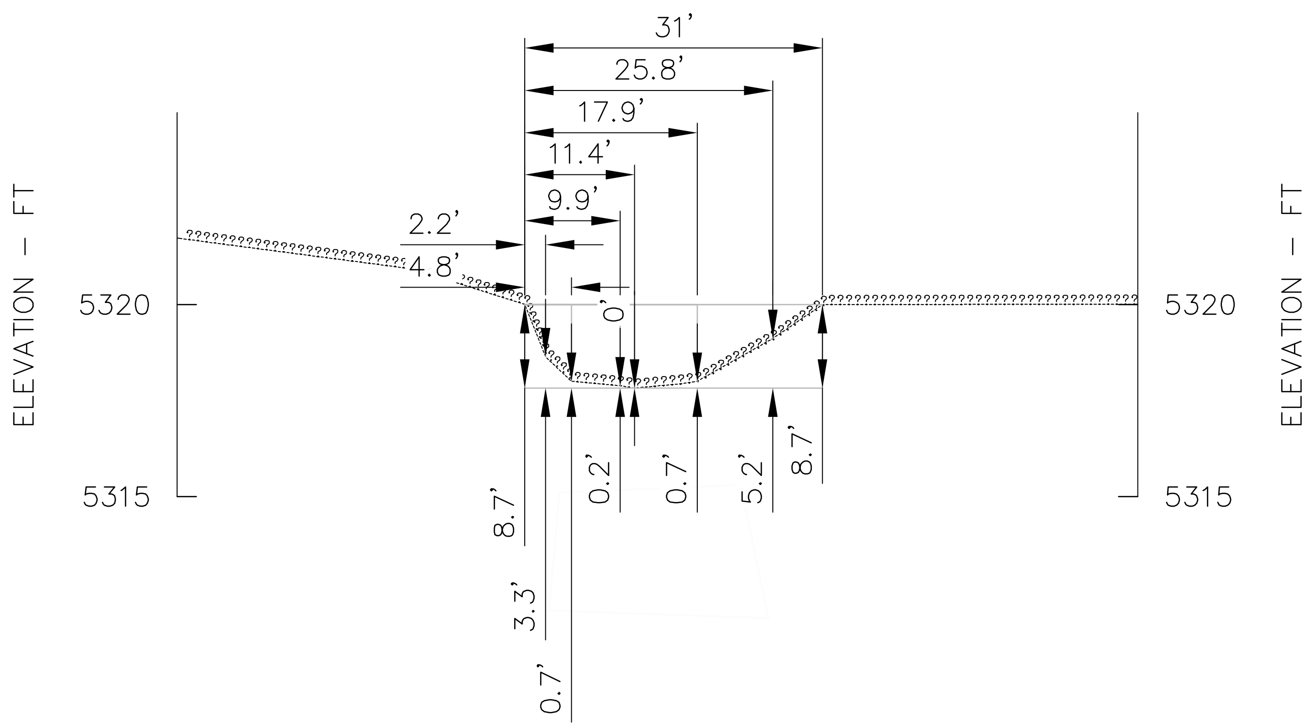
VERTICAL SCALE
0 2.5 5 10 15
SCALE IN FEET

HORIZONTAL SCALE
0 10 20 40 60
SCALE IN FEET

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/26/2020 8:42 AM

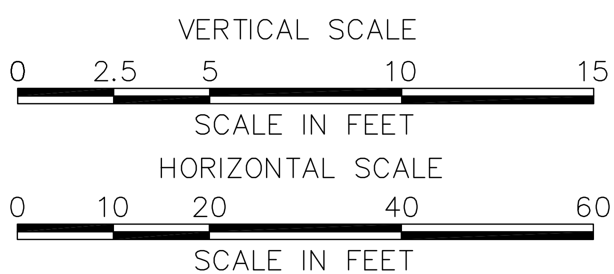
RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION- BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 17
	PROJECT NO. 16134	August 2020 **Figure 19**

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

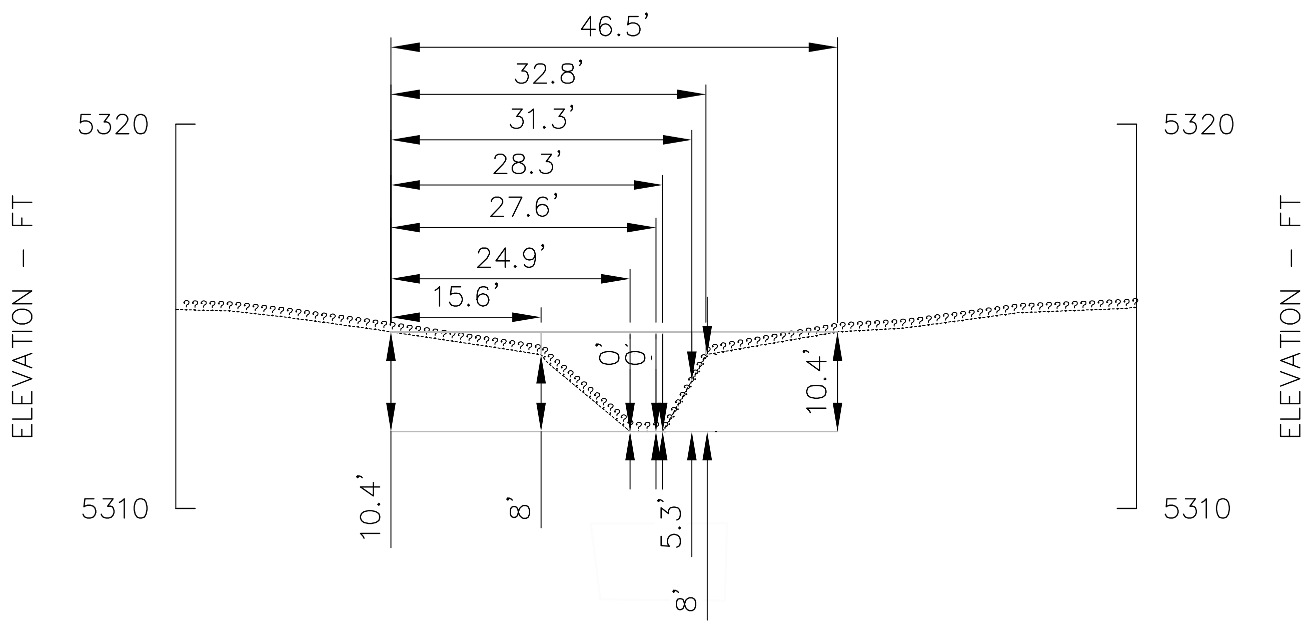


RJH CONSULTANTS, INC.

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION- BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 18
	PROJECT NO. 16134	August 2020 **Figure 20**

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/26/2020 8:50 AM

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

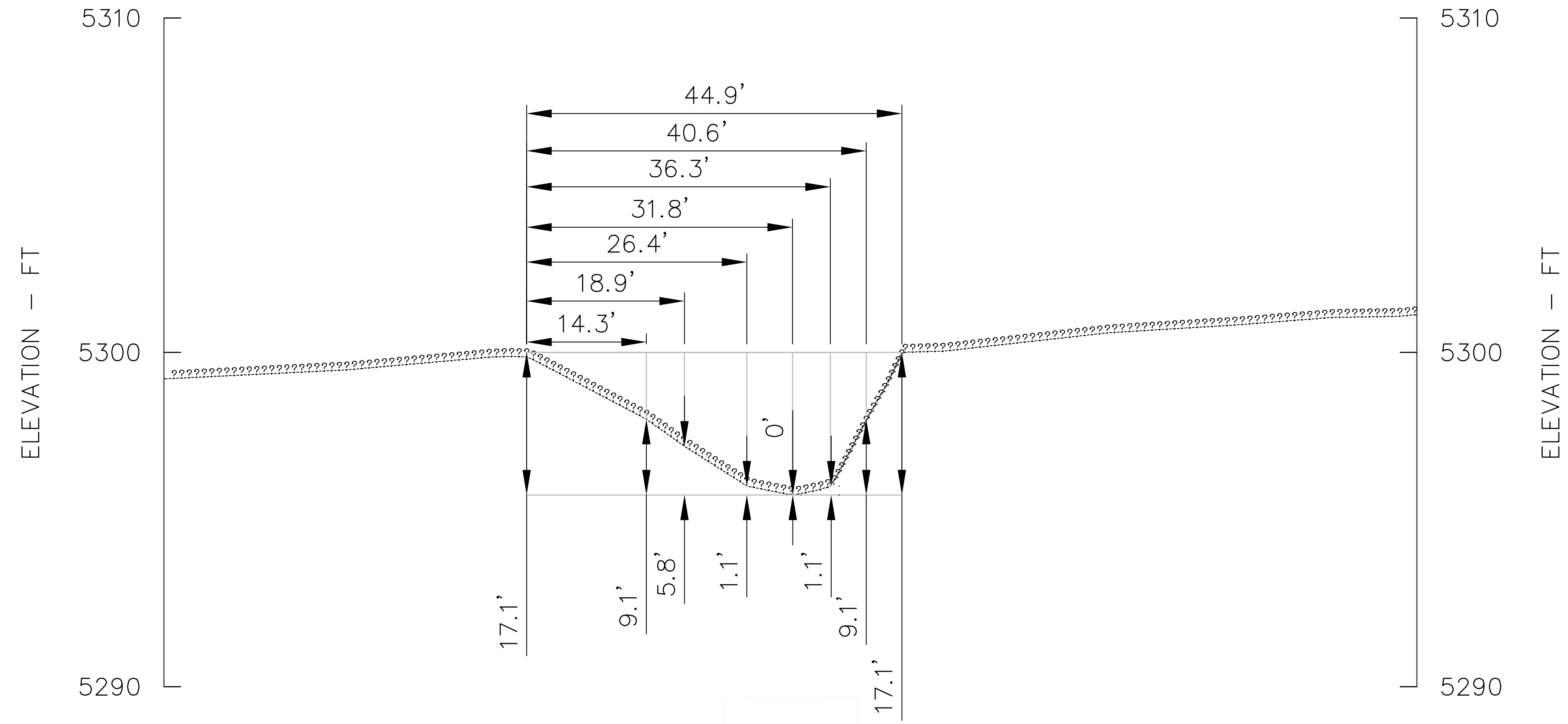
0 10 20 40 60

SCALE IN FEET

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 19
	PROJECT NO. 16134	August 2020 **Figure 21**

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/26/2020 9:03 AM

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

0 10 20 40 60

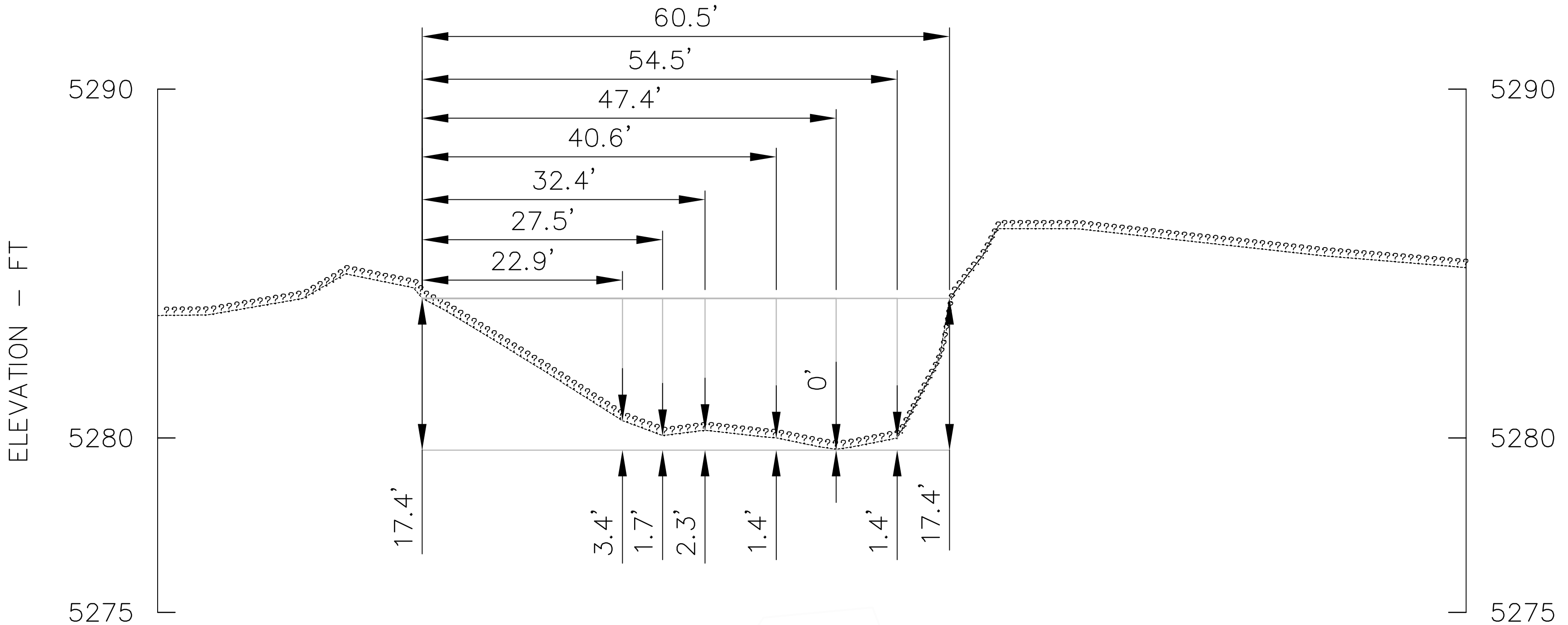
SCALE IN FEET

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION-BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 20	
PROJECT NO. 16134	August 2020	**Figure 22**

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/26/2020 9:18 AM

8/5/2020 ABP



NOTES:

1. SECTION LOOKING DOWNSTREAM

VERTICAL SCALE

0 2.5 5 10 15

SCALE IN FEET

HORIZONTAL SCALE

0 10 20 40 60

SCALE IN FEET

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\INTERNAL CALCS\SFR SEGMENT XS.DWG 7/26/2020 9:55 AM

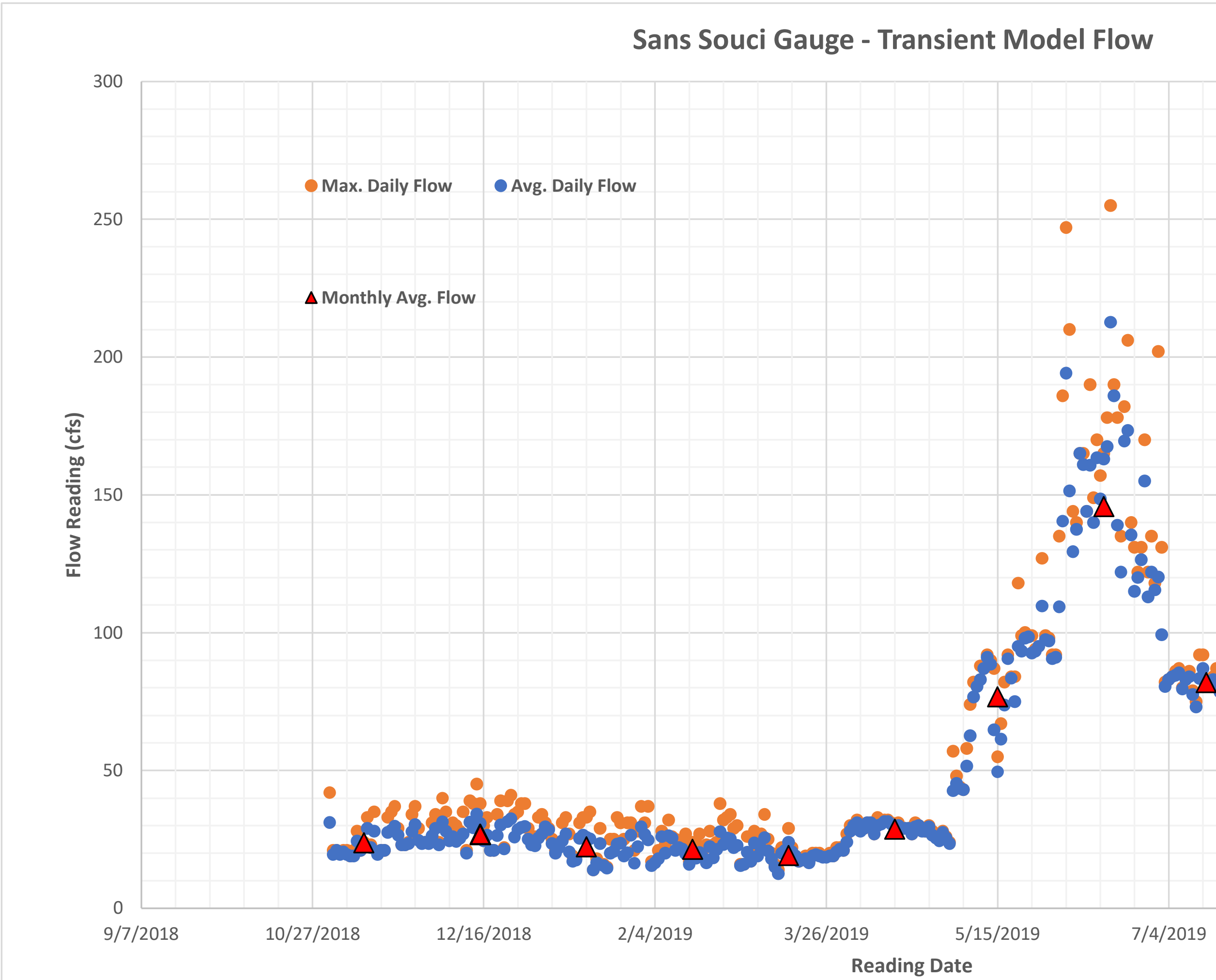
RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION- BASELINE GROUNDWATER MODEL REPORT	SBC CROSS SECTIONS SFR SEGMENT 21
	PROJECT NO. 16134	August 2020 **Figure 23**

7/29/2020 LEA
8/5/2020 ABP

TABLE 5-6. VALUES OF THE ROUGHNESS COEFFICIENT n (*continued*)

Type of channel and description	Minimum	Normal	Maximum
C. EXCAVATED OR DREDGED			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	**0.022**	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.028	0.030	0.035
5. Stony bottom and weedy banks	0.025	0.035	0.040
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
D. NATURAL STREAMS			
D-1. Minor streams (top width at flood stage <100 ft)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	**0.030**	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	$\boxed{0.045}$	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

8/4/2020 JNH
Sans Souci Flow Data_Analysis
8/5/2020 ABP



Avg. Flow (ft^3/s)	Avg. Flow (ft^3/d)	Stress Period	Month
24	2073600	1 + 2	November 2018
27	2332800	3	December 2018
22	1900800	4	January 2019
21	1814400	5	February 2019
19	1641600	6	March 2019
29	2505600	7	April 2019
77	6652800	8	May 2019
146	12614400	9	June 2019
82	7084800	10	July 2019
48	4147200	11	August 2019
41	3542400	12	September 2019
43	3715200	13	October 2019

REPRODUCE IN COLOR

RJH Consultants, Inc.
16134 - South Boulder Creek
Transient Model Ditch Diversion Rates

By: ATMerook **Date:** 5/11/2020
Checked: LEA **Date:** 8/4/2020
Approved: **Date:**

Diversion Gauge	Corresponding SFR Segment	1 + 2	3	4	5	6	7	8	9	10	11	12	13
		Diverted Flow (ft^3/d)											
		Nov. 2018	Dec. 2018	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sept. 2019	Oct. 2019
Anderson Extension Ditch (1)	--	0	0	0	0	17283	199302	0	0	0	0	0	0
Dry Creek No. 2 Ditch (2)	--	0	0	0	0	0	0	128488	507750	527048	181996	0	0
East Boulder Ditch	21	0	0	0	0	0	0	20347	246506	134895	122769	50980	6689
Howard Ditch	16	0	0	0	0	0	147886	129233	439782	336606	412359	385143	267978
Marshallville Ditch	2	0	0	0	0	0	0	586135	739881	711279	101172	0	0
McGinn Ditch	10	0	0	0	0	0	0	69513	377868	292934	207360	156105	0
New Dry Creek Carrier Ditch	14	0	0	0	0	44572	102381	2341195	0	0	0	0	0
S. Boulder Bear Creek Ditch	--	0	0	0	0	0	0	0	56904	108759	284292	34558	22300
S. Boulder Canon Ditch	5	0	0	0	0	0	0	619859	1278733	739424	0	0	0
Schearer Ditch	4	0	0	0	0	0	0	0	207941	30099	770928	326018	0

Notes:

1. Anderson Extension Ditch (Anderson Ditch) adds flow to SBC; however, this flow is generally diverted by the New Dry Creek Carrier Ditch. The flow added by Anderson Ditch is not included in the SFR boundary condition because it is typically accounted for in the diversion by New Dry Creek Carrier Ditch.

2. Dry Creek No.2 Ditch and S. Boulder Bear Creek Ditch diversions are not included in the SFR boundary condition because these diversions take place upstream of the SFR boundary condition and upstream of the Sans Souci stream gauge. They are included here for reference only.

(see Page 3) for locations

GWV7 XS Inputs:

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	11.900	
2	2	28.500	8.500	
3	3	35.800	0.500	
4	4	44.700	0.000	
5	5	49.500	0.300	
6	6	53.800	0.500	
7	7	58.600	8.500	
8	8	60.500	11.900	
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Stress Period 1 Segment 1 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	16.300	
2	2	1.900	14.700	
3	3	5.600	8.300	
4	4	12.600	0.300	
5	5	22.200	0.000	
6	6	26.900	0.300	
7	7	34.500	8.200	
8	8	47.500	16.300	
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Stress Period 1 Segment 2 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	9.000	
2	2	11.600	1.000	
3	3	19.100	0.400	
4	4	24.200	0.000	
5	5	31.300	0.500	
6	6	38.500	1.000	
7	7	45.900	8.000	
8	8	47.100	9.000	
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Stress Period 1 Segment 3 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	9.200	
2	2	21.800	2.000	
3	3	23.300	1.200	
4	4	29.500	0.400	
5	5	32.800	0.000	
6	6	36.500	0.500	
7	7	41.700	1.200	
8	8	46.900	9.200	
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Stress Period 1 Segment 4 Import... Copy OK Paste Cancel

8/4/2020 JNH

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Client: INTERNAL			
Checked	8/4/2020	By	LEA
Subject: SFR Flow Inputs			
Approved	8/5/2020	By	ABP

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	17.900	
2	2	7.700	9.900	
3	3	15.800	6.400	
4	4	25.300	1.900	
5	5	40.300	0.000	
6	6	55.500	1.900	
7	7	63.700	9.900	
8	8	73.500	17.900	
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Stress Period 1 Segment 5 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	16.600	
2	2	3.100	12.600	
3	3	4.900	4.500	
4	4	6.400	0.600	
5	5	22.500	0.000	
6	6	30.300	0.600	
7	7	37.400	4.600	
8	8	44.600	16.600	
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Stress Period 1 Segment 6 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	12.000	
2	2	3.300	9.500	
3	3	5.400	6.800	
4	4	8.000	0.000	
5	5	23.100	0.900	
6	6	38.100	0.000	
7	7	39.900	4.000	
8	8	50.900	12.000	
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Stress Period 1 Segment 7 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	24.000	
2	2	16.800	20.000	
3	3	25.800	12.000	
4	4	36.700	4.000	
5	5	68.300	0.000	
6	6	81.300	0.000	
7	7	85.800	4.000	
8	8	93.900	8.000	
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Stress Period 1 Segment 8 Import... Copy OK Paste Cancel

8/4/2020 JNH

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Date	7/26/2020	By	ATMerook
Client: INTERNAL			
Checked	7/29/2020	By	LEA
Subject: SFR Flow Inputs			
Approved	8/5/2020	By	ABP

Surface Flow Routing (SFR) Section Information

	Number	X ✓	Z ✓	
1	1	0.000	13.300	
2	2	14.900	12.000	
3	3	22.900	0.000	
4	4	34.300	0.400	
5	5	44.500	0.000	
6	6	47.500	4.000	
7	7	48.100	8.000	
8	8	69.600	12.000	
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Stress Period 1 Segment 9 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X ✓	Z ✓	
1	1	0.000	13.200	
2	2	5.800	9.200	
3	3	11.600	1.200	
4	4	23.700	0.400	
5	5	33.000	0.000	
6	6	43.000	5.200	
7	7	48.200	9.200	
8	8	57.800	13.200	
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Stress Period 1 Segment 10 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X ✓	Z ✓	
1	1	0.000	12.400	
2	2	9.700	4.400	
3	3	13.300	0.400	
4	4	21.200	0.000	
5	5	33.500	0.400	
6	6	43.600	0.400	
7	7	46.500	4.400	
8	8	47.300	8.400	
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Stress Period 1 Segment 11 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X ✓	Z ✓	
1	1	0.000	8.400	
2	2	1.500	5.100	
3	3	2.500	4.400	
4	4	5.400	0.400	
5	5	22.200	0.000	
6	6	37.300	0.400	
7	7	42.500	4.400	
8	8	53.000	8.400	
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Stress Period 1 Segment 12 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z
1	1	0.000	7.800
2	2	6.200	7.000
3	3	11.000	0.900
4	4	14.700	1.100
5	5	19.300	0.500
6	6	22.000	1.200
7	7	57.700	0.000
8	8	61.900	6.200
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Stress Period 1 Segment 13 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z
1	1	0.000	20.000
2	2	4.000	16.000
3	3	11.100	0.000
4	4	24.500	0.000
5	5	26.000	4.000
6	6	31.200	8.000
7	7	45.100	12.000
8	8	52.830	20.000
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Stress Period 1 Segment 14 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z
1	1	0.000	16.000
2	2	9.400	11.900
3	3	17.800	8.000
4	4	24.900	0.000
5	5	25.500	0.000
6	6	29.300	5.500
7	7	32.400	12.000
8	8	35.000	16.000
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Stress Period 1 Segment 15 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z
1	1	0.000	10.600
2	2	16.000	8.900
3	3	22.900	8.000
4	4	28.600	7.000
5	5	47.900	0.000
6	6	54.000	0.000
7	7	69.100	8.100
8	8	73.700	12.600
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Stress Period 1 Segment 16 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	17.000	
2	2	15.300	13.000	
3	3	32.100	9.000	
4	4	38.800	1.000	
5	5	43.700	0.000	
6	6	48.200	1.000	
7	7	64.700	9.000	
8	8	71.600	17.000	
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Stress Period 1 Segment 17 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	8.700	
2	2	2.200	3.300	
3	3	4.800	0.700	
4	4	9.900	0.200	
5	5	11.400	0.000	
6	6	17.900	0.700	
7	7	25.800	5.200	
8	8	31.000	8.700	
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Stress Period 1 Segment 18 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	10.400	
2	2	15.600	8.000	
3	3	24.900	0.000	
4	4	27.600	0.000	
5	5	28.300	0.000	
6	6	31.300	5.300	
7	7	32.800	8.000	
8	8	46.500	10.400	
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Stress Period 1 Segment 19 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	17.100	
2	2	14.300	9.100	
3	3	18.900	5.800	
4	4	26.400	1.100	
5	5	31.800	0.000	
6	6	36.300	1.100	
7	7	40.600	9.100	
8	8	44.900	17.100	
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Stress Period 1 Segment 20 Import... Copy OK Paste Cancel

Surface Flow Routing (SFR) Section Information

	Number	X	Z	
1	1	0.000	17.400	
2	2	22.900	3.400	
3	3	27.500	1.700	
4	4	32.400	2.300	
5	5	40.600	1.400	
6	6	47.400	0.000	
7	7	54.500	1.400	
8	8	60.500	17.400	
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Stress Period 1 Segment 21 Import... Copy OK Paste Cancel

GWV7 Flow Inputs:

Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	prioı	strpt	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bwdth
1	1	2	2	0	0	0	2.074e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 1 Copy Paste OK Cancel

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Project	16134	Page	35/41
Date	7/26/2020	By	ATMerook
Checked	7/29/2020	By	LEA
Approved	8/5/2020	By	ABP

Client INTERNAL

Subject SFR Flow Inputs

Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	prior	strpt	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bwdth
1	1	2	2	0	0	0	2.074e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 2

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Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	prior	strpt	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bwdth
1	1	2	2	0	0	0	2.333e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 3

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8/4/2020 JNH

RJH CONSULTANTS, INC.

Project	16134	Page	36/41
Date	7/26/2020	By	ATMerook
Checked	7/29/2020	By	LEA
Approved	8/5/2020	By	ABP

Client INTERNAL

Subject SFR Flow Inputs

Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	prior	strpt	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bwdth
1	1	2	2	0	0	0	1.901e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 4

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Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	prior	strpt	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bwdth
1	1	2	2	0	0	0	1.814e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 5

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Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	prior	strpt	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bwdth
1	1	2	2	0	0	0	1.642e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	-4.457e+004	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 6

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Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	prior	strpt	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bwdth
1	1	2	2	0	0	0	2.506e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	-1.024e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	-1.479e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 7

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CONSULTANTS, INC.

Project	16134	Page	38/41
Date	7/26/2020	By	ATMerook
Client: INTERNAL			
Checked	7/29/2020	By	LEA
Subject: SFR Flow Inputs			
Approved	8/5/2020	By	ABP

Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	prior	strpt	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bwdth
1	1	2	2	0	0	0	6.653e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	-5.861e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	-6.199e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	-6.951e+004	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	-2.341e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	-1.292e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 8

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Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	prior	strpt	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bwdth
1	1	2	2	0	0	0	1.261e+007	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	-7.399e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	-2.079e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	-1.279e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	-3.779e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	-4.398e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 9

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Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	prior	strpt	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bwdth
1	1	2	2	0	0	0	7.085e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	-7.113e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	-3.010e+004	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	-7.394e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	-2.929e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	-3.366e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 10

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Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	iprior	nstrpts	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bw
1	1	2	2	0	0	0	4.147e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	-1.012e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	-7.709e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	-2.074e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	-4.124e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 11

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8/4/2020 JNH

Project	16134	Page	40/41
Date	7/26/2020	By	ATMerook
Checked	8/4/2020	By	LEA
Approved	8/5/2020	By	ABP

Client INTERNAL

Subject SFR Flow Inputs

Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	iprior	nstrpts	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bw
1	1	2	2	0	0	0	3.542e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	-3.260e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	-1.561e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	-3.851e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 12

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Surface Flow Routing (SFR) Segment Information

	Seg.	icalc	outseg	iupseg	iprior	nstrpts	flow	runoff	etsw	pptsw	roughch	roughbk	cdpth	fdpth	awdth	bw
1	1	2	2	0	0	0	3.715e+006	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
2	2	2	3	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
3	3	2	4	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
4	4	2	5	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
5	5	2	6	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
6	6	2	7	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
7	7	2	8	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
8	8	2	9	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
9	9	2	10	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
10	10	2	11	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
11	11	2	12	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
12	12	2	13	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
13	13	2	14	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
14	14	2	15	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
15	15	2	16	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
16	16	2	17	0	0	0	-2.680e+005	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
17	17	2	18	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0
18	18	2	19	0	0	0	0.0	0.0	0.0	0.0	4.500e-002	4.500e-002	0.0	0.0	0.0	0.0

Stress Period 13

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RJH Consultants, Inc.
South Boulder Creek Regional Detention
Project 16134
SFR BC Segment Data

By: ATMerook **Date:** 8/3/2020
Checked: JNH **Date:** 8/4/2020
Approved: **Date:**
8/5/2020 ABP

p.27 p. 28

Segment	Stress Period Flow Inputs												
	Steady State	Nov. 2018	Dec. 2018	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	2.074E+06	2.074E+06	2.333E+06	1.901E+06	1.814E+06	1.642E+06	2.506E+06	6.653E+06	1.261E+07	7.085E+06	4.147E+06	3.542E+06	3.715E+06
2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-5.861E+05	-7.399E+05	-7.113E+05	-1.012E+05	0.000E+00	0.000E+00
3	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-2.079E+05	-3.010E+04	-7.709E+05	-3.260E+05	0.000E+00
5	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-6.199E+05	-1.279E+06	-7.394E+05	0.000E+00	0.000E+00	0.000E+00
6	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-6.951E+04	-3.779E+05	-2.929E+05	-2.074E+05	-1.561E+05	0.000E+00
11	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
12	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
13	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
14	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-4.457E+04	-1.024E+05	-2.341E+06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
15	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
16	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-1.479E+05	-1.292E+05	-4.398E+05	-3.366E+05	-4.124E+05	-3.851E+05	-2.680E+05
17	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
18	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
19	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
20	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
21	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-2.035E+04	-2.465E+05	-1.349E+05	-1.228E+05	-5.098E+04	-6.689E+03

Notes:

1. All flows are reported in cubic feet per day (ft^3/d) consistent with the GWV7 model input units.
2. Positive flows represent flow into the boundary condition. Negative flows represent~~ation~~ flows out of the boundary condition (diversions)

This table summarizes the inflow into the upstream end of the SFR boundary condition (Segment 1) and losses that occur from diversions for each month. The data in this table do not show the following stream routing process that occurs within the SFR:

The outflow from a Segment is equal to the Segment inflow plus or minus any interaction that occurs between the stream and aquifer along the segment (stream gains or losses). The outflow from a segment becomes the inflow into the next segment.

APPENDIX G

SOUTH BOULDER CREEK SFR BOUNDARY CONDITION AND TOPOGRAPHIC PROFILES

Purpose:
Compare the linear SFR approximations with topographic data for the South Boulder Creek Detention Project (Project) Groundwater Vistas 7 (GWV7) transient groundwater model.

References:

1. Available ground surface topography data for the Project area includes Light Detection and Ranging (LiDAR) data provided by the City and County of Boulder and aerial and field survey data provided by Flatirons, Inc. RJH combined the LiDAR and aerial survey data into a single surface that was used to develop the model ground surface.

Approach:

- The SFR boundary condition representing South Boulder Creek (SBC) was input as 21 linear segments
- Segments were defined spatially along SBC with upstream and downstream endpoint elevations to follow composite topographic surface as defined in Reference #1 (p. 8).

(p. 2-7); see note p. 2

and was documented in a separate appendix to this report "South Boulder Creek SFR Boundary Condition Development. "

Summary:

- Streamwise distances and elevations of SFR segment endpoints are tabulated below:

(as measured linerally along the SFR boundary condition from the downstream end)

Streamwise Distance (ft)	Model Cell Elevations (ft)
19231	5463.93
18800	5460.04
17834	5448.55
14812	5414.00
12127	5388.94
11229	5375.91
10319	5365.05
9729	5362.25
9506	5358.71
8943	5353.30
8598	5349.10
8407	5348.85
7205	5338.00
6824	5333.16
6371	5327.12
6034	5325.89
5714	5320.69
5406	5319.89
5130	5317.90
2991	5298.15
2186	5291.07
674	5273.89

Segment 1
Segment 2
Segment 3
Segment 4
Segment 5
Segment 6
Segment 7
Segment 8
Segment 9
Segment 10
Segment 11
Segment 12
Segment 13
Segment 14
Segment 15
Segment 16
Segment 17
Segment 18
Segment 19
Segment 20
Segment 21

GWV7 Inputs:

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	194	Stage of Stream	5464.42964803
Column number:	40	Streambed Elevation (Stop)	5463.92964803
Layer number:	1	Width of Stream	20
SubLayer/cell:	2	Length of Stream	20.4
Reach number:	1	Thickness of Stream Bed	1
Segment number:	1	Hydraulic Conductivity	1.6

Segment 1 upstream endpoint elevation

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	192	Stage of Stream	5460.53550348574
Column number:	44	Streambed Elevation (Stop)	5460.03550348574
Layer number:	1	Width of Stream	20
SubLayer/cell:	2	Length of Stream	10.1
Reach number:	28	Thickness of Stream Bed	1
Segment number:	1	Hydraulic Conductivity	1.6

Segment 1 downstream endpoint elevation;

Subsequent segment endpoint elevations are always the downstream elevation. Upstream endpoint elevations are automatically based on previous segment downstream endpoint elevation

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	182	Stage of Stream	5449.04801052361
Column number:	49	Streambed Elevation (Stop)	5448.54801052361
Layer number:	1	Width of Stream	20
SubLayer/cell:	5	Length of Stream	10.1
Reach number:	62	Thickness of Stream Bed	1
Segment number:	2	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	154	Stage of Stream	5414.49547888608
Column number:	65	Streambed Elevation (Stop)	5413.99547888608
Layer number:	1	Width of Stream	20
SubLayer/cell:	2	Length of Stream	9.9
Reach number:	190	Thickness of Stream Bed	1
Segment number:	3	Hydraulic Conductivity	1.6
		Flow Entering Segment	0

Project	16134	Page	3/8
Date	8/10/2020	By	ATMerook
Checked	8/11/2020	By	JNH
Approved	8/11/20	By	ABP

Client City of Boulder

Subject SFR Profile Comparison

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	130	Stage of Stream	5389.43531050025
Column number:	78	Streambed Elevation (Stop)	5388.93531050025
Layer number:	1	Width of Stream	20
SubLayer/cell:	6	Length of Stream	9.9
Reach number:	171	Thickness of Stream Bed	1
Segment number:	4	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	119	Stage of Stream	5376.40515548028
Column number:	78	Streambed Elevation (Stop)	5375.90515548028
Layer number:	1	Width of Stream	20
SubLayer/cell:	7	Length of Stream	9.9
Reach number:	51	Thickness of Stream Bed	1
Segment number:	5	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	108	Stage of Stream	5365.55292420165
Column number:	80	Streambed Elevation (Stop)	5365.05292420165
Layer number:	1	Width of Stream	20
SubLayer/cell:	3	Length of Stream	9.9
Reach number:	53	Thickness of Stream Bed	1
Segment number:	6	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	100	Stage of Stream	5362.74620021406
Column number:	82	Streambed Elevation (Stop)	5362.24620021406
Layer number:	1	Width of Stream	20
SubLayer/cell:	15	Length of Stream	19.3
Reach number:	37	Thickness of Stream Bed	1
Segment number:	7	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	98	Stage of Stream	5359.2134730562
Column number:	84	Streambed Elevation (Stop)	5358.7134730562
Layer number:	1	Width of Stream	20
SubLayer/cell:	8	Length of Stream	20.2
		Thickness of Stream Bed	1
Reach number:	14	Hydraulic Conductivity	1.6
Segment number:	8		

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	92	Stage of Stream	5353.80343067833
Column number:	86	Streambed Elevation (Stop)	5353.30303649972
Layer number:	1	Width of Stream	20
SubLayer/cell:	0	Length of Stream	19.6
		Thickness of Stream Bed	1
Reach number:	69	Hydraulic Conductivity	1.6
Segment number:	9		

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	88	Stage of Stream	5349.59890609462
Column number:	87	Streambed Elevation (Stop)	5349.09889673737
Layer number:	1	Width of Stream	20
SubLayer/cell:	1	Length of Stream	19.4
		Thickness of Stream Bed	1
Reach number:	21	Hydraulic Conductivity	1.6
Segment number:	10		

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	85	Stage of Stream	5349.3466787335
Column number:	87	Streambed Elevation (Stop)	5348.84763699142
Layer number:	1	Width of Stream	20
SubLayer/cell:	11	Length of Stream	19.9
		Thickness of Stream Bed	1
Reach number:	12	Hydraulic Conductivity	1.6
Segment number:	11		

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	72	Stage of Stream	5338.50706957705
Column number:	85	Streambed Elevation (Stop)	5338.00309637436
Layer number:	1	Width of Stream	20
SubLayer/cell:	3	Length of Stream	19.8
Reach number:	76	Thickness of Stream Bed	1
Segment number:	12	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	67	Stage of Stream	5333.65800684195
Column number:	87	Streambed Elevation (Stop)	5333.15800684195
Layer number:	1	Width of Stream	20
SubLayer/cell:	13	Length of Stream	17.3
Reach number:	25	Thickness of Stream Bed	1
Segment number:	13	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	62	Stage of Stream	5327.61768080689
Column number:	88	Streambed Elevation (Stop)	5327.11768080689
Layer number:	1	Width of Stream	20
SubLayer/cell:	5	Length of Stream	19.9
Reach number:	26	Thickness of Stream Bed	1
Segment number:	14	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	58	Stage of Stream	5326.3853298303
Column number:	88	Streambed Elevation (Stop)	5325.8853298303
Layer number:	1	Width of Stream	20
SubLayer/cell:	2	Length of Stream	20
Reach number:	18	Thickness of Stream Bed	1
Segment number:	15	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	55	Stage of Stream	5321.18984632884
Column number:	90	Streambed Elevation (Stop)	5320.68984632884
Layer number:	1	Width of Stream	20
SubLayer/cell:	2	Length of Stream	19.9
Reach number:	20	Thickness of Stream Bed	1
Segment number:	16	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	52	Stage of Stream	5320.39100309699
Column number:	93	Streambed Elevation (Stop)	5319.89100309699
Layer number:	1	Width of Stream	20
SubLayer/cell:	0	Length of Stream	20.2
Reach number:	22	Thickness of Stream Bed	1
Segment number:	17	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	50	Stage of Stream	5318.39964784013
Column number:	96	Streambed Elevation (Stop)	5317.89964784013
Layer number:	1	Width of Stream	20
SubLayer/cell:	8	Length of Stream	19.8
Reach number:	18	Thickness of Stream Bed	1
Segment number:	18	Hydraulic Conductivity	1.6

Modify One Boundary Cell

Spatial Location		Stream Characteristics	
Row number:	29	Stage of Stream	5298.64924140009
Column number:	100	Streambed Elevation (Stop)	5298.14924140009
Layer number:	1	Width of Stream	20
SubLayer/cell:	4	Length of Stream	20
Reach number:	137	Thickness of Stream Bed	1
Segment number:	19	Hydraulic Conductivity	1.6

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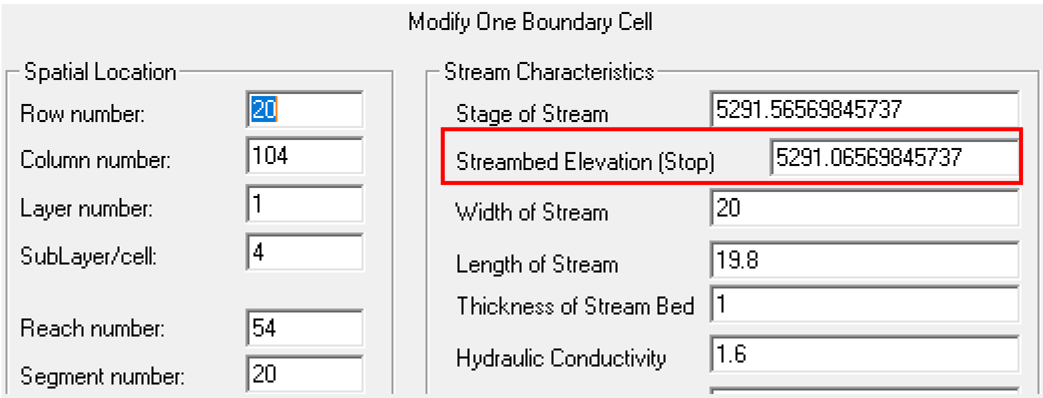
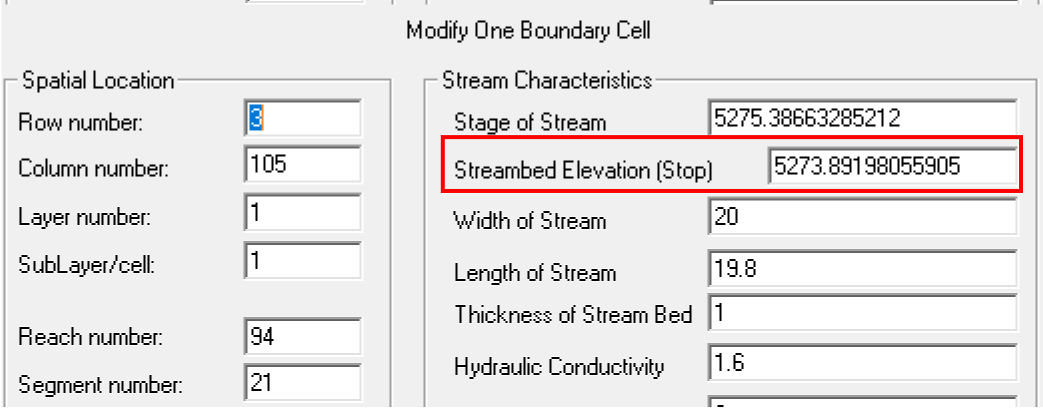
Client	City of Boulder	Checked	8/11/2020	By	JNH
Subject	SFR Profile Comparison	Approved	8/11/20	By	ABP





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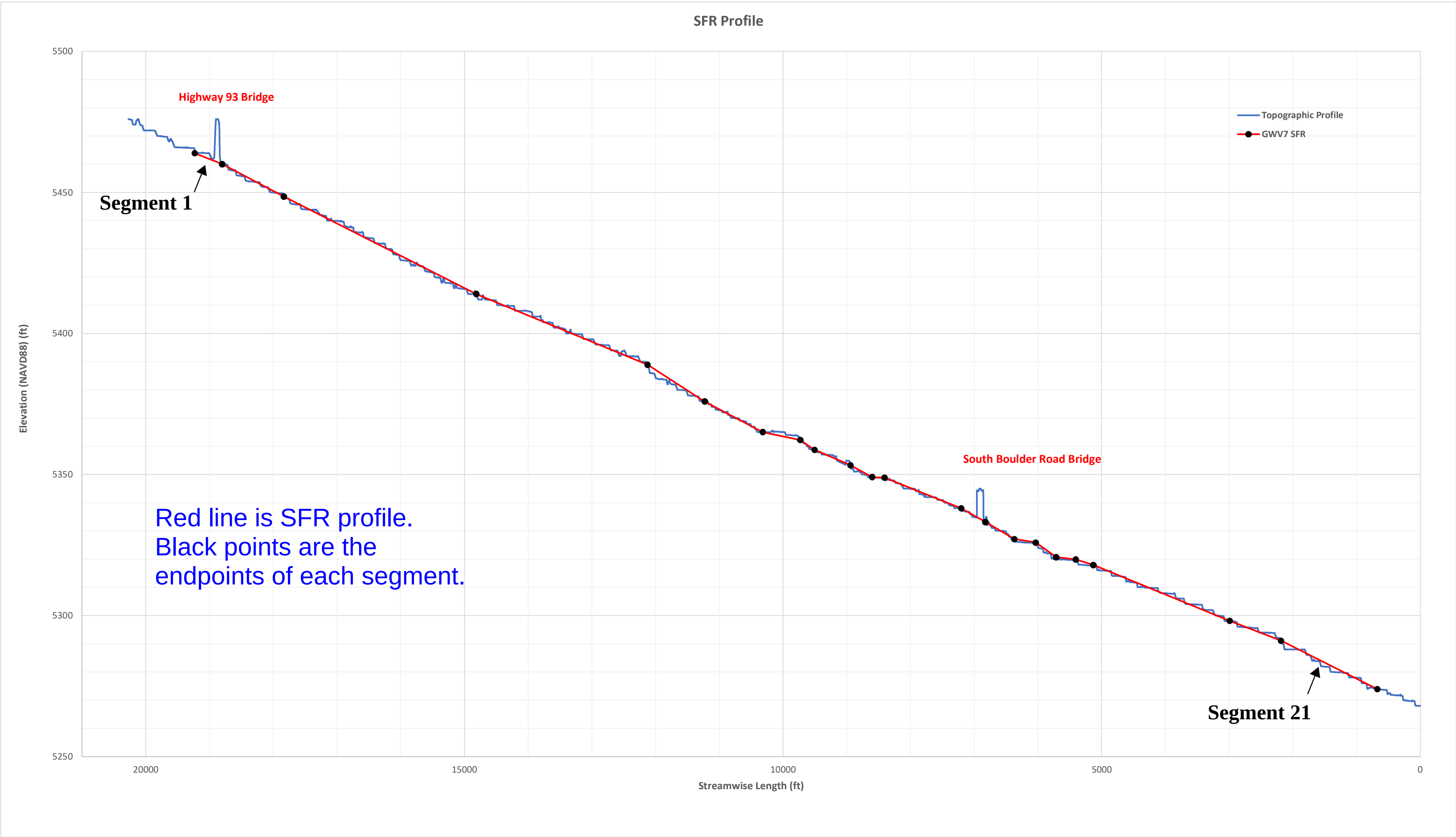

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APPENDIX H

BACKGROUND RECHARGE DEVELOPMENT

Purpose:

Document the background recharge rates over the South Boulder Creek Regional Detention Project (Project) area as a model boundary input for the Groundwater Vistas 7 (GWV7) transient groundwater model.

References:

1. A separate appendix to this report “Study Area Climate Data and Water Cycle” presents climate data near the Project via National Weather Service (NWS) climate and precipitation records from the Denver-Boulder Forecast Office (NOAA Earth System Research Laboratory) (p.4).
2. Jasechko et al. (2014) evaluates the seasonality of groundwater recharge as a portion of precipitation across different biomes using isotope tracing and global hydrological modeling (p.6-9).

Approach:

There are four types of background recharge within the Project GWV7 model domain: natural background recharge, natural background recharge impacted by fill, background recharge over developed areas with impervious/paved surfaces, and direct precipitation over open-water areas. The background recharge model zonation is presented on p.3.

Natural Background Recharge:

- Jasechko et al. (2014) reports the global mean annual groundwater recharge ratio (unit recharge per unit precipitation) to be approximately 16% (p. 7)
- The wintertime groundwater recharge ratio at study locations in arid and temperate climates was observed to be consistently greater than those in summertime (p. 6).
- For a number of sites evaluated in the study by Jasechko et al., temperate and arid locations had a winter groundwater recharge ratio 2~5 times greater than the summer groundwater recharge ratio (p. 8-9).
- RJH selected winter natural background recharge ratios that exceeded summer natural background recharge ratios to reflect the arid/temperate climate near the Project.

Fill Background Recharge

- Natural background recharge over the fill unit on CU property was ~~decreased~~ lower than the Natural Background Recharge to account for potential cycles of precipitation entrapment within the surficial fine-grained soils and organics and subsequent evapotranspiration, ultimately limiting interaction with the groundwater table.

Developed-Area Background Recharge:

- Background recharge over developed areas was input as a lower percentage of natural background recharge to account for impervious pavement, rooftops, etc.

Open-Water Background Recharge:

(ponds and South Boulder Creek)

- Background recharge over open-water (~~three CU ponds; CU wetlands pond south of levee~~) was input as the direct precipitation rate from NWS/NOAA climate data.

Methods:

Natural Background Recharge:

1. An average monthly background groundwater recharge ratio of 12% was selected for the summer months when OSMP fields were irrigated (April-October). This value generally improved head calibration across the model and is similar to the 16% annual global average referenced in Jasechko et al. (2014).
2. An average monthly background groundwater recharge ratio of 25% was selected for the winter months when OSMP fields are not irrigated (November-March). This value generally improved head calibration across the model and coincides with a wintertime groundwater recharge ratio 2~5 times greater than in summer as observed in some arid/temperate locations in Jasechko et al. (2014).
3. The background recharge rate for each transient model stress period was calculated by multiplying the groundwater recharge ratio by the average daily precipitation rate computed from monthly local precipitation data (p. 4- 5).

Fill Background Recharge

1. Background recharge over fill was input as 60% of the natural background recharge rate based on judgment to account for finer soils and potential water losses from ~~interception~~ entrapment in the vadose zone and evapotranspiration prior to reaching the groundwater table.

Developed-Area Background Recharge:

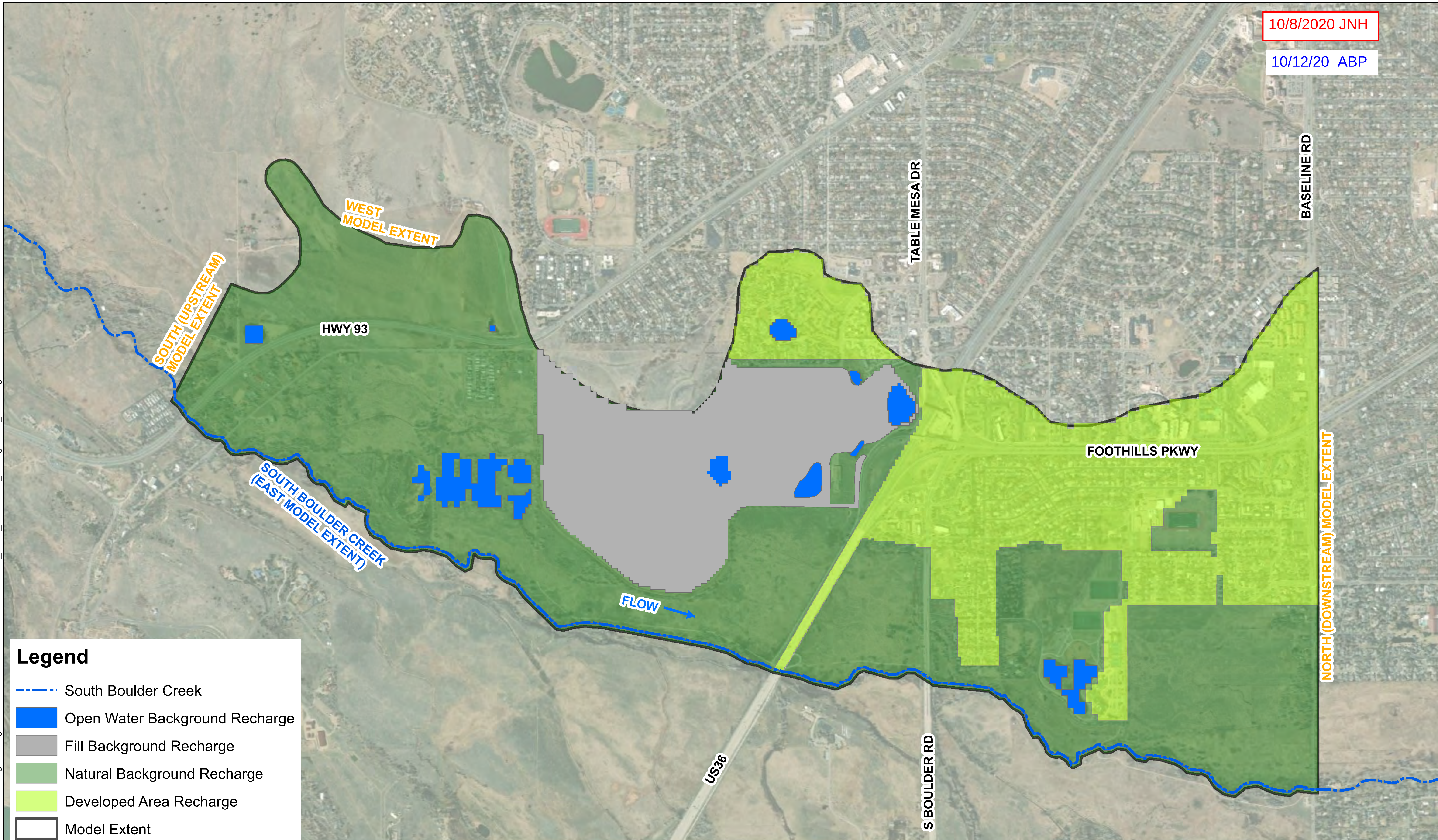
1. Background recharge over developed areas was input as 50% of the natural background recharge rate based on judgment to account ~~of~~ for impervious pavement, rooftops, etc.
2. RJH did not account for private irrigation of lawns because it is anticipated that applied water will remain in the shallow root zone and will be consumed as ET without significantly affecting the groundwater table.

Open-Water Background Recharge:

1. Background recharge over open-water ~~(three CU ponds; CU wetlands pond south of levee)~~ was input as the direct precipitation rate from NWS/NOAA climate data as reported in "Study Area Climate Data and Water Cycle" as presented on p. 4 .

Results/Summary:

GWV7 background recharge rate inputs are presented on p. 5 .



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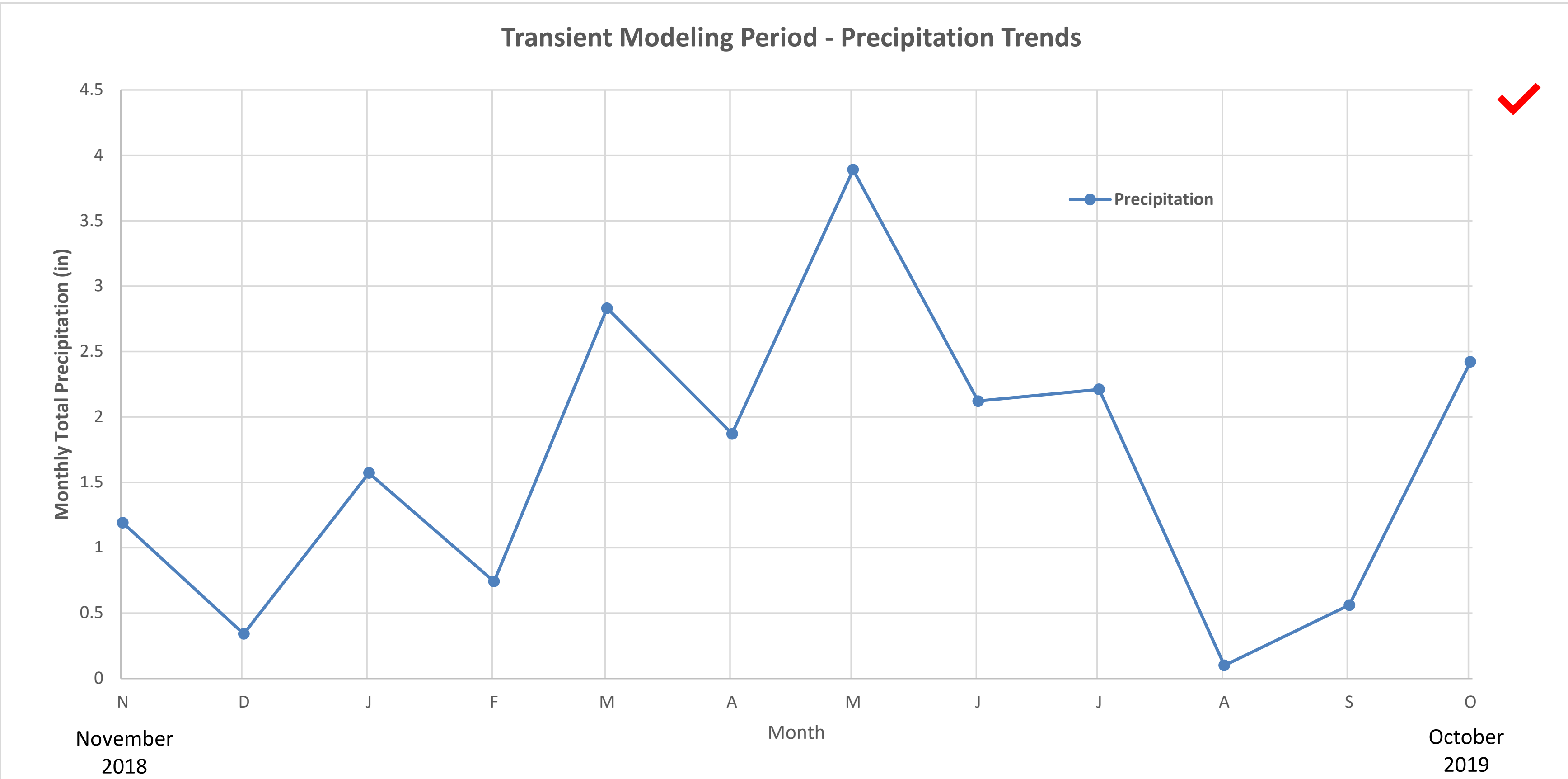
SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	BACKGROUND RECHARGE ZONES
PROJECT NO. 16134	October 2020 **Figure 1**

RJH Consultants, Inc.
South Boulder Creek Regional Detention
Project 16134
Groundwater Model
Transient Model Recharge Trends

By:	ATMerook	**Date:**	10/8/2020
Checked:	JNH	**Date:**	10/8/2020
Approved:	ABP	**Date:**	10/12/20

These precipitation rates also apply to the second year of the transient simulation (Stress Periods 14-25).

	Nov. 2018											*Oct. 2019*
Number of Days	30	31	31	28	31	30	31	30	31	31	30	31
Model Stress Period	**1 + 2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Month	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**
NOAA Precip (in)	1.19	0.34	1.57	0.74	2.83	1.87	3.89	2.12	2.21	0.1	0.56	2.42



RJH Consultants, Inc.
South Boulder Creek Regional Detention
Project 16134
Groundwater Model
Transient Model Background Recharge

By:	ATMerook	**Date:**	10/7/2020
Checked:	JNH	**Date:**	10/8/2020
Approved:	ABP	**Date:**	10/12/20

These precipitation rates also apply to the second year of the transient simulation (Stress Periods 14-25).

Stress Period		Input Rates (ft/d)			
		Natural Background Recharge	**Fill Background Recharge**	**Developed-Area Background Recharge**	**Open-Water Background Recharge**
1	Steady State	8.3E-04	5.0E-04	4.1E-04	3.3E-03
2	November 2018	8.3E-04	5.0E-04	4.1E-04	3.3E-03
3	December 2018	2.3E-04	1.4E-04	1.1E-04	9.4E-04
4	January 2019	1.1E-03	6.3E-04	5.3E-04	4.4E-03
5	February 2019	5.5E-04	3.3E-04	2.8E-04	2.1E-03
6	March 2019	1.9E-03	1.1E-03	9.5E-04	7.9E-03
7	April 2019	6.2E-04	3.7E-04	3.1E-04	5.2E-03
8	May 2019	1.3E-03	7.5E-04	6.3E-04	1.1E-02
9	June 2019	7.1E-04	4.2E-04	3.5E-04	5.9E-03
10	July 2019	7.1E-04	4.3E-04	3.6E-04	6.1E-03
11	August 2019	3.2E-05	1.9E-05	1.6E-05	2.8E-04
12	September 2019	1.9E-04	1.1E-04	9.3E-05	1.6E-03
13	October 2019	7.8E-04	4.7E-04	3.9E-04	6.7E-03

Rates for open-water background recharge were calculated based on 30-day months only and are not anticipated to significantly affect overall model results.

0.25 is used instead of 0.12 during summer months.

Stress Period 1 Example Calculation:

Open-Water Background Recharge = Avg. Daily NOAA Precipitation = 1.19 in./ 30 days = **3.3E-3 ft/d**

Natural Background Recharge = Avg. Daily NOAA Precipitation x Groundwater Recharge Ratio = (3.3E-3 ft/d)(0.25) = **8.3E-4 ft/d**

Fill Background Recharge = Natural Background Recharge x 60% = (8.3E-4 ft/d)(0.6) = **5.0E-4 ft/d**

Developed-Area Background Recharge = Natural Background Recharge x 50% = (8.3E-4 ft/d)(0.5) = **4.1E-4 ft/d**

AGU PUBLICATIONS

Water Resources Research

RESEARCH ARTICLE

10.1002/2014WR015809

Key Points:
- Recharge ratios are highest during the winter in arid and temperate climates
- Recharge ratios are at a maximum during the wet season in the tropics
- Groundwater $\delta^{18}O$ and $\delta^{2}H$ values are often lower than annual precipitation

Supporting Information:
- Readme
- Supplementary information

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Citation:
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The pronounced seasonality of global groundwater recharge

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Abstract Groundwater recharged by meteoric water supports human life by providing two billion people with drinking water and by supplying 40% of cropland irrigation. While annual groundwater recharge rates are reported in many studies, fewer studies have explicitly quantified intra-annual (i.e., seasonal) differences in groundwater recharge. Understanding seasonal differences in the fraction of precipitation that recharges aquifers is important for predicting annual recharge groundwater rates under changing seasonal precipitation and evapotranspiration regimes in a warming climate, for accurately interpreting isotopic proxies in paleoclimate records, and for understanding linkages between ecosystem productivity and groundwater recharge. Here we determine seasonal differences in the groundwater recharge ratio, defined here as the ratio of groundwater recharge to precipitation, at 54 globally distributed locations on the basis of $^{18}O/^{16}O$ and $^{2}H/^{1}H$ ratios in precipitation and groundwater. Our analysis shows that arid and temperate climates have wintertime groundwater recharge ratios that are consistently higher than summertime groundwater recharge ratios, while tropical groundwater recharge ratios are at a maximum during the wet season. The isotope-based recharge ratio seasonality is consistent with monthly outputs from a global hydrological model (PCR-GLOBWB) for most, but not all locations. The pronounced seasonality in groundwater recharge ratios shown in this study signifies that, from the point of view of predicting future groundwater recharge rates, a unit change in winter (temperate and arid regions) or wet season (tropics) precipitation will result in a greater change to the annual groundwater recharge rate than the same unit change to summer or dry season precipitation.

1. Introduction

Groundwater resources support one third of human water use [*Wada et al.*, 2014] and represent ~99% of Earth's unfrozen fresh water [*Aeschbach-Hertig and Gleeson*, 2012]. Groundwater has inputs from the infiltration of water from the surface, and has losses via discharge to the surface (streams, springs, seeps, lakes, and ocean), terrestrial transpiration and evaporation and groundwater pumping. Groundwater provides two billion people with drinking water and supplies 40% of global cropland irrigation [*Siebert et al.*, 2010; *Foley et al.*, 2011]. In spite of groundwater's pivotal importance to human livelihood, current extractions are depleting certain aquifers at several times the nature rate of replenishment [*Konikow and Kendy*, 2005; *Wada et al.*, 2010; *Konikow*, 2011; *Gleeson et al.*, 2012]. Examples of nonsustainable groundwater use have been observed in multiple regions including the northern Gangetic Plain (India) [*Rodell et al.*, 2009], the North China Plain [*Feng et al.*, 2013], the Middle East [*Voss et al.*, 2013; *Joodaki et al.*, 2014], the High Plains (central United States) [*Scanlon et al.*, 2012; *Steward et al.*, 2013], the Colorado River basin (southwest United States) [*Castle et al.*, 2014], and the Californian Central Valley (western United States) [*Famiglietti et al.*, 2011; *Scanlon et al.*, 2012]. The reversal of current nonsustainable groundwater extraction rates will require setting long-term pumping rate goals that will achieve a balance with groundwater recharge and ecosystem groundwater requirements [*Gleeson et al.*, 2012; *Aeschbach-Hertig and Gleeson*, 2012]. To determine sustainable groundwater pumping rates requires accurate estimates of groundwater recharge rates and thorough understanding of seasonal controls upon recharge.

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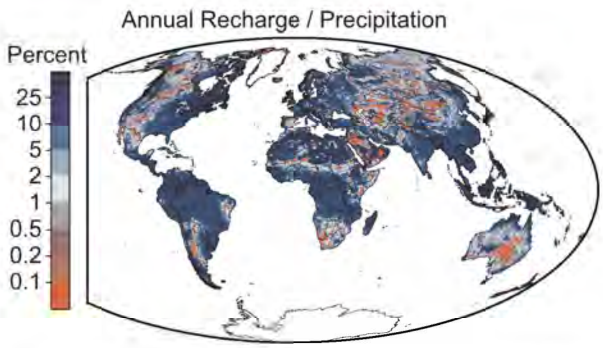

Figure 1. The global mean annual groundwater recharge ratio (i.e., recharge as a proportion of precipitation) calculated using a global hydrological model (PCR-GLOBWB) [*Wada et al.*, 2010].

Groundwater recharge is a complex ecohydrological process controlled by the physical state, amount and intensity of precipitation, and by the topography, water table level, geology, soil type, vegetation characteristics, boundary layer climatology, and irrigation return flows. Global syntheses of chloride mass balance recharge fluxes suggest that vegetation characteristics are the second most important determinant for groundwater recharge after precipitation fluxes [*Kim and Jackson*, 2012]. This is consistent with recent work showing that transpiration exceeds physical evaporation on continents [*Jasechko et al.*, 2013]. While investigations of annual groundwater recharge are common [e.g., *Scanlon et al.*, 2006; *Döll and Fielder*, 2008; *Wada et al.*, 2010] and several have explored mechanistically the interaction of the various ecological and physical factors controlling recharge in different settings [e.g., *Pangle et al.*, 2014; *Kurylyk et al.*, 2014], few investigations have studied explicitly the seasonal distribution of groundwater recharge. Examining this seasonal distribution or intra-annual variability in groundwater recharge is important because human-induced climate change impacts the hydrology of each season differently [e.g., *Hayhoe et al.*, 2004; *Vera et al.*, 2006].

Here we examine the seasonality of recharge with the *groundwater recharge ratio*, defined herein as groundwater recharge as a proportion of precipitation (recharge/precipitation). Previous work has estimated the annual global groundwater recharge ratio using a hydrological model and found a global mean of ~16% (PCR-GLOBWB) [*Wada et al.*, 2010] (Figure 1). However, model estimates are highly uncertain as a result of sparse hydrogeological data and because of static land use representations in current models [e.g., *Döll and Fielder*, 2008; *Wada et al.*, 2010]. Furthermore, projections of change to groundwater recharge from climate warming may neglect the importance of extreme events or changes to seasonal processes if based solely upon averages [*Portmann et al.*, 2013].

Intuitively, groundwater recharge during spring snowmelt in higher latitudes should be the largest of the hydrological year given the multiweek concentrated input and lack of competing evapotranspiration demands on water inputs [*Dunne and Leopold*, 1978; *Clark and Fritz*, 1997]. In more arid regions, one would likewise expect intuitively that disproportionate amounts of groundwater recharge would occur during summer monsoon conditions or during periods of concentrated high intensity rainfall. Indeed, site-specific modeling and field-studies have shown many examples this is the case, with winter recharge ratios that are higher than summer recharge ratios in Belgium [*Leterme et al.*, 2012], Greenland [*Leterme et al.*, 2012], the northeastern United States [*Heppner et al.*, 2007; *Yeh and Famiglietti*, 2009; *Dripps and Bradbury*, 2010; *Dripps*, 2012], and Croatia [*Jukić and Denić-Jukić*, 2009], and summer recharge that is restricted solely to high intensity thundershowers in some locations (e.g., Wisconsin, USA) [*Dripps*, 2012]. In terms of the groundwater recharge ratio, long-term monitoring of groundwater recharge in Tanzania, for instance, has shown that the recharge ratio is at a maximum during intense rain events [*Taylor et al.*, 2013] and occurs almost exclusively during the wet season. Similarly, winter recharge in temperate climates has been found to be an extreme and rapid process during spring freshet [*Sklash and Farvolden*, 1979] in highly fractured systems [*Gleeson et al.*, 2009], with seasonal frozen ground exerting an important control on the proportion of snowmelt recharging aquifers [*Granger et al.*, 1984]. Indeed, field monitoring in Sweden [*Rodhe*, 1981], Idaho [*Flerchinger et al.*, 1992], and the United States midwest [*Delin et al.*, 2007; *Dripps*, 2012] have found that the spring snowmelt constitutes the bulk of annual groundwater recharge.

In spite of the aforementioned examples, a seasonal difference in the groundwater recharge ratio has not been found in all cases (e.g., Spain) [*Leterme et al.*, 2012], advocating for a broader, global analysis to test the spatial variability of season differences in the efficiency of groundwater recharge. Most critically, knowledge and synthesis of intra-annual groundwater recharge fluxes are needed for accurately assessing and

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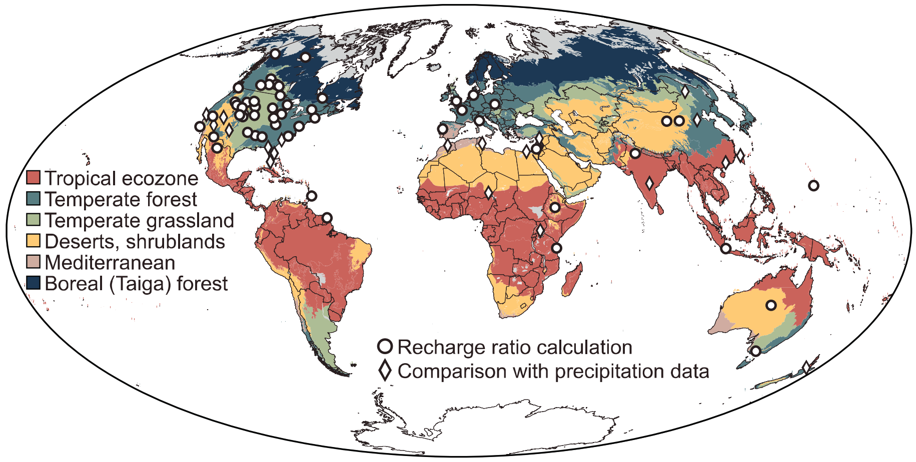

Figure 3. Locations where seasonal differences in recharge ratios (recharge/precipitation) are calculated on the basis of $\delta^{18}O$ and δ^2H values of precipitation and local groundwaters (white circles). White diamonds mark settings where a comparison of the isotopic compositions of groundwater and precipitation were made, but did not have sufficient data for a calculation of the groundwater recharge ratio.

each year with more than 10 months of data) were completed using a Welch t-test—that accounts for unequal variance between the precipitation and groundwater data (i.e., heteroscedastic)— to investigate the significance of differences between the two data pools: $\delta_{P(annual)}$ and $\delta_{Groundwater}$.

2.4. Model-Based Groundwater Recharge Ratios

Isotope-based groundwater recharge ratios were compared with outputs from the global hydrological model PCR-GLOBWB. Site-by-site isotope-based values of $(R/P)_{winter}$ and $(R/P)_{summer}$ were compared with modeled winter and summer average groundwater recharge ratios at the same location. The model itself integrates different hydrological processes occurring within the critical zone near to Earth's surface. In brief, the global hydrological model PCR-GLOBWB simulates for each grid cell (0.5° × 0.5° globally over the land) and for each time step (daily) the water storage in two vertically stacked soil layers and an underlying groundwater layer, as well as the water exchange between the layers (infiltration, percolation, and capillary rise) and between the top layer and the atmosphere (rainfall, evapotranspiration, and snowmelt). The model also calculates canopy interception and snow storage. Subgrid variability is taken into account by considering separately tall and short vegetation, open water (lakes, reservoirs, floodplains, and wetlands), different soil types, and the area fraction of saturated soil as well as the frequency distribution of groundwater depth. The groundwater layer represents the deeper part of the soil that is exempt from any direct influence of vegetation and constitutes a groundwater reservoir fed by active recharge. The groundwater store is explicitly parameterized based on lithology and topography, and represented as a linear reservoir model. For the detailed description, we refer to *Wada et al.* [2012a, 2012b].

3. Results

In this study, we quantify the seasonality of recharge at 54 globally distributed locations that lie within a variety of biomes to test the relative importance of individual seasons for groundwater recharge (Figure 3). Isotopic data for groundwater and the amount-weighted annual precipitation used to calculate groundwater recharge ratios are shown in Figure 4. Our isotope-based calculation of winter and summer groundwater recharge ratios (i.e., $(R/P)_{winter}/(R/P)_{summer}$) is shown in Figure 5 and Table 2.

Winter groundwater recharge ratios are higher than summer groundwater recharge ratios for the majority of deserts (7 of a total of 9), temperate grasslands (11 of a total of 13), and temperate forests (16 of a total of 18; median of $\delta^{18}O$-based results calculated using every combination of annual-precipitation and groundwater isotopic data at each location; Figure 5). Winter groundwater recharge ratios are more than twice summer groundwater recharge ratios for half of all temperate grasslands and temperate forests (15 of the 31 locations) and for three quarters of deserts and xeric shrublands (7 of the 9 locations). Further, one

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AGU Water Resources Research

10.1002/2014WR015809

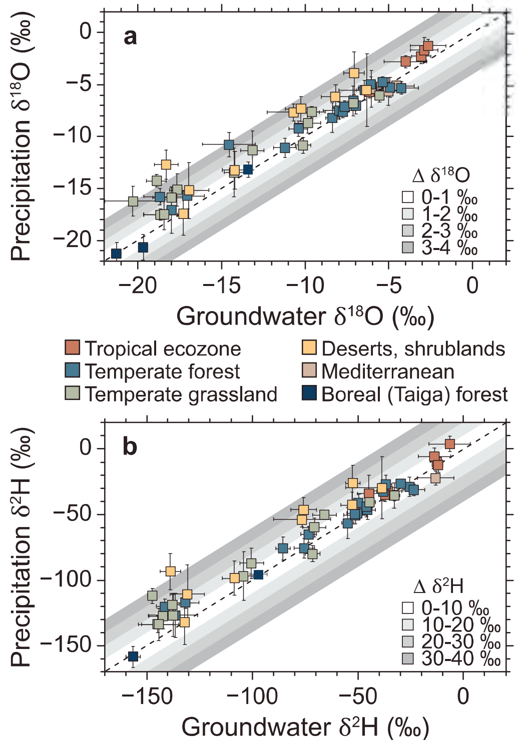

Figure 4. Isotopic compositions of precipitation and groundwater at 54 locations used in our calculation of groundwater recharge ratios. Precipitation $\delta^{18}O$ and δ^2H values are amount-weighted at a monthly time step. Error bars mark one standard deviation of interannual variability in the amount-weighted isotopic composition of precipitation and of all available groundwater data.

quarter of temperate or arid locations have a winter groundwater recharge ratio that is more than five times that of the summer.

Tropical groundwater recharge ratios were found to be much higher during the wet season relative to the dry season in all seven locations (i.e., $(R/P)_{wet} >> (R/P)_{dry}$; Figure 5). Only a few locations were available for Mediterranean climates ($n = 3$) and boreal forests ($n = 3$). Mediterranean climates examined here showed very little variability between summer and winter precipitation $\delta^{18}O$ and δ^2H values, resulting in highly uncertain isotope-based calculations of groundwater recharge ratios for these coastal locations (i.e., small change between $\delta_{P(summer)}$ and $\delta_{P(winter)}$; Figure 6). Boreal forests sites explored in the study ($n = 3$) show a similar groundwater recharge ratio during the summer and winter seasons.

4. Discussion

4.1. Comparison of Precipitation and Groundwater Isotopic Data

Recharge ratios were calculated for 54 aquifer-precipitation pairings that met all the criteria outlined in sections 2.1 and 2.2. Further, an additional 16 sites were available for a comparison of precipitation and groundwater $\delta^{18}O$ and δ^2H values, but were not suited for quantifying groundwater recharge ratios due to the lack of summer or winter precipitation end-members. Locations that were excluded from the recharge ratio calculation on the basis of indistinguishable summer and winter precipitation isotopic compositions are marked as diamonds in Figure 3. A comparison of $\delta^{18}O$ and δ^2H values for the amount-weighted isotopic composition of precipitation and groundwater is shown in Figure 7 for these 70 locations (average ± 1 SD uncertainty). Groundwater matched the amount-weighted precipitation from nearby monitoring stations within 1‰ for $\delta^{18}O$ and within 9‰ for δ^2H for half of the locations in this study, or within 2‰ for $\delta^{18}O$ and within 16‰ for δ^2H for the majority (80%) of study sites.

One third of the 70 aquifers have groundwater oxygen isotopic compositions that are significantly distinct ($p < 0.05$) from the isotopic composition of annual precipitation. Groundwater $\delta^{18}O$ values are lower than amount-weighted precipitation $\delta^{18}O$ values for 23 of the 24 locations having a statistically significant difference between annual precipitation and groundwater. For these locations, the difference between the precipitation and groundwater isotopic compositions ranged from +1.8‰ to −5.6‰ for $\delta^{18}O$ and from +9‰ to −45‰ for δ^2H. The closest match between the isotopic composition of groundwater and precipitation were found in regions with high overall $\delta^{18}O$ and δ^2H values. For example, all locations with average groundwater $\delta^{18}O$ values higher than −5‰ have amount-weighted precipitation values that match groundwater $\delta^{18}O$ values within 1.5‰. In contrast, regions with a lower groundwater $\delta^{18}O$ values have a broader range of differences between groundwater and precipitation. At locations where groundwater $\delta^{18}O$ values are <−10‰ ($n = 24$), the difference between groundwater and annual precipitation isotopic compositions (i.e., $\delta^{18}O_{Groundwater} - \delta^{18}O_{P(annual)}$) ranged between −5.6‰ and +1.0‰.

The larger difference between groundwater $\delta^{18}O$ and precipitation $\delta^{18}O$ found in regions with lower overall $\delta^{18}O$ values appears to be explained by spatial differences in the intra-annual fluctuations in precipitation isotopes. Regions that have higher $\delta^{18}O$ and δ^2H values also generally have more subdued seasonal fluctuations in the isotopic composition of precipitation (Figure 6). Conversely, regions with lower $\delta^{18}O_{P(annual)}$ and

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APPENDIX I

IRRIGATION RECHARGE DEVELOPMENT AND RATE CHECK

Purpose:

Document irrigation groundwater recharge rates as model boundary inputs for the South Boulder Creek Regional Detention Project (Project) Groundwater Vistas 7 (GWV7) transient groundwater model.

Verify that modeled irrigation recharge rates do not conflict with diversion records of temporal or volumetric availability.

References:

1. Natural background recharge rates were computed in a separate appendix to this report "Background Recharge Inputs".
2. Irrigation ditch diversion records used to compute applied flood irrigation recharge rates were analyzed and presented in a separate appendix to this report "Ditch Diversion Records".

Approach:

- Three primary irrigation ditches flow through the Project area: S. Boulder and Bear Creek Ditch, Dry Creek No. 2 Ditch (DC2D), and Howard Ditch (p. 3). These ditches divert flow directly from South Boulder Creek and are gauged. OSMP records show individual fields within the Project area that are irrigated by these ditches. (page 3)
- Lateral distributions of water within irrigated fields are temporally and spatially variable. These distributions are not gauged and are supported only by limited field observations.
- Irrigation recharge zones were delineated over individual OSMP fields to allow for varying rates of irrigation to be assigned to various fields each stress period as part of an iterative calibration process for groundwater head and drawdown responses.
- All irrigation recharge zones include the natural background recharge rate for each stress period as computed in "Background Recharge Inputs".
- Applied irrigation rates within the model were selected based on model calibration and are not intended to be prescriptive. or a unique solution.

Analysis:

Rate Development:

1. OSMP fields irrigated by DC2D, S. Boulder and Bear Creek Ditch, and Howard Ditch are shown on p. 3 .
2. Various recharge areas (Zones 3-4, 6-10, and 12 as shown on page 4) were developed using an iterative calibration process to represent the irrigated OSMP fields in GWV7.
3. The total recharge rate to be applied to each Zone each month was developed using an iterative calibration process. The total recharge rates applied in GWV7 are summarized on pages 5-9. These total recharge rates include both natural background recharge and irrigation.

		Project	16134	Page	2/18
		Date	10/8/2020	By	ATMerook
Client	City of Boulder	Checked	10/13/2020	By	JNH
Subject	Irrigation Recharge Calculations and Verification	Approved	10/14/20	By	ABP

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Rate Verification: Rate verification was computed for months when irrigation was occurring (April 2019 through October 2019) only.

1. Modeled irrigation zone assignments are shown on p. 4 .
2. Applied irrigation water for each stress period was computed by subtracting the daily natural background recharge rate (p. 10) from the daily total recharge rate over each irrigated zone (p. 5). This daily rate was then multiplied by the zonal area and the number of days in each month-long stress period (30 days) to compute a total volume of water applied over each zone for each stress period. (p. 11-18).
3. Zone 4 includes all upstream fields irrigated by S. Boulder and Bear Creek Ditch. Zone 12 includes all fields irrigated by Howard Ditch. Zones 3 and 6-10 include all fields irrigated by DC2D. Total computed water applied to each of the three field groups is compared to total amount of water diverted from the irrigation source ditch as presented in the "Ditch Diversion Records" appendix to verify that the amount of available irrigation water is not exceeded for any ditch during any stress period. (p. 11-18).
4. Irrigation diversions did not occur ~~before April 2019~~ from November 2018 through March 2019. Only Howard Ditch was active during April 2019. ~~All ditches were active through August 2019. Howard Ditch and~~ Dry Creek No. 2 Ditch was inactive in September and October 2019. There is an ungauged confluence of S. Boulder and Bear Creek Ditch with DC2D south of the CU levee. Measurable flows have been observed during field visits leaving S. Boulder and Bear Creek Ditch to enter the DC2D. We considered that this ungauged exchange of water could allow irrigation of OSMP fields denoted to receive diversions from DC2D during September and October 2019 when the ditch is not actively diverting (p. 16-17). Irrigation application over the DC2D receiving fields during these two months improved transient model calibration.

Active diversions were as follows:

Howard Ditch: April 2019 through October 2019

DC2D: May 2019 through August 2019

S. Boulder and Bear Creek Ditch: June 2019 through October 2019

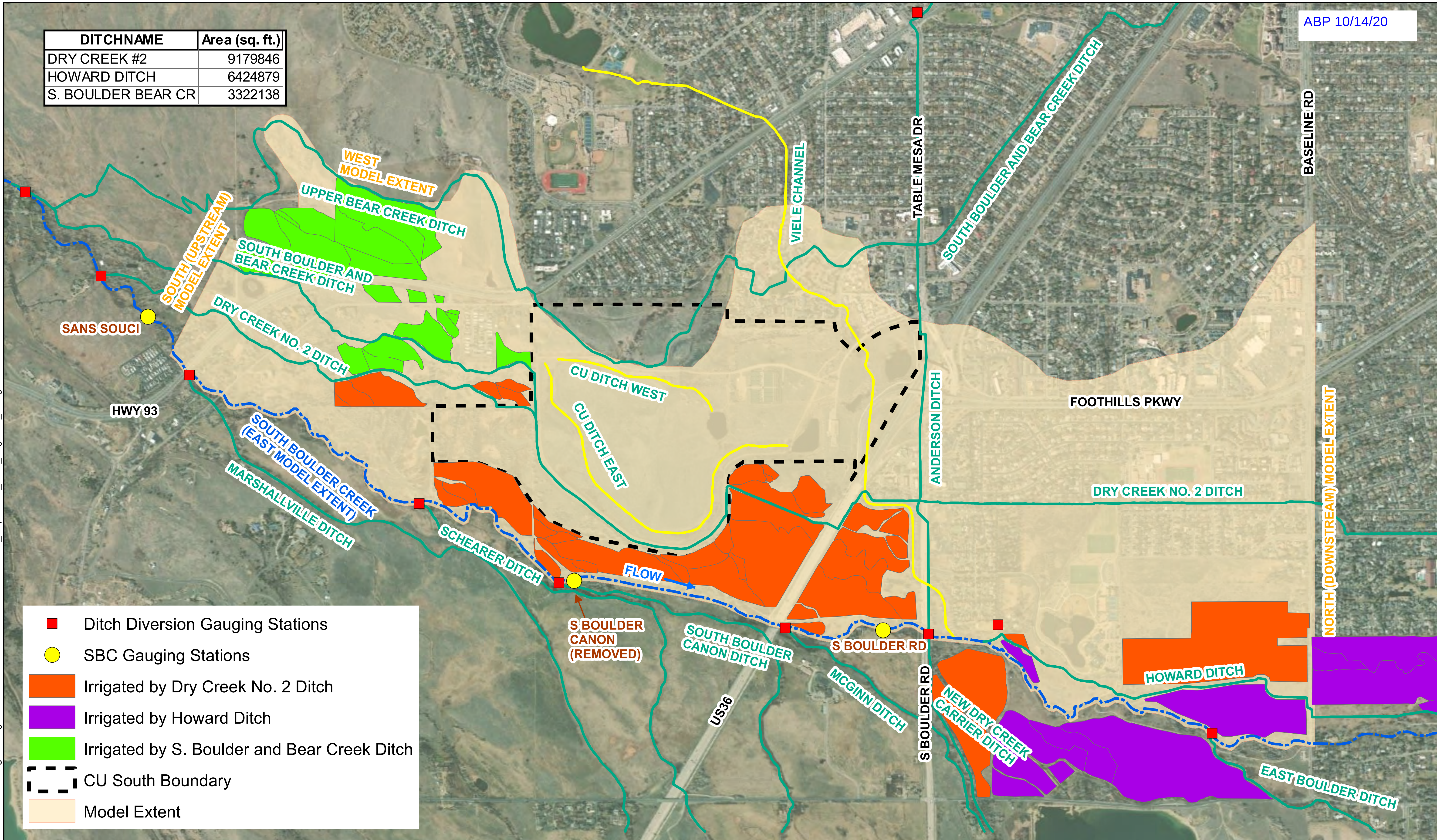
Summary:

- Computed ~~irrigation~~ recharge rates for each stress period are presented on p. 5 .
- GWV7 recharge zone input tables are presented on p. 6-9 .
- Irrigation application-availability ratios are computed and presented on p. 11-17 .

- Results summary is on page 18. The amount of irrigation that is applied to the OSMP fields ranges from about 1 percent to 74 percent of the water that is diverted by the respective ditch each month.

ABP 10/14/20

DITCHNAME	Area (sq. ft.)
DRY CREEK #2	9179846
HOWARD DITCH	6424879
S. BOULDER BEAR CR	3322138



Ditch Diversion Gauging Stations
SBC Gauging Stations
Irrigated by Dry Creek No. 2 Ditch
Irrigated by Howard Ditch
Irrigated by S. Boulder and Bear Creek Ditch
CU South Boundary
Model Extent

0 600 1,200 2,400 Feet

REPRODUCE IN COLOR

N

CITY OF BOULDER

RJH CONSULTANTS, INC.

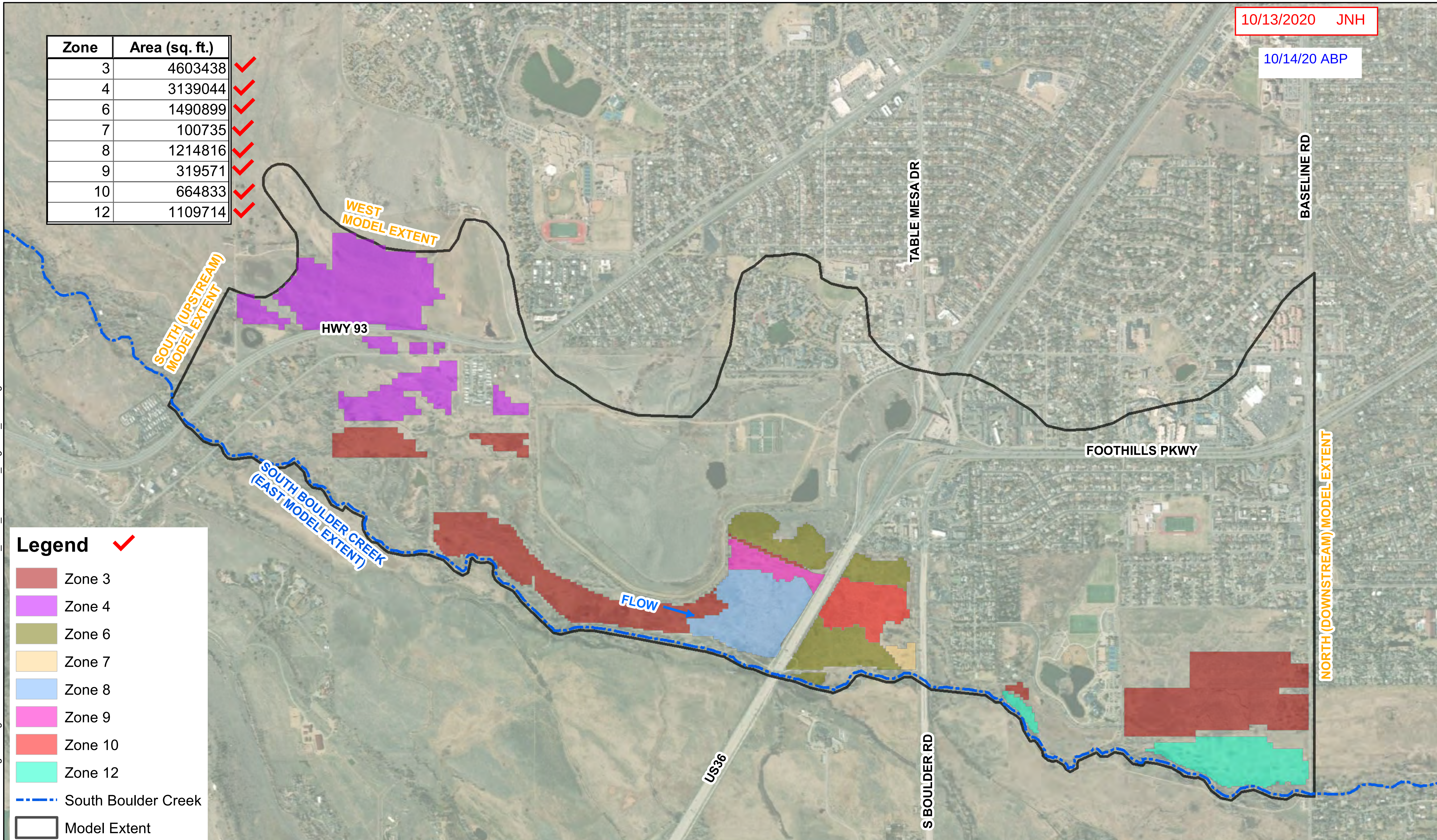
SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	SOUTH BOULDER CREEK AND IRRIGATION GAUGING STATIONS, DITCHES, AND FIELDS
PROJECT NO. 16134	August 2020 **Figure 2.1**

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline_Report\2.1_SBC_Irrigation_Gauges.mxd

Zone	Area (sq. ft.)
3	4603438 ✓
4	3139044 ✓
6	1490899 ✓
7	100735 ✓
8	1214816 ✓
9	319571 ✓
10	664833 ✓
12	1109714 ✓

10/13/2020 JNH

10/14/20 ABP



0 600 1,200 2,400 Feet

REPRODUCE IN COLOR

N

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

IRRIGATION RECHARGE ZONES

PROJECT NO. 16134

October 2020

Figure 2

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\16134_3004_07272020_Irrigation_Recharge.mxd

RJH Consultants, Inc.
South Boulder Creek Regional Detention
Project 16134
Groundwater Model
Transient Model Recharge Trends

By:	ATMerook	**Date:**	10/7/2020
Checked:	JNH	**Date:**	10/13/2020
Approved:	ABP	**Date:**	10/14/20

TOTAL RECHARGE RATE (FT/D)

	Stress Period	*Zones 3* Miscellaneous Irrigated Fields	*Zone 4* Upstream Fields	*Zone 6* B-121, B-108, B-126, and B-124 (no irrigation)	*Zone 7* B-107	*Zone 8* B-116, B-123, and OSMP 2S	*Zone 9* B-110, B-122, OSMP 1S	*Zone 10* B-125, OSMP 2N, OSMP 4, and OSMP 6	*Zone 12* Howard Ditch-sourced Fields
1	Steady State	8.3E-04	8.3E-04	8.3E-04	8.3E-04	8.3E-04	8.3E-04	8.3E-04	8.3E-04
2	November 2018	8.3E-04	8.3E-04	8.3E-04	8.3E-04	8.3E-04	8.3E-04	8.3E-04	8.3E-04
3	December 2018	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04
4	January 2019	1.1E-03	1.1E-03	1.1E-03	1.1E-03	1.1E-03	1.1E-03	1.1E-03	1.1E-03
5	February 2019	5.5E-04	5.5E-04	5.5E-04	5.5E-04	5.5E-04	5.5E-04	5.5E-04	5.5E-04
6	March 2019	1.9E-03	1.9E-03	1.9E-03	1.9E-03	1.9E-03	1.9E-03	1.9E-03	1.9E-03
7	April 2019	6.2E-04	6.2E-04	6.2E-04	6.2E-04	6.2E-04	6.2E-04	6.2E-04	7.7E-03
8	May 2019	1.4E-02	1.3E-03	6.7E-03	1.4E-02	1.6E-02	1.4E-02	1.6E-02	1.4E-02
9	June 2019	1.4E-02	1.4E-02	1.4E-02	1.4E-02	1.4E-02	1.4E-02	1.4E-02	1.4E-02
10	July 2019	1.4E-02	1.4E-02	7.1E-04	5.9E-03	5.9E-03	5.9E-03	5.9E-03	1.4E-02
11	August 2019	1.2E-02	1.2E-02	3.2E-05	5.0E-04	5.0E-04	2.4E-03	5.0E-04	1.2E-02
12	September 2019	3.5E-03	3.5E-03	1.9E-04	1.3E-03	1.3E-03	4.1E-04	1.3E-03	3.5E-03
13	October 2019	3.1E-03	3.1E-03	7.8E-04	7.8E-04	7.8E-04	9.3E-04	1.5E-03	3.1E-03

Total recharge rate is recharge from background + irrigation.

Total recharge was developed through an iterative calibration process.

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STRESS PERIOD

TOTAL

(ft/d)

NOTE: Zones 1-2, 5, and 11 contribute only background recharge and are computed/checked in Appendix H.

SP01

```
                                     rechargedatabase
Recharge  Conc  Ponding_Depth         *All
 12
1  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
2  5.000000e-004  0.000000e+000  0.000000e+000  0.000000e+000
3  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
4  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
5  4.100000e-004  0.000000e+000  0.000000e+000  0.000000e+000
6  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
7  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
8  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
9  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
10  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
11  3.300000e-003  0.000000e+000  0.000000e+000  0.000000e+000
12  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
```

SP02

```
 12
1  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
2  5.000000e-004  0.000000e+000  0.000000e+000  0.000000e+000
3  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
4  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
5  4.100000e-004  0.000000e+000  0.000000e+000  0.000000e+000
6  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
7  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
8  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
9  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
10  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
11  3.300000e-003  0.000000e+000  0.000000e+000  0.000000e+000
12  8.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
```

SP03

```
 12
1  2.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
2  1.400000e-004  0.000000e+000  0.000000e+000  0.000000e+000
3  2.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
4  2.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
5  1.100000e-004  0.000000e+000  0.000000e+000  0.000000e+000
6  2.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
7  2.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
8  2.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
9  2.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
10  2.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
11  9.400000e-004  0.000000e+000  0.000000e+000  0.000000e+000
12  2.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
```

SP04

```
 12
1  1.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
2  6.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
3  1.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
4  1.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
5  5.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
6  1.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
7  1.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
```

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10/14/20 ABP

rechargedatabase

SP04

```
8  1.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
9  1.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
10  1.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
11  4.400000e-003  0.000000e+000  0.000000e+000  0.000000e+000
12  1.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
 12
```

SP05

```
1  5.500000e-004  0.000000e+000  0.000000e+000  0.000000e+000
2  3.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
3  5.500000e-004  0.000000e+000  0.000000e+000  0.000000e+000
4  5.500000e-004  0.000000e+000  0.000000e+000  0.000000e+000
5  2.800000e-004  0.000000e+000  0.000000e+000  0.000000e+000
6  5.500000e-004  0.000000e+000  0.000000e+000  0.000000e+000
7  5.500000e-004  0.000000e+000  0.000000e+000  0.000000e+000
8  5.500000e-004  0.000000e+000  0.000000e+000  0.000000e+000
9  5.500000e-004  0.000000e+000  0.000000e+000  0.000000e+000
10  5.500000e-004  0.000000e+000  0.000000e+000  0.000000e+000
11  2.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
12  5.500000e-004  0.000000e+000  0.000000e+000  0.000000e+000
 12
```

SP06

```
1  1.900000e-003  0.000000e+000  0.000000e+000  0.000000e+000
2  1.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
3  1.900000e-003  0.000000e+000  0.000000e+000  0.000000e+000
4  1.900000e-003  0.000000e+000  0.000000e+000  0.000000e+000
5  9.500000e-004  0.000000e+000  0.000000e+000  0.000000e+000
6  1.900000e-003  0.000000e+000  0.000000e+000  0.000000e+000
7  1.900000e-003  0.000000e+000  0.000000e+000  0.000000e+000
8  1.900000e-003  0.000000e+000  0.000000e+000  0.000000e+000
9  1.900000e-003  0.000000e+000  0.000000e+000  0.000000e+000
10  1.900000e-003  0.000000e+000  0.000000e+000  0.000000e+000
11  7.900000e-003  0.000000e+000  0.000000e+000  0.000000e+000
12  1.900000e-003  0.000000e+000  0.000000e+000  0.000000e+000
 12
```

SP07

```
1  6.200000e-004  0.000000e+000  0.000000e+000  0.000000e+000
2  3.700000e-004  0.000000e+000  0.000000e+000  0.000000e+000
3  6.200000e-004  0.000000e+000  0.000000e+000  0.000000e+000
4  6.200000e-004  0.000000e+000  0.000000e+000  0.000000e+000
5  3.100000e-004  0.000000e+000  0.000000e+000  0.000000e+000
6  6.200000e-004  0.000000e+000  0.000000e+000  0.000000e+000
7  6.200000e-004  0.000000e+000  0.000000e+000  0.000000e+000
8  6.200000e-004  0.000000e+000  0.000000e+000  0.000000e+000
9  6.200000e-004  0.000000e+000  0.000000e+000  0.000000e+000
10  6.200000e-004  0.000000e+000  0.000000e+000  0.000000e+000
11  5.200000e-003  0.000000e+000  0.000000e+000  0.000000e+000
12  7.700000e-003  0.000000e+000  0.000000e+000  0.000000e+000
 12
```

SP08

```
1  1.300000e-003  0.000000e+000  0.000000e+000  0.000000e+000
2  7.500000e-004  0.000000e+000  0.000000e+000  0.000000e+000
3  1.400000e-002  0.000000e+000  0.000000e+000  0.000000e+000
```

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10/14/20 ABP

rechargedatabase

SP08

4	1.300000e-003	0.000000e+000	0.000000e+000	0.000000e+000
5	6.300000e-004	0.000000e+000	0.000000e+000	0.000000e+000
6	6.700000e-003	0.000000e+000	0.000000e+000	0.000000e+000
7	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000
8	1.600000e-002	0.000000e+000	0.000000e+000	0.000000e+000
9	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000
10	1.600000e-002	0.000000e+000	0.000000e+000	0.000000e+000
11	1.100000e-002	0.000000e+000	0.000000e+000	0.000000e+000
12	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000

12

SP09

1	7.100000e-004	0.000000e+000	0.000000e+000	0.000000e+000
2	4.200000e-004	0.000000e+000	0.000000e+000	0.000000e+000
3	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000
4	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000
5	3.500000e-004	0.000000e+000	0.000000e+000	0.000000e+000
6	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000
7	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000
8	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000
9	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000
10	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000
11	5.900000e-003	0.000000e+000	0.000000e+000	0.000000e+000
12	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000

12

SP10

1	7.100000e-004	0.000000e+000	0.000000e+000	0.000000e+000
2	4.300000e-004	0.000000e+000	0.000000e+000	0.000000e+000
3	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000
4	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000
5	3.600000e-004	0.000000e+000	0.000000e+000	0.000000e+000
6	7.100000e-004	0.000000e+000	0.000000e+000	0.000000e+000
7	5.900000e-003	0.000000e+000	0.000000e+000	0.000000e+000
8	5.900000e-003	0.000000e+000	0.000000e+000	0.000000e+000
9	5.900000e-003	0.000000e+000	0.000000e+000	0.000000e+000
10	5.900000e-003	0.000000e+000	0.000000e+000	0.000000e+000
11	6.100000e-003	0.000000e+000	0.000000e+000	0.000000e+000
12	1.400000e-002	0.000000e+000	0.000000e+000	0.000000e+000

12

SP11

1	3.200000e-005	0.000000e+000	0.000000e+000	0.000000e+000
2	1.900000e-005	0.000000e+000	0.000000e+000	0.000000e+000
3	1.200000e-002	0.000000e+000	0.000000e+000	0.000000e+000
4	1.200000e-002	0.000000e+000	0.000000e+000	0.000000e+000
5	1.600000e-005	0.000000e+000	0.000000e+000	0.000000e+000
6	3.200000e-005	0.000000e+000	0.000000e+000	0.000000e+000
7	5.000000e-004	0.000000e+000	0.000000e+000	0.000000e+000
8	5.000000e-004	0.000000e+000	0.000000e+000	0.000000e+000
9	2.400000e-003	0.000000e+000	0.000000e+000	0.000000e+000
10	5.000000e-004	0.000000e+000	0.000000e+000	0.000000e+000
11	2.800000e-004	0.000000e+000	0.000000e+000	0.000000e+000
12	1.200000e-002	0.000000e+000	0.000000e+000	0.000000e+000

10/13/2020 JNH

10/14/20 ABP

rechargedatabase

SP12

```
 12
1  1.900000e-004  0.000000e+000  0.000000e+000  0.000000e+000
2  1.100000e-004  0.000000e+000  0.000000e+000  0.000000e+000
3  3.500000e-003  0.000000e+000  0.000000e+000  0.000000e+000
4  3.500000e-003  0.000000e+000  0.000000e+000  0.000000e+000
5  9.300000e-005  0.000000e+000  0.000000e+000  0.000000e+000
6  1.900000e-004  0.000000e+000  0.000000e+000  0.000000e+000
7  1.300000e-003  0.000000e+000  0.000000e+000  0.000000e+000
8  1.300000e-003  0.000000e+000  0.000000e+000  0.000000e+000
9  4.100000e-004  0.000000e+000  0.000000e+000  0.000000e+000
10  1.300000e-003  0.000000e+000  0.000000e+000  0.000000e+000
11  1.600000e-003  0.000000e+000  0.000000e+000  0.000000e+000
12  3.500000e-003  0.000000e+000  0.000000e+000  0.000000e+000
```

SP13

```
 12
1  7.800000e-004  0.000000e+000  0.000000e+000  0.000000e+000
2  4.700000e-004  0.000000e+000  0.000000e+000  0.000000e+000
3  3.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
4  3.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
5  3.900000e-004  0.000000e+000  0.000000e+000  0.000000e+000
6  7.800000e-004  0.000000e+000  0.000000e+000  0.000000e+000
7  7.800000e-004  0.000000e+000  0.000000e+000  0.000000e+000
8  7.800000e-004  0.000000e+000  0.000000e+000  0.000000e+000
9  9.300000e-004  0.000000e+000  0.000000e+000  0.000000e+000
10  1.500000e-003  0.000000e+000  0.000000e+000  0.000000e+000
11  6.700000e-003  0.000000e+000  0.000000e+000  0.000000e+000
12  3.100000e-003  0.000000e+000  0.000000e+000  0.000000e+000
```

10/13/2020 JNH

RJH Consultants, Inc.
South Boulder Creek Regional Detention
Project 16134
Groundwater Model
Transient Model Background Recharge

By: ATMerook **Date:** 10/7/2020
Checked: **Date:**
Approved: **Date:**

10/14/20 ABP

TYP. ALL stress periods (SP): rates also apply to the second year of the transient simulation (Stress Periods 14-25).

See appendix "Background Recharge Development" to the Report for detailed check of this table and example calculations.

Stress Period		Input Rates (ft/d)			
		Natural Background Recharge	Fill Background Recharge	Developed-Area Background Recharge	Open-Water Background Recharge
1	Steady State	8.3E-04	5.0E-04	4.1E-04	3.3E-03
2	November 2018	8.3E-04	5.0E-04	4.1E-04	3.3E-03
3	December 2018	2.3E-04	1.4E-04	1.1E-04	9.4E-04
4	January 2019	1.1E-03	6.3E-04	5.3E-04	4.4E-03
5	February 2019	5.5E-04	3.3E-04	2.8E-04	2.1E-03
6	March 2019	1.9E-03	1.1E-03	9.5E-04	7.9E-03
7	April 2019	6.2E-04	3.7E-04	3.1E-04	5.2E-03
8	May 2019	1.3E-03	7.5E-04	6.3E-04	1.1E-02
9	June 2019	7.1E-04	4.2E-04	3.5E-04	5.9E-03
10	July 2019	7.1E-04	4.3E-04	3.6E-04	6.1E-03
11	August 2019	3.2E-05	1.9E-05	1.6E-05	2.8E-04
12	September 2019	1.9E-04	1.1E-04	9.3E-05	1.6E-03
13	October 2019	7.8E-04	4.7E-04	3.9E-04	6.7E-03

Stress Period 1 Example Calculation:

Open-Water Background Recharge = Avg. Daily NOAA Precipitation = 1.19 in./ 30 days = **3.3E-3 ft/d**

Natural Background Recharge = Avg. Daily NOAA Precipitation x Groundwater Recharge Ratio = (3.3E-3 ft/d)(0.25) = **8.3E-4 ft/d**

Fill Background Recharge = Natural Background Recharge x 60% = (8.3E-4 ft/d)(0.6) = **5.0E-4 ft/d**

Developed-Area Background Recharge = Natural Background Recharge x 50% = (8.3E-4 ft/d)(0.5) = **4.1E-4 ft/d**

RJH Consultants, Inc.	By:	ATMerook	Date:	10/8/2020
South Boulder Creek Regional Detention	Checked:	JNH	Date:	10/13/2020
Project 16134	Approved:	ABP	Date:	10/14/20
GW Model Irrigation Diversions				

For Zone 12, April 2019

Background Recharge Rate: 6.23E-04 FT/D

Howard Ditch

Zone 12 Area	1109714	SF
Zone 12 Irrigation Recharge	7.0E-03	FT/D
Daily Applied Water	7.8E+03	CF/D
Month Applied Water	5.4	AF
Month Available Water	102.0	AF
Percent Used	**5.3**	**%**

South Boulder and Bear Creek Ditch

Zone 4 Area	3139044	SF
Zone 4 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0.0E+00	CF/D
Month Applied Water	0.0	AF
Month Available Water	0.0	AF
Percent Used	**0.0**	**%**

Dry Creek No. 2 Ditch

Zone 3 Area	4603438	SF
Zone 3 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0.0E+00	CF/D
Month Applied Water	0.0	AF
Zone 6 Area	1490899	SF
Zone 6 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0.0E+00	CF/D
Month Applied Water	0.0	AF
Zone 7 Area	100735	SF
Zone 7 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0.0	CF/D
Month Applied Water	0.0	AF
Zone 8 Area	1214816	SF
Zone 8 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0	CF/D
Month Applied Water	0.0	AF
Zone 9 Area	319571	SF
Zone 9 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0	CF/D
Month Applied Water	0.0	AF
Zone 10 Area	664833	SF
Zone 10 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0	CF/D
Month Applied Water	0.0	AF
Total Irrigation Water Applied	0.0	AF
Total Irrigation Water Available	0.0	AF
Percent Used	**0.0**	**%**

Sample Calculation:

Irrigation Recharge = Total Recharge (p. 5) - Background Recharge (p. 10)

(7.7E-03 ft/d) - (6.2E-4 ft/d) = 7.0E-03 ft/d

Daily Applied Water = Irrigation Recharge x Area (p. 4)

(7.0E-03 ft/d) x (1109714 ft^2) = 7.8E+03 ft^3/d

Month Applied Water = Daily Applied Water x 30 Days

(7.8E+03 ft^3/d) x (30 d) / (43560 ft^3/ac-ft) = 5.4 ac-ft

Percent Used = Month Applied Water / Month Available Water

5.4 ac-ft / 102 ac-ft = 5.3%

Available water per month is in a separate appendix "Ditch Diversion Records" (Reference #2)

RJH Consultants, Inc.	By:	ATMerook	Date:	10/8/2020
South Boulder Creek Regional Detention	Checked:	JNH	Date:	10/13/2020
Project 16134	Approved:	ABP	Date:	10/14/20
GW Model Irrigation Diversions				

Background Recharge Rate: 1.25E-03 FT/D

Howard Ditch

Zone 12 Area	1109714	SF
Zone 12 Irrigation Recharge	1.2E-02	FT/D
Daily Applied Water	1.4E+04	CF/D
Month Applied Water	9.4	AF
Month Available Water	92.0	AF
Percent Used	**10.2**	**%**

South Boulder and Bear Creek Ditch

Zone 4 Area	3139044	SF
Zone 4 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0.0E+00	CF/D
Month Applied Water	0.0	AF
Month Available Water	0.0	AF
Percent Used	**0.0**	**%**

Dry Creek No. 2 Ditch

Zone 3 Area	4603438	SF
Zone 3 Irrigation Recharge	1.2E-02	FT/D
Daily Applied Water	5.6E+04	CF/D
Month Applied Water	38.9	AF
Zone 6 Area	1490899	SF
Zone 6 Irrigation Recharge	5.4E-03	FT/D
Daily Applied Water	8.1E+03	CF/D
Month Applied Water	5.6	AF
Zone 7 Area	100735	SF
Zone 7 Irrigation Recharge	1.2E-02	FT/D
Daily Applied Water	1234.5	CF/D
Month Applied Water	0.9	AF
Zone 8 Area	1214816	SF
Zone 8 Irrigation Recharge	1.4E-02	FT/D
Daily Applied Water	17369	CF/D
Month Applied Water	12.0	AF
Zone 9 Area	319571	SF
Zone 9 Irrigation Recharge	1.2E-02	FT/D
Daily Applied Water	3916	CF/D
Month Applied Water	2.7	AF
Zone 10 Area	664833	SF
Zone 10 Irrigation Recharge	1.4E-02	FT/D
Daily Applied Water	9505	CF/D
Month Applied Water	6.5	AF
Total Irrigation Water Applied	66.5	AF
Total Irrigation Water Available	91	AF
Percent Used	**73.1**	**%**

RJH Consultants, Inc.	**By:** ATMerook	**Date:** 10/8/2020	
South Boulder Creek Regional Detention	**Checked:** JNH	**Date:** 10/13/2020	
Project 16134	**Approved:** ABP	**Date:** 10/14/20	
GW Model Irrigation Diversions			

Background Recharge Rate: 7.1E-04 FT/D

Howard Ditch

Zone 12 Area	1109714	SF
Zone 12 Irrigation Recharge	1.3E-02	FT/D
Daily Applied Water	1.5E+04	CF/D
Month Applied Water	10.1	AF
Month Available Water	303.0	AF
Percent Used	**3.3**	**%**

South Boulder and Bear Creek Ditch

Zone 4 Area	3139044	SF
Zone 4 Irrigation Recharge	1.3E-02	FT/D
Daily Applied Water	4.2E+04	CF/D
Month Applied Water	28.7	AF
Month Available Water	39	AF
Percent Used	**73.5**	**%**

Dry Creek No. 2 Ditch

Zone 3 Area	4603438	SF
Zone 3 Irrigation Recharge	1.3E-02	FT/D
Daily Applied Water	6.1E+04	CF/D
Month Applied Water	42.1	AF
Zone 6 Area	1490899	SF
Zone 6 Irrigation Recharge	1.3E-02	FT/D
Daily Applied Water	2.0E+04	CF/D
Month Applied Water	13.6	AF
Zone 7 Area	100735	SF
Zone 7 Irrigation Recharge	1.3E-02	FT/D
Daily Applied Water	1336.5	CF/D
Month Applied Water	0.9	AF
Zone 8 Area	1214816	SF
Zone 8 Irrigation Recharge	1.3E-02	FT/D
Daily Applied Water	16117	CF/D
Month Applied Water	11.1	AF
Zone 9 Area	319571	SF
Zone 9 Irrigation Recharge	1.3E-02	FT/D
Daily Applied Water	4240	CF/D
Month Applied Water	2.9	AF
Zone 10 Area	664833	SF
Zone 10 Irrigation Recharge	1.3E-02	FT/D
Daily Applied Water	8821	CF/D
Month Applied Water	6.1	AF
Total Irrigation Water Applied	76.7	AF
Total Irrigation Water Available	350	AF
Percent Used	**21.9**	**%**

RJH Consultants, Inc.		**By:**	ATMerook	**Date:**	10/8/2020
South Boulder Creek Regional Detention		**Checked:**	JNH	**Date:**	10/13/2020
Project 16134		**Approved:**	ABP	**Date:**	10/14/20
GW Model Irrigation Diversions					

Background Recharge Rate:	7.1E-04	FT/D

Howard Ditch

Zone 12 Area	1109714	SF
Zone 12 Irrigation Recharge	1.3E-02	FT/D
Daily Applied Water	1.4E+04	CF/D
Month Applied Water	9.8	AF
Month Available Water	240.0	AF
Percent Used	**4.1**	**%**

South Boulder and Bear Creek Ditch

Zone 4 Area	3139044	SF
Zone 4 Irrigation Recharge	1.3E-02	FT/D
Daily Applied Water	4.0E+04	CF/D
Month Applied Water	27.8	AF
Month Available Water	77	AF
Percent Used	**36.1**	**%**

Dry Creek No. 2 Ditch

Zone 3 Area	4603438	SF
Zone 3 Irrigation Recharge	1.3E-02	FT/D
Daily Applied Water	5.9E+04	CF/D
Month Applied Water	40.7	AF
Zone 6 Area	1490899	SF
Zone 6 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0.0E+00	CF/D
Month Applied Water	0.0	AF
Zone 7 Area	100735	SF
Zone 7 Irrigation Recharge	5.1E-03	FT/D
Daily Applied Water	517.6	CF/D
Month Applied Water	0.4	AF
Zone 8 Area	1214816	SF
Zone 8 Irrigation Recharge	5.1E-03	FT/D
Daily Applied Water	6241	CF/D
Month Applied Water	4.3	AF
Zone 9 Area	319571	SF
Zone 9 Irrigation Recharge	5.1E-03	FT/D
Daily Applied Water	1642	CF/D
Month Applied Water	1.1	AF
Zone 10 Area	664833	SF
Zone 10 Irrigation Recharge	5.1E-03	FT/D
Daily Applied Water	3416	CF/D
Month Applied Water	2.4	AF
Total Irrigation Water Applied	48.9	AF
Total Irrigation Water Available	375.1	AF
Percent Used	**13.0**	**%**

RJH Consultants, Inc.	**By:** ATMerook	**Date:** 10/8/2020
South Boulder Creek Regional Detention	**Checked:** JNH	**Date:** 10/13/2020
Project 16134	**Approved:** ABP	**Date:** 10/14/20
GW Model Irrigation Diversions		

Background Recharge Rate:	3.2E-05	FT/D

Howard Ditch

Zone 12 Area	1109714	SF
Zone 12 Irrigation Recharge	1.2E-02	FT/D
Daily Applied Water	1.3E+04	CF/D
Month Applied Water	8.9	AF
Month Available Water	293	AF
Percent Used	**3.0**	**%**

South Boulder and Bear Creek Ditch

Zone 4 Area	3139044	SF
Zone 4 Irrigation Recharge	1.2E-02	FT/D
Daily Applied Water	3.6E+04	CF/D
Month Applied Water	25.1	AF
Month Available Water	202	AF
Percent Used	**12.4**	**%**

Dry Creek No. 2 Ditch

Zone 3 Area	4603438	SF
Zone 3 Irrigation Recharge	1.2E-02	FT/D
Daily Applied Water	5.3E+04	CF/D
Month Applied Water	36.8	AF
Zone 6 Area	1490899	SF
Zone 6 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0.0E+00	CF/D
Month Applied Water	0.0	AF
Zone 7 Area	100735	SF
Zone 7 Irrigation Recharge	4.6E-04	FT/D
Daily Applied Water	46.8	CF/D
Month Applied Water	0.0	AF
Zone 8 Area	1214816	SF
Zone 8 Irrigation Recharge	4.6E-04	FT/D
Daily Applied Water	564	CF/D
Month Applied Water	0.4	AF
Zone 9 Area	319571	SF
Zone 9 Irrigation Recharge	2.3E-03	FT/D
Daily Applied Water	742	CF/D
Month Applied Water	0.5	AF
Zone 10 Area	664833	SF
Zone 10 Irrigation Recharge	4.6E-04	FT/D
Daily Applied Water	309	CF/D
Month Applied Water	0.2	AF
Total Irrigation Water Applied	37.9	AF
Total Irrigation Water Available	130	AF
Percent Used	**29.2**	**%**

RJH Consultants, Inc.	By:	ATMerook	Date:	10/8/2020
South Boulder Creek Regional Detention	Checked:	JNH	Date:	10/13/2020
Project 16134	Approved:	ABP	Date:	10/14/20
GW Model Irrigation Diversions				

Background Recharge Rate: 1.87E-04 FT/D

Howard Ditch

Zone 12 Area	1109714	SF
Zone 12 Irrigation Recharge	3.3E-03	FT/D
Daily Applied Water	3.7E+03	CF/D
Month Applied Water	2.5	AF
Month Available Water	265	AF
Percent Used	**1.0**	**%**

South Boulder and Bear Creek Ditch

Zone 4 Area	3139044	SF
Zone 4 Irrigation Recharge	3.3E-03	FT/D
Daily Applied Water	1.0E+04	CF/D
Month Applied Water	7.2	AF
Month Available Water	24	AF
Percent Used	**30.0**	**%**

Dry Creek No. 2 Ditch

Zone 3 Area	4603438	SF
Zone 3 Irrigation Recharge	3.3E-03	FT/D
Daily Applied Water	1.5E+04	CF/D
Month Applied Water	10.5	AF
Zone 6 Area	1490899	SF
Zone 6 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0.0E+00	CF/D
Month Applied Water	0.0	AF
Zone 7 Area	100735	SF
Zone 7 Irrigation Recharge	1.1E-03	FT/D
Daily Applied Water	111.7	CF/D
Month Applied Water	0.1	AF
Zone 8 Area	1214816	SF
Zone 8 Irrigation Recharge	1.1E-03	FT/D
Daily Applied Water	1347	CF/D
Month Applied Water	0.9	AF
Zone 9 Area	319571	SF
Zone 9 Irrigation Recharge	2.2E-04	FT/D
Daily Applied Water	71	CF/D
Month Applied Water	0.0	AF
Zone 10 Area	664833	SF
Zone 10 Irrigation Recharge	1.1E-03	FT/D
Daily Applied Water	737	CF/D
Month Applied Water	0.5	AF
Total Irrigation Water Applied	12.1	AF
Total Irrigation Water Available	24	AF
Percent Used	**50.4**	**%**

TYP. Sept 2019 and Oct 2019: water available from S. Boulder and Bear Creek Ditch diversion

Allocation of South Boulder Bear Creek Ditch including diversion to Dry Creek No. 2 fields:	**80.4**	**%**

Allocating water available from South Boulder Bear Creek Ditch to apply over Dry Creek No. 2 Ditch.

RJH Consultants, Inc.	By:	ATMerook	Date:	10/8/2020
South Boulder Creek Regional Detention	Checked:	JNH	Date:	10/13/2020
Project 16134	Approved:	ABP	Date:	10/14/20
GW Model Irrigation Diversions				

Background Recharge Rate: 7.81E-04 FT/D

Howard Ditch

Zone 12 Area	1109714	SF
Zone 12 Irrigation Recharge	2.3E-03	FT/D
Daily Applied Water	2.6E+03	CF/D
Month Applied Water	1.8	AF
Month Available Water	191	AF
Percent Used	**0.9**	**%**

South Boulder and Bear Creek Ditch

Zone 4 Area	3139044	SF
Zone 4 Irrigation Recharge	2.3E-03	FT/D
Daily Applied Water	7.2E+03	CF/D
Month Applied Water	5.0	AF
Month Available Water	16	AF
Percent Used	**31.1**	**%**

Dry Creek No. 2 Ditch

Zone 3 Area	4603438	SF
Zone 3 Irrigation Recharge	2.3E-03	FT/D
Daily Applied Water	1.1E+04	CF/D
Month Applied Water	7.3	AF
Zone 6 Area	1490899	SF
Zone 6 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0.0E+00	CF/D
Month Applied Water	0.0	AF
Zone 7 Area	100735	SF
Zone 7 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0.0	CF/D
Month Applied Water	0.0	AF
Zone 8 Area	1214816	SF
Zone 8 Irrigation Recharge	0.0E+00	FT/D
Daily Applied Water	0	CF/D
Month Applied Water	0.0	AF
Zone 9 Area	319571	SF
Zone 9 Irrigation Recharge	1.5E-04	FT/D
Daily Applied Water	49	CF/D
Month Applied Water	0.0	AF
Zone 10 Area	664833	SF
Zone 10 Irrigation Recharge	7.7E-04	FT/D
Daily Applied Water	510	CF/D
Month Applied Water	0.4	AF
Total Irrigation Water Applied	7.7	AF
Total Irrigation Water Available	16	AF
Percent Used	**48.0**	**%**

Allocation of South Boulder Bear Creek Ditch including diversion to Dry Creek No. 2 fields:	**79.1**	**%**

Allocating water available from South Boulder Bear Creek Ditch to apply over Dry Creek No. 2 Ditch.

RJH Consultants, Inc.
South Boulder Creek Regional Detention
Project 16134
GW Model Irrigation Diversions

By: ATMerook **Date:** 10/8/2020
Checked: JNH **Date:** 10/13/2020
Approved: ABP **Date:** 10/14/20

Baseline Model			
Irrigation Month	Percent Available Water Applied		
	Howard	South Boulder and Bear Creek	Dry Creek No. 2
April 2019 (SP07)	5.3	-	-
May 2019 (SP08)	10.2	-	73.1
June 2019 (SP09)	3.3	73.5	21.9
July 2019 (SP10)	4.1	36.1	13.0
August 2019 (SP11)	3.0	12.4	29.2
September 2019 (SP12)*	1.0	30.0	50.4
October 2019 (SP13)*	0.9	31.1	48.0

NOTE: DC2D irrigation in SP12 and SP13 is ~~dependent upon S. Boulder and Bear Creek Ditch diversions~~.

reported as a percentage of the total flows in both S. Boulder and Bear Creek Ditch and Dry Creek No. 2 Ditch.

APPENDIX J

MODEL SETTINGS AND INPUTS

Purpose:

To document numerical model settings and selected inputs into the Groundwater Vistas 7 software program for the Baseline Model of the South Boulder Creek Regional Detention Project (Project). Background information is provided in the Report text.

References:

Fetter, C.W. (2001). Applied Hydrogeology (Fourth Edition). Prentice-Hall, Inc.

Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, M., and Hughes, J.D. (2013). MODFLOW-USG version 1: An Unstructured Grid Version of MODFLOW for Simulating Groundwater Flow and Tightly Coupled Processes Using a Control Volume Finite-Difference Formulation: U.S. Geological Survey Techniques and Methods, Book 6, Chapter A45, 66 p. Available at: https://pubs.usgs.gov/tm/06/a45.

Model Settings:

The numerical process of MODFLOW-USG is based on two governing principles (Panday et al., 2013 and Fetter, 2001):

1. Conservation of fluid mass (i.e., water balance): any change in mass flowing into an element must be balanced by a corresponding change in mass flowing out of the element, a change in mass stored in the element, or a combination.
2. Darcy's Law: specific discharge is equal to the hydraulic conductivity multiplied by the hydraulic gradient.

For a transient model of an unconfined aquifer, the above two principles can be combined into a single formula that is known as the groundwater flow equation and is solved by MODFLOW-USG:

$$\frac{\partial}{\partial x}\left(K_x h \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y h \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z h \frac{\partial h}{\partial z}\right) = S_y \frac{\partial h}{\partial t} \quad \text{(Equation 1)}$$

Where K_n is hydraulic conductivity in the n direction ($n = x, y, or\ z$), h is the groundwater head, $\frac{\partial h}{\partial n}$ is the hydraulic gradient in the n direction, S_y is the specific yield, and $\frac{\partial h}{\partial t}$ is the change in groundwater head with time. For steady-state conditions, the right side of Equation 1 is equal to zero because there is no change in groundwater head over time.

The numerical model was used to evaluate steady-state and transient conditions. Key settings for the transient numerical model were:

- Numerical Engine = MODFLOW-USG ✓
- Solver = Sparse Matrix Solver (SMS) ✓

- Flow package = Layer-Property Flow (LPF) ✓
- Saturated analysis with no active transport ✓
- Model duration = ~~12 months, sequence simulated twice~~

The model duration was 24 months. Conditions from November 2018 to October 2019 were simulated twice in series.

- Layer types = USG Upstream Water Table (Type 4) or Unconfined (T Varies) (Type 3) ✓
- Length Units = Feet ✓
- Time Units = Days ✓

Model Inputs:

Inputs to define model solver convergence are:

- Head change criterion for outer iterations (HCLOSE) was ~~0.01~~ 0.02 foot. For each time step, the iterative solution of the nonlinear model proceeds until the maximum head change is less than HCLOSE for all model cells. If the maximum change is less than the defined HCLOSE value, the head change criterion is met and the next time step is computed. Subsequent iterations must differ by less than ~~0.01~~ 0.02 foot for the model execution to progress. Most time steps converged via the HCLOSE criteria in fewer than 10 outer iterations. ✓
- Maximum number of outer iterations (MXITER) was 250. The MXITER term defines the maximum number of outer iterations allowed before the numerical model forces convergence and begins computing the next time step. A large value (i.e., 250) was selected to allow many iterations in order to achieve a small head-change before computing the next time step. To achieve convergence, both MXITER and HCLOSE must be satisfied. No model time step used the MXITER criterion to advance the numerical processes. ✓
- Residual convergence tolerance criterion (RRCTOL): 0. The RRCTOL term defines the maximum RMS residual of the matrix solution between prior and current iterations. A value of 0 was input to force HCLOSE as the primary convergence criterion. We did not rely on RRCTOL because the model achieved convergence by completing successive iterations that satisfied HCLOSE and MXITER. ✓

Tables of input data:

- Table 1. Simulated Specified Head Boundary Conditions Values per Stress Period (p. _3__) ✓
- Table 2. Simulated Background Recharge per Zone per Stress Period (p. _4__) ✓
- Table 3. Simulated Irrigation Recharge per Zone per Stress Period (p. _5__) ✓
- Table 4. Simulated Evapotranspiration Rates per Zone per Stress Period (p. _6__) ✓
- Table 5. Simulated Head Calibration per Well per Stress Period (p. _7__) ✓

Table 6. Simulated SFR Segment Flow Inputs and Diversions Per Stress Period (p. 8)

By: JNH Date: 9/8/2020
Checked: CLS Date: 9/9/2020
ABP 9/11/20

TABLE 1. SIMULATED SPECIFIED HEAD BOUNDARY CONDITIONS VALUES PER STRESS PERIOD

Specified Head Boundary Condition[1]	Stress Period - Groundwater Elevation (ft)												
	1	2 & 14	3 & 15	4 & 16	5 & 17	6 & 18	7 &19	8 & 20	9 & 21	10 & 22	11 & 23	12 & 24	13 & 25
	Steady-State	Nov. 2018	Dec. 2018	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019
Upstream	5463.4	5463.4	5463.6	5463.8	5463.9	5464.2	5464.2	5464.4	5464.2	5463.9	5463.5	5463.3	5463.5
Downstream, Segment 1	5277.3	5277.3	5276.8	5276.6	5276.7	5277.1	5277.4	5277.6	5277.4	5277.6	5276.7	5276.5	5276.9
Downstream, Segment 2	5278.3	5278.3	5277.8	5277.6	5277.7	5278.1	5278.4	5278.6	5278.4	5278.6	5277.7	5277.5	5277.9
Downstream, Segment 3	5279.3	5279.3	5278.8	5278.6	5278.7	5279.1	5279.4	5279.6	5279.4	5279.6	5278.7	5278.5	5278.9
Downstream, Segment 4	5280.3	5280.3	5279.8	5279.6	5279.7	5280.1	5280.4	5280.6	5280.4	5280.6	5279.7	5279.5	5279.9
Downstream, Segment 5	5281.3	5281.3	5280.8	5280.6	5280.7	5281.1	5281.4	5281.6	5281.4	5281.6	5280.7	5280.5	5280.9
Downstream, Segment 6	5282.3	5282.3	5281.8	5281.6	5281.7	5282.1	5282.4	5282.6	5282.4	5282.6	5281.7	5281.5	5281.9
Downstream, Segment 7	5283.3	5283.3	5282.8	5282.6	5282.7	5283.1	5283.4	5283.6	5283.4	5283.6	5282.7	5282.5	5282.9

Note:
1. Specified head boundary condition locations are shown in the Report on ~~Figure 4.1.~~
Figure 5.1.

By: ATMerook Date: 10/13/2020
Checked: CLS Date: 10/15/2020
ABP 10/16/2020

TABLE 2. SIMULATED BACKGROUND RECHARGE PER ZONE PER STRESS PERIOD

Background Recharge Zone[1]	Stress Period - Background Recharge Rate (inches/month)												
	1	**2 & 14**	**3 & 15**	**4 & 16**	**5 & 17**	**6 & 18**	**7 & 19**	**8 & 20**	**9 & 21**	**10 & 22**	**11 & 23**	**12 & 24**	**13 & 25**
	Steady-State	**Nov. 2018**	**Dec. 2018**	**Jan. 2019**	**Feb. 2019**	**Mar. 2019**	**Apr. 2019**	**May 2019**	**Jun. 2019**	**Jul. 2019**	**Aug. 2019**	**Sep. 2019**	**Oct. 2019**
Zone 1 = Natural	0.30	0.30	0.08	0.38	0.20	0.68	0.22	0.45	0.25	0.26	0.01	0.07	0.28
Zone 2 = Fill	0.18	0.18	0.05	0.23	0.12	0.41	0.13	0.27	0.15	0.15	0.01	0.04	0.17
Zone 5 = Developed Area	0.15	0.15	0.04	0.19	0.10	0.34	0.11	0.23	0.13	0.13	0.006	0.03	0.14
Zone 11 = Open Water	1.19	1.19	0.34	1.57	0.74	2.83	1.87	3.89	2.12	2.21	0.10	0.56	2.42

Note:
1. Background recharge zones are shown in the Report on Figure 5.6.

By: ATMerook Date: 10/14/2020
Checked: CLS Date: 10/15/2020
ABP 10/16/20

TABLE 3. SIMULATED IRRIGATION RECHARGE PER ZONE PER STRESS PERIOD

Irrigation Recharge Zone[1]	Stress Period - Irrigation Recharge Rate (inches/month)												
	1	2 & 14	3 & 15	4 & 16	5 & 17	6 & 18	7 & 19	8 & 20	9 & 21	10 & 22	11 & 23	12 & 24	13 & 25
	Steady-State	Nov. 2018	Dec. 2018	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019
Zone 3 = Irrigation	0.0	0.0	0.0	0.0	0.0	0.0	0.00	4.41	4.78	4.62	4.18	1.20	0.83
Zone 4 = Irrigation	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	4.78	4.62	4.18	1.20	0.83
Zone 6 = Irrigation	0.0	0.0	0.0	0.0	0.0	0.0	0.00	1.96	4.78	0.00	0.00	0.00	0.00
Zone 7 = Irrigation	0.0	0.0	0.0	0.0	0.0	0.0	0.00	4.41	4.78	1.85	0.17	0.40	0.00
Zone 8 = Irrigation	0.0	0.0	0.0	0.0	0.0	0.0	0.00	5.15	4.78	1.85	0.17	0.40	0.00
Zone 9 = Irrigation	0.0	0.0	0.0	0.0	0.0	0.0	0.00	4.41	4.78	1.85	0.84	0.08	0.06
Zone 10 = Irrigation	0.0	0.0	0.0	0.0	0.0	0.0	0.00	5.15	4.78	1.85	0.17	0.40	0.28
Zone 12 = Irrigation	0.0	0.0	0.0	0.0	0.0	0.0	2.53	4.41	4.78	4.62	4.18	1.20	0.83

Note:

1. Irrigation recharge zones are shown in the Report on Figure ~~5.6~~. The recharge rates input into Groundwater Vistas for each zone consist of the sum of the irrigation recharge rates presented in Table 3 and the background recharge rates presented in Table 2.
5.8

natural

By: ATMerook Date: 10/14/2020
Checked: CLS Date: 10/16/2020
ABP 10/16/20

TABLE 4. SIMULATED EVAPOTRANSPIRATION RATES PER ZONE PER STRESS PERIOD

Evapotranspiration Zone[1]	Stress Period - Evapotranspiration Rate (inches/month)												
	1	2 & 14	3 & 15	4 & 16	5 & 17	6 & 18	7 & 19	8 & 20	9 & 21	10 & 22	11 & 23	12 & 24	13 & 25
	Steady-State	Nov. 2018	Dec. 2018	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019
Irrigated Grass	1.96	1.96	1.51	1.65	1.50	1.76	2.30	3.46	5.19	6.08	5.54	4.50	2.62
Background/Native Grass	0.39	0.39	0.38	0.50	0.58	1.12	1.93	2.30	3.37	4.26	3.32	2.02	0.92
Riparian/Phreatophyte	2.52	2.52	2.16	2.16	2.89	3.60	4.66	5.37	7.20	7.91	6.85	6.14	5.02
Open Water	2.54	2.54	1.80	2.16	2.15	3.22	4.98	4.96	6.70	7.86	7.16	5.81	3.38
Developed Area	0.20	0.20	0.19	0.25	0.29	0.56	0.96	1.15	1.69	2.13	1.66	1.01	0.46

Note:

1. Evapotranspiration zones are shown in the Report on Figure 5.9.

By:	ATMerook	Date:	9/8/2020
Checked:	JNH	Date:	9/9/2020
	ABP		9/11/20

TABLE 5. SIMULATED HEAD CALIBRATION PER WELL PER STRESS PERIOD

Well I.D.[1]	Stress Period - Groundwater or Surface Water Elevation (ft)												
	1	2 & 14	3 & 15	4 & 16	5 & 17	6 & 18	7 & 19	8 & 20	9 & 21	10 & 22	11 & 23	12 & 24	13 & 25
	Steady-State	Nov. 2018	Dec. 2018	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019
B-101(P)	5437.6	5437.6	5437.1	5437.2	5437.3	5438.1	5438.6	5439.1	5438.6	5437.5	5437.1	5436.7	5436.6
B-102(P)	5463.4	5463.4	5463.6	5463.8	5463.9	5464.2	5464.2	5464.4	5464.2	5463.9	5463.5	5463.3	5463.5
B-103(P)	5418.4	5418.4	5418.6	5418.7	5418.7	5418.9	5418.8	5419.1	5419.2	5418.9	5418.5	5418.1	5418.3
B-105(P)	5283.5	5283.5	5283.1	5282.9	5282.9	5283.5	5285.0	5285.9	5285.6	5284.4	5285.5	5284.6	5283.8
B-106(P)	5277.3	5277.3	5276.8	5276.6	5276.7	5277.1	5277.4	5277.6	5277.4	5277.6	5276.7	5276.5	5276.9
B-107(P)	5334.2	5334.2	5334.2	5334.4	5334.5	5335.0	5335.7	5336.5	5337.3	5337.3	5335.2	5334.1	5334.0
B-108(P)	5337.6	5337.6	5337.7	5337.8	5337.9	5338.3	5338.6	5338.9	5338.8	5338.4	5338.0	5337.8	5337.7
B-109(P)	[2]	[2]	[2]	[2]	5355.8	5356.1	5356.2	5357.0	5357.3	5357.7	5356.2	5355.7	5355.8
B-110(P)	[2]	[2]	[2]	[2]	5350.7	5351.8	5353.2	5354.7	5356.2	5355.7	5353.9	5352.2	5351.1
B-111(P)	5344.1	5344.1	5344.1	5344.1	5344.2	5344.6	5344.9	5345.2	5345.1	5344.8	5344.3	5343.9	5343.8
B-112(P)	5336.8	5336.8	5336.9	5337.1	5337.2	5337.3	5337.7	5337.8	5337.8	5337.2	5336.6	5336.3	5336.2
B-113(P)	5342.2	5342.2	5341.8	5341.6	5341.6	5342.3	5343.4	5344.6	5345.0	5344.4	5343.2	5342.3	5341.7
B-114(P)	5354.0	5354.0	5354.7	5355.5	5356.0	5356.3	5356.4	5356.5	5356.2	5354.9	5353.8	5353.4	5353.4
B-115(P)	5350.1	5350.1	5350.2	5350.5	5351.2	5352.8	5354.4	5354.3	5353.6	5352.4	5351.4	5350.5	5349.9
B-116(P)	5366.6	5366.6	5367.0	5367.1	5367.5	5368.1	5368.3	5368.5	5368.1	5369.0	5367.5	5366.5	5366.5
B-117(P)	5372.5	5372.5	5372.6	5372.9	5373.0	5373.5	5373.4	5373.7	5373.0	5372.3	5371.7	5371.4	5372.3
B-118(P)	5381.0	5381.0	5381.2	5381.4	5382.0	5382.6	5383.6	5383.6	5383.4	5382.7	5381.9	5381.0	5380.0
B-119(P)	5410.4	5410.4	5410.1	5410.5	5410.6	5411.1	5411.0	5411.3	5411.4	5412.2	5410.2	5408.8	5408.7
B-121(P)	5350.5	5350.5	5350.3	5350.0	5349.8	5349.8	5350.3	5351.0	5351.7	5351.7	5351.3	5351.0	5350.8
B-122(P)	5353.7	5353.7	5353.4	5353.2	5353.2	5354.0	5355.8	5357.5	5359.8	5360.2	5356.5	5355.2	5354.4
B-123(P)	5358.3	5358.3	5358.5	5358.6	5358.9	5359.6	5360.5	5361.1	5361.5	5363.0	5360.3	5358.6	5358.1
B-124(P)	5341.9	5341.9	5341.8	5341.7	5341.8	5342.6	5343.6	5344.2	5344.4	5344.1	5343.6	5342.7	5342.0
B-125(P)	5345.2	5345.2	5345.3	5345.3	5345.6	5346.3	5347.2	5347.9	5348.7	5349.0	5346.7	5345.6	5345.1
B-126(P)	5343.7	5343.7	5343.7	5343.9	5344.1	5345.1	5346.0	5347.4	5347.8	5348.3	5345.0	5343.4	5343.4
OSMP 1S	[2]	[2]	5352.7	[2]	[2]	5353.9	5354.5	5355.2	5357.1	5356.7	5354.3	5353.0	5352.4
OSMP 2S	5354.4[3]	5354.4[3]	5354.7	[2]	[2]	5355.4	5355.9	5356.2	5356.0	5356.6	5354.9	5354.0	5354.0
OSMP 2N	[2]	[2]	5338.2	[2]	[2]	5339.2	5340.6	5341.7	5342.3	5342.3	5341.8	5339.0	5338.3
OSMP 4	[2]	[2]	5341.8	[2]	[2]	5342.6	5345.1	5346.3	5347.5	5347.6	5346.0	5343.7	5342.5
OSMP 6	[2]	[2]	5346.2	[2]	[2]	5347.5	5349.0	5350.0	5350.8	5350.9	5349.3	5347.1	5346.1
SW-101	5362.2	5362.2	5362.1	5362.1	5362.2	5362.4	[2]	5364.5	5364.3	[2]	5362.9	5362.2	5361.7
SW-102	5349.0	5349.0	5349.1	5349.1	5349.2	5349.3	5349.3	5349.4	5349.3	5349.3	5349.1	5348.8	5348.8
SW-103	5335.0	5335.0	5334.9	5334.9	5335.0	5335.1	5335.3	5335.7	5335.9	5335.8	5335.4	5334.9	5334.6

Note:

1. Well locations are shown on Figure 6.1.
2. No data are available and these points were omitted from the calibration statistics.
3. Values were based on linear interpolation between data recorded for the two adjacent months.

By:	JNH	Date:	9/4/2020
Checked:	CLS	Date:	9/4/2020
	ABP		10/16/20

TABLE 6. SIMULATED SFR SEGMENT FLOW INPUTS AND DIVERSIONS PER STRESS PERIOD

SFR Segment No.[1]	Stress Period - Flow Inputs[2,3] (cfs)												
	1	2 & 14	3 & 15	4 & 16	5 & 17	6 & 18	7 & 19	8 & 20	9 & 21	10 & 22	11 & 23	12 & 24	13 & 25
	Steady-State	Nov. 2018	Dec. 2018	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019
1	24.0	24.0	27.0	22.0	21.0	19.0	29.0	77.0	145.9	82.0	48.0	41.0	43.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-6.8	-8.6	-8.2	-1.2	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.4	-0.3	-8.9	-3.8	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-7.2	-14.8	-8.6	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.8	-4.4	-3.4	-2.4	-1.8	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	-0.5	-1.2	-27.1	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	-1.7	-1.5	-5.1	-3.9	-4.8	-4.5	-3.1
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-2.9	-1.6	-1.4	-0.6	-0.1

Notes:

1. SFR segment locations are shown in this Report on Figure 5.1.
2. This table summarizes the inflow into the upstream end of the SFR boundary condition (Segment 1) (positive) and losses that occur from diversions for each month (negative).
3. The data in this table do not show the following stream routing processes that occur within the SFR:
    a. The outflow from a Segment is equal to the Segment inflow plus or minus any interaction that occurs between the stream and aquifer along the segment (stream gains or losses).
    b. The outflow from a segment becomes the inflow into the next segment.

APPENDIX K

MODEL RESULTS

APPENDIX K.1

APPROXIMATELY QUARTERLY CALIBRATION PLOTS

Project 16134 Page 1/4
Date 10/12/2020 By ATMerook
Client City of Boulder Checked 10/16/2020 By JNH
Subject Quarterly Calibration Plots Approved 10/19/20 By ABP

Purpose:

calibration

Document and visualize computed Head simulation results from the South Boulder Creek Detention Project (Project) Groundwater Vistas 7 (GWV7) Baseline groundwater model at approximately each quarter.

References:

1. Residuals were computed from "Observed" elevations which represent groundwater elevation readings taken across the Project area from both manual and automated records during the modeling period. (Note 1)

Summary:

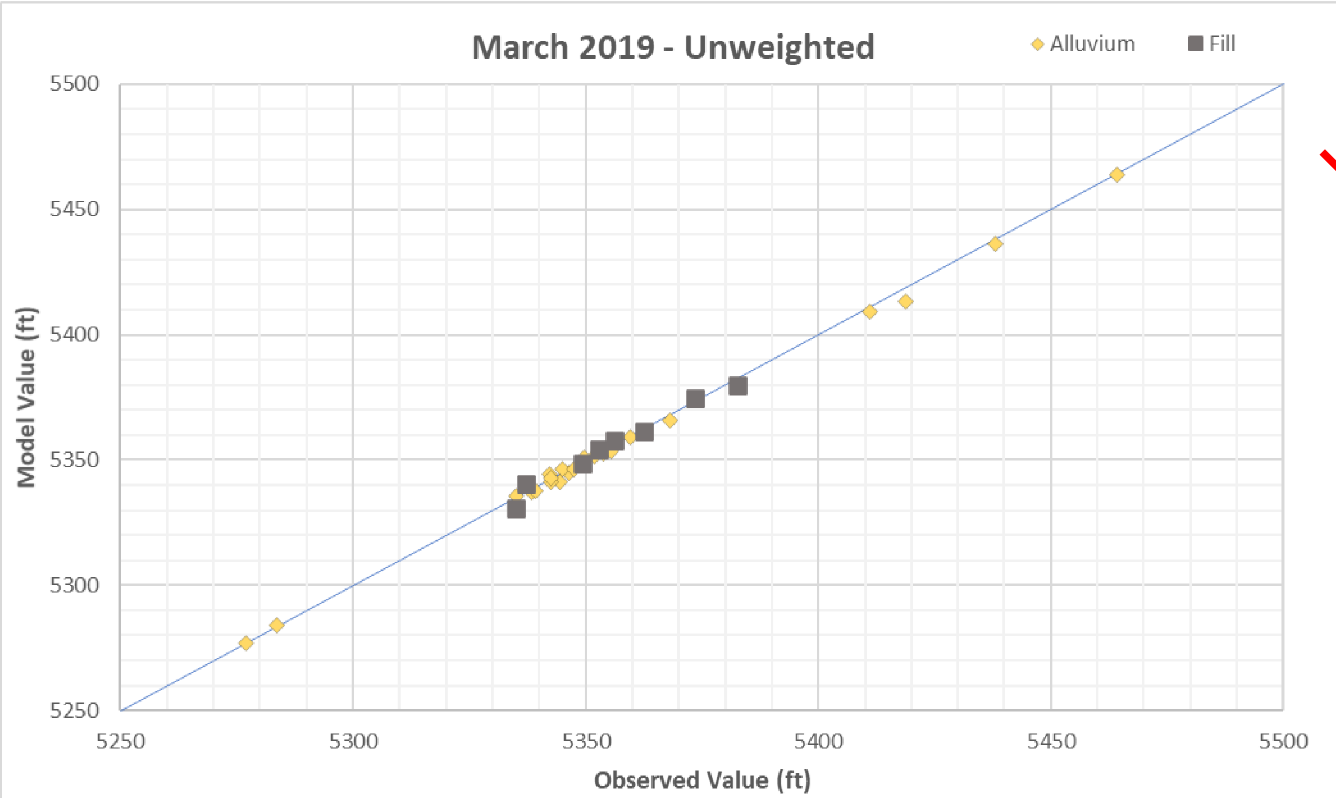
- All elevations reference the North American Vertical Datum of 1988 (NAVD88).
- A 1:1 line representing perfect agreement between modeled and observed values is plotted with the model results for reference.
- Plots are shown on p. 2-4 . (Note 2)

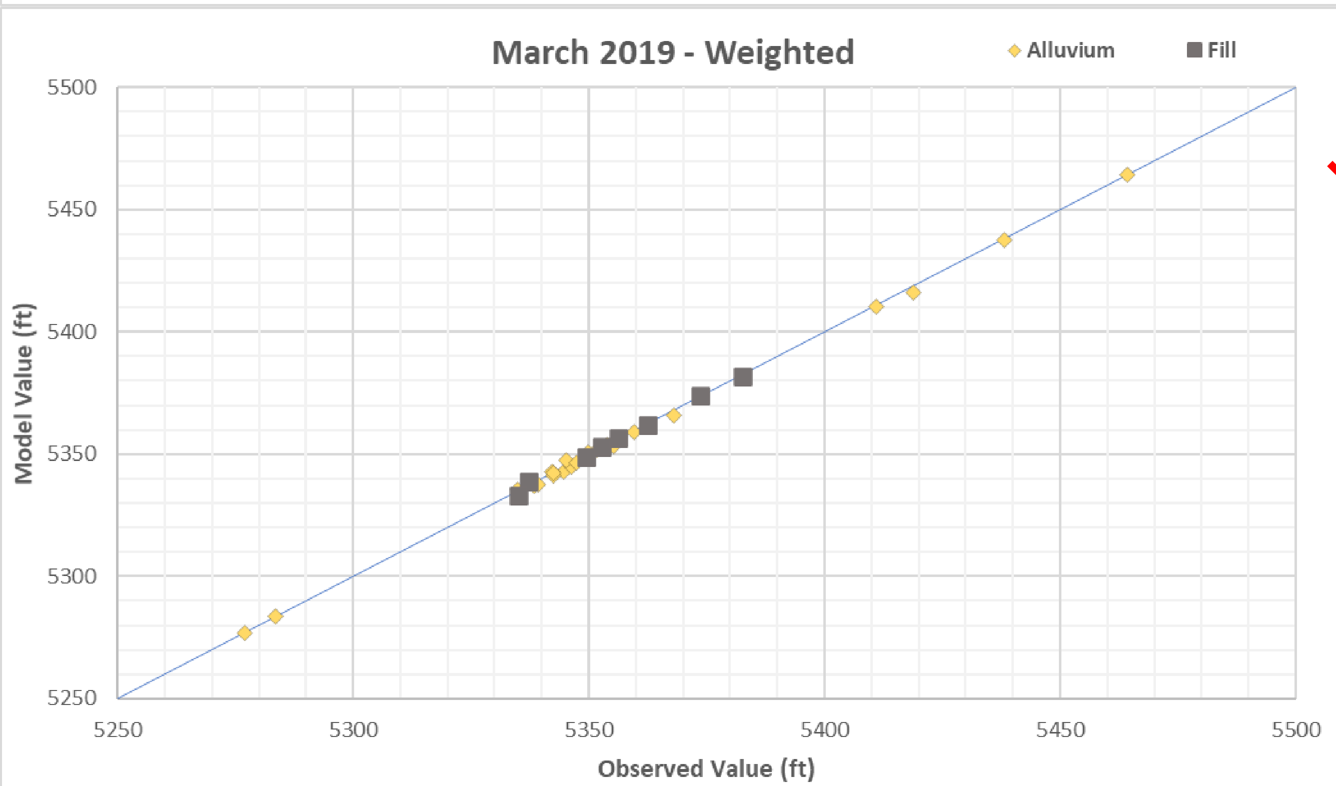
Notes:

1. The "Observed" elevations are the monthly head calibration data for each well, which generally represent the monthly average of the measured data.

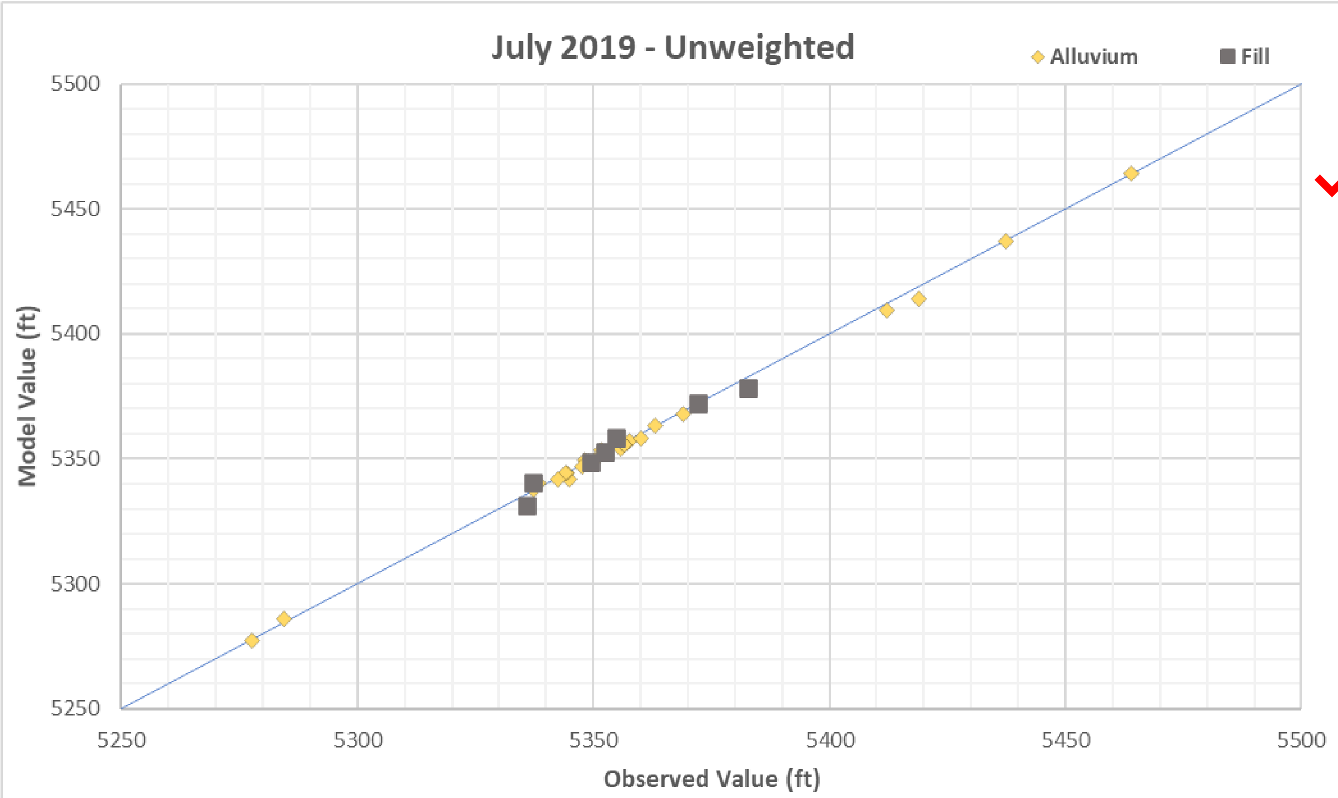
2. Calibration plots for March 2019, July 2019, and September 2019 are shown on pages 2-4. The upper plot on each page shows unweighted model calibration to heads and the lower plot on each page shows weighted model calibration to heads.

The head weighting technique is described in the Report text.

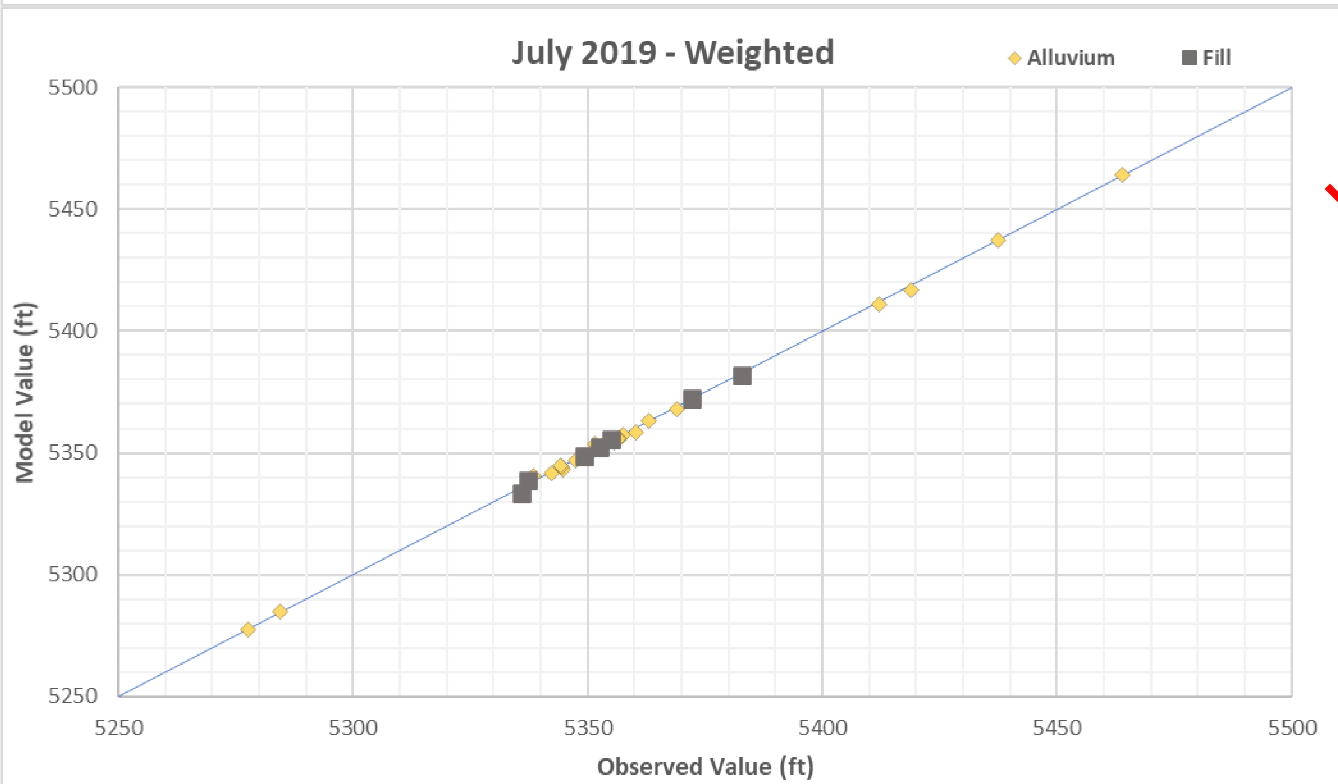




NOTES (TYP. ALL):
1. MODEL VALUES AND OBSERVED VALUES ARE GROUNDWATER HEAD IN FEET.
2. EACH DATA POINT REPRESENTS AN INDIVIDUAL WELL.



July 2019 - Unweighted
Alluvium
Fill
Model Value (ft)
Observed Value (ft)
5250
5300
5350
5400
5450
5500



July 2019 - Weighted
Alluvium
Fill
Model Value (ft)
Observed Value (ft)
5250
5300
5350
5400
5450
5500

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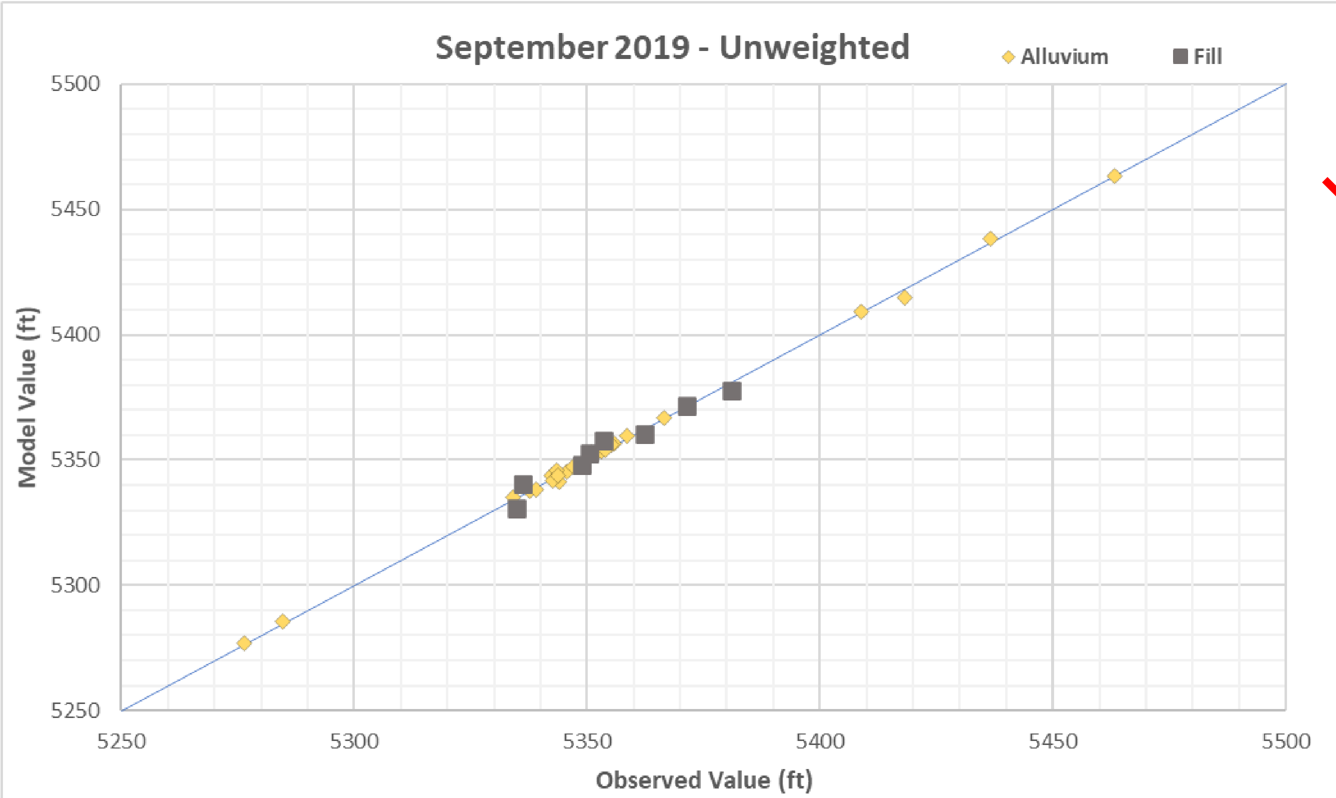
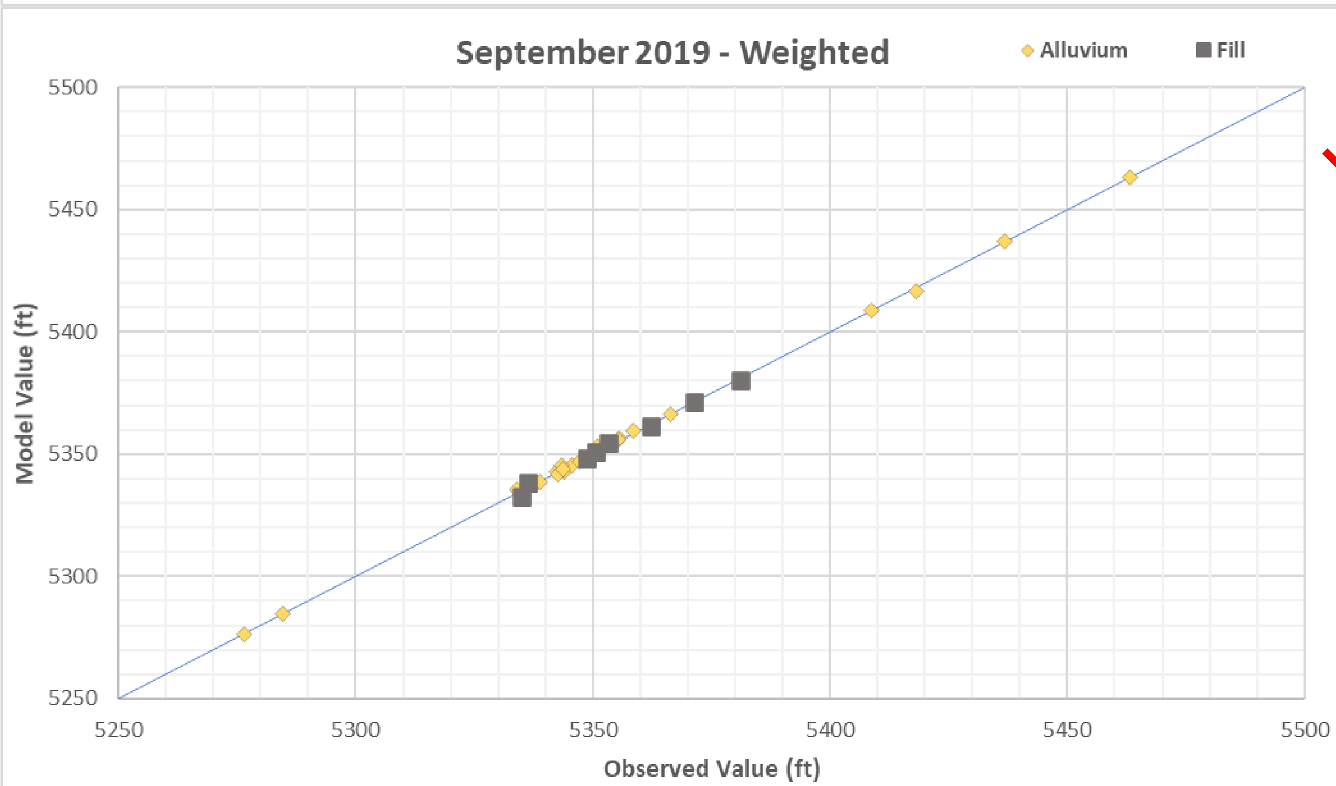
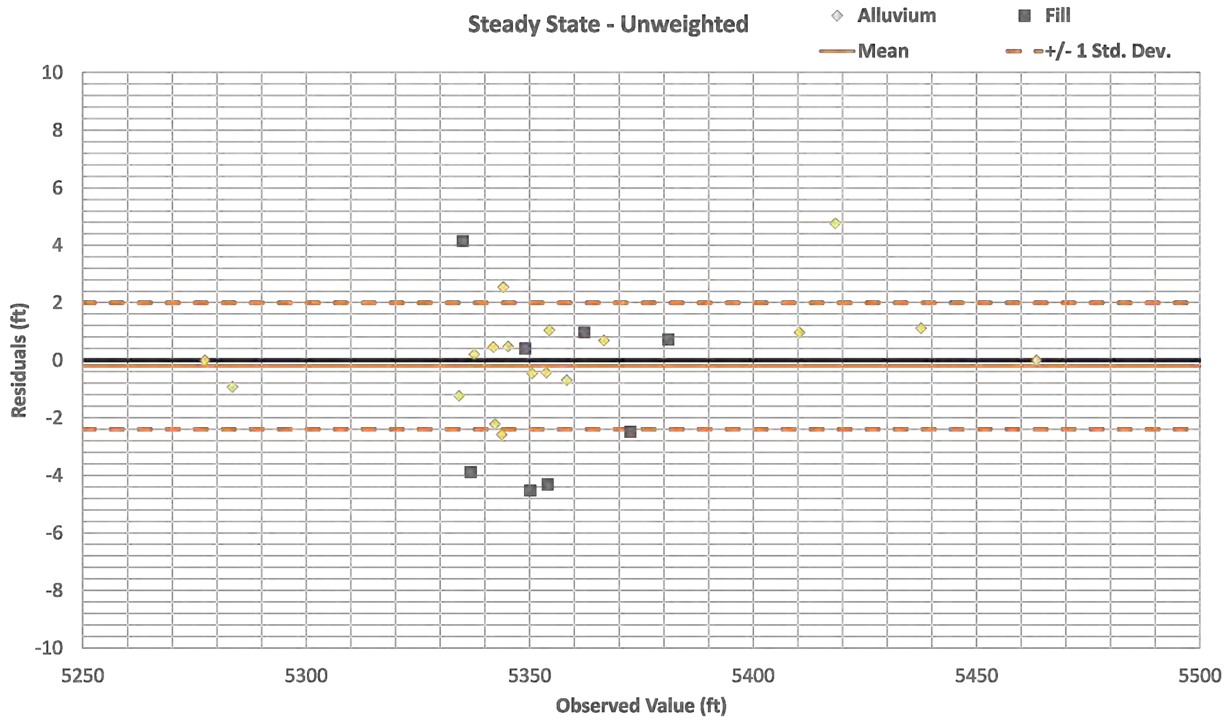
Subject	Quarterly Calibration Plots	Approved	10/19/20	By	ABP

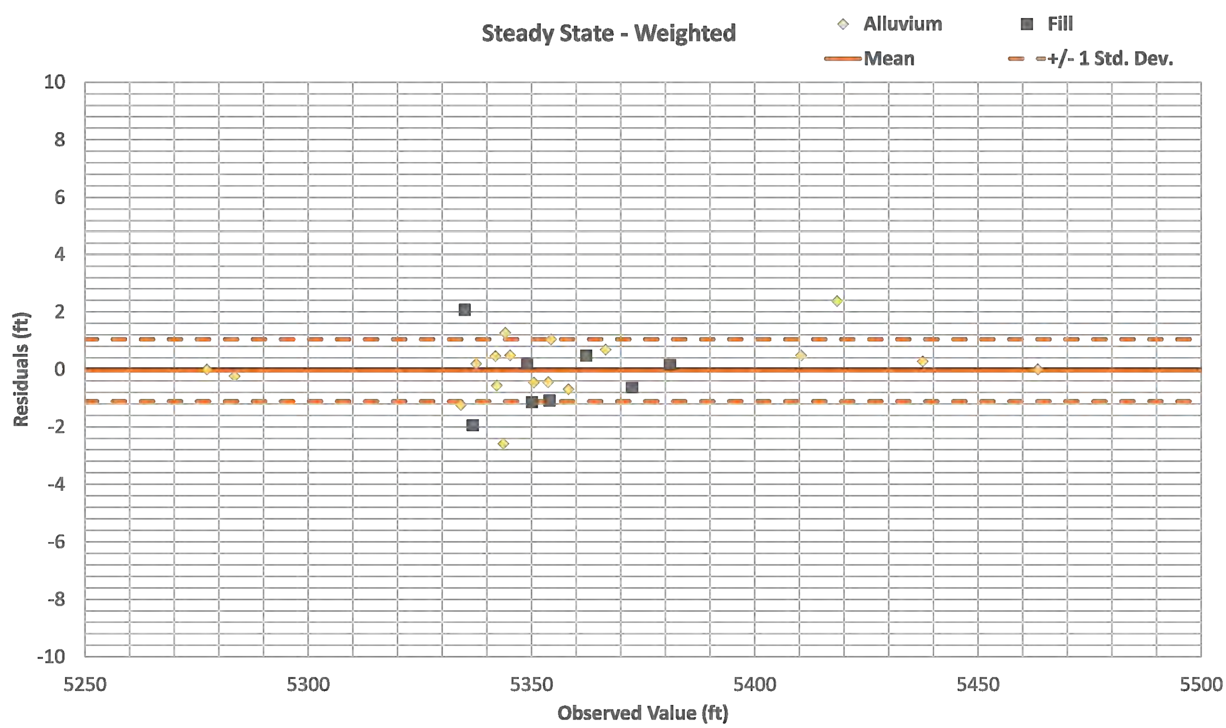




APPENDIX K.2

HEAD RESIDUAL PLOTS





NOTES:

1. OBSERVED VALUES ARE GROUNDWATER HEAD IN FEET.
2. EACH DATA POINT REPRESENTS AN INDIVIDUAL WELL. WELL LOCATIONS ARE SHOWN ON FIGURE 6.1.

P:\16134 – SOUTH BOULDER CREEK\CAD\FIGURES\GROUNDWATER\BASELINE_REPORT\16134_3004_FIGURES_CALIBRATION_PLOTS.DWG 3/26/2021 11:44 AM

RJH CONSULTANTS, INC.

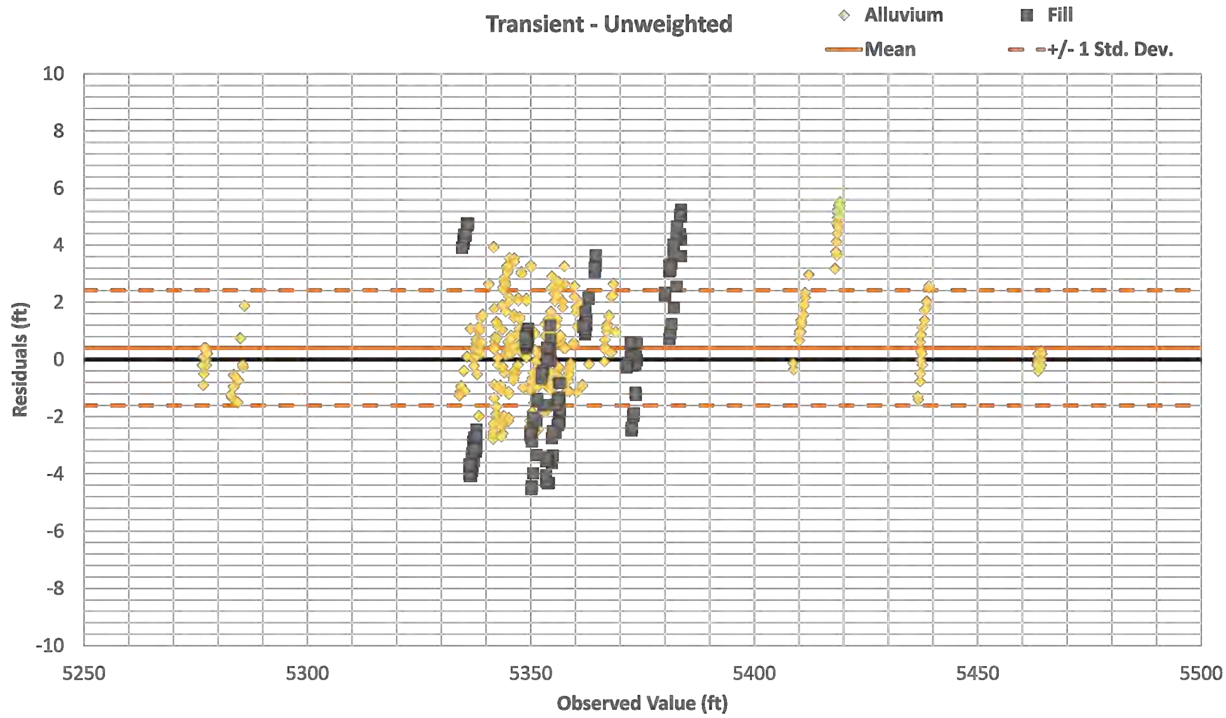
SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

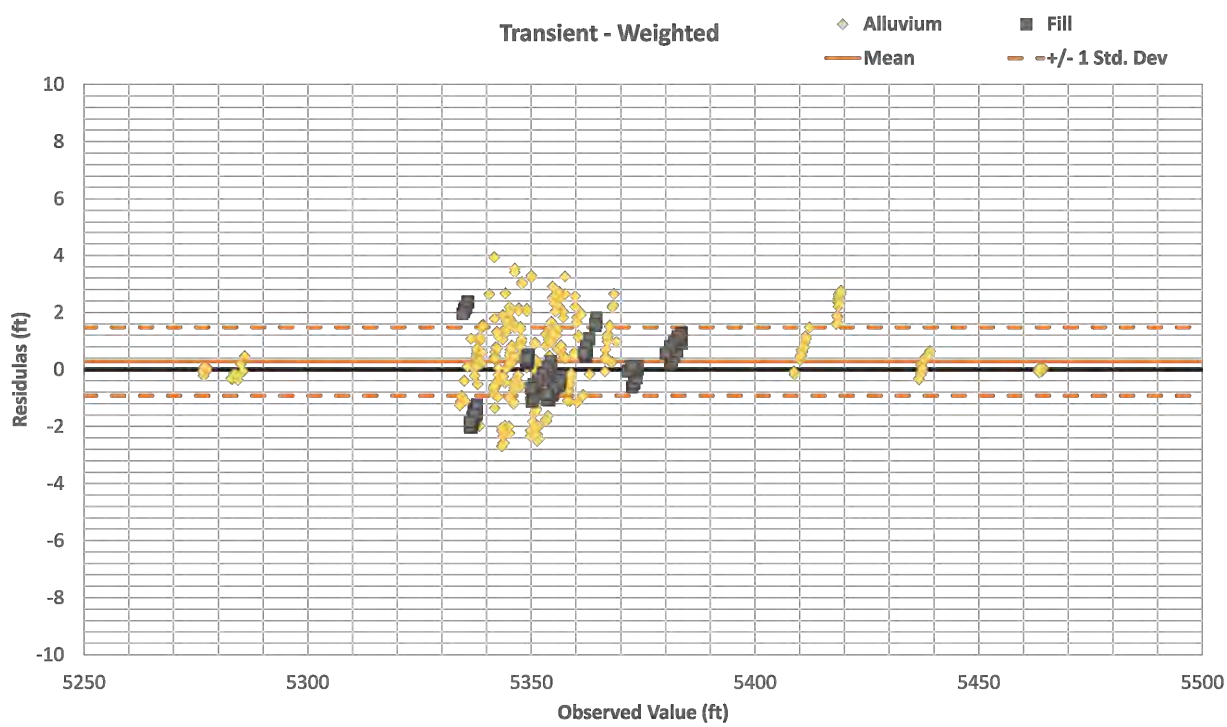
PROJECT NO. 16134

HEAD RESIDUALS PLOTS - BASELINE STEADY-STATE MODEL

April 2021

Figure K.2.1





NOTES:

1. OBSERVED VALUES ARE GROUNDWATER HEAD IN FEET.
2. EACH DATA POINT REPRESENTS ONE STRESS PERIOD FROM AN INDIVIDUAL WELL. WELL LOCATIONS ARE SHOWN ON FIGURE 6.1.

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RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT	HEAD RESIDUALS PLOTS - BASELINE TRANSIENT MODEL	
	PROJECT NO. 16134	April 2021	Figure K.2.2

APPENDIX K.3

WELL HEAD AND DRAWDOWN RESULTS

Purpose:

Document computed Head and Drawdown simulation results from the South Boulder Creek Detention Project (Project) Groundwater Vistas 7 (GWV7) Baseline groundwater model.

References:

1. Presented "Observed" plot lines represent groundwater elevation readings taken across the Project area from both manual and automated recordings during the modeling period. (Note 1)

Summary:

- All elevations reference the North American Vertical Datum of 1988 (NAVD88).
- Head and Drawdown response curves are presented on p. 2-33 . (Note 2)
- Negative drawdown values represent a rise in water level.
- Elevations presented on the vertical axes of all head results graphs vary for each well. (Note 3)

Notes:

1. The "Observed" plot lines are the monthly head calibration data for each well, which generally represent the monthly average of the measured data.

2. Results from one well are shown on each page. The upper plot on each page shows heads and the lower plot on each page shows drawdown.

3. The elevations vary depending on the measured groundwater levels in each well, however all graphs are shown at the same scale. Each Head response plot and Each Drawdown response plot span a vertical range of 11 feet.

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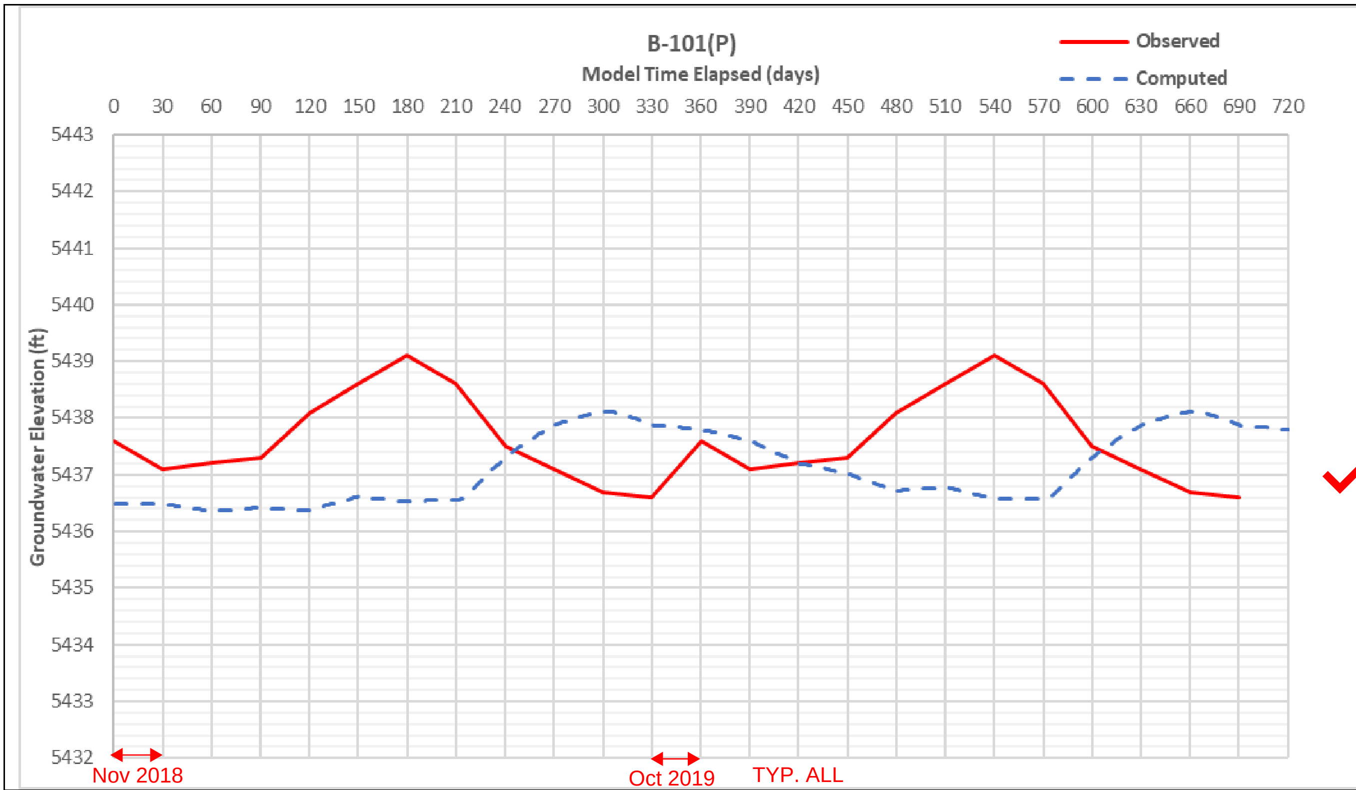
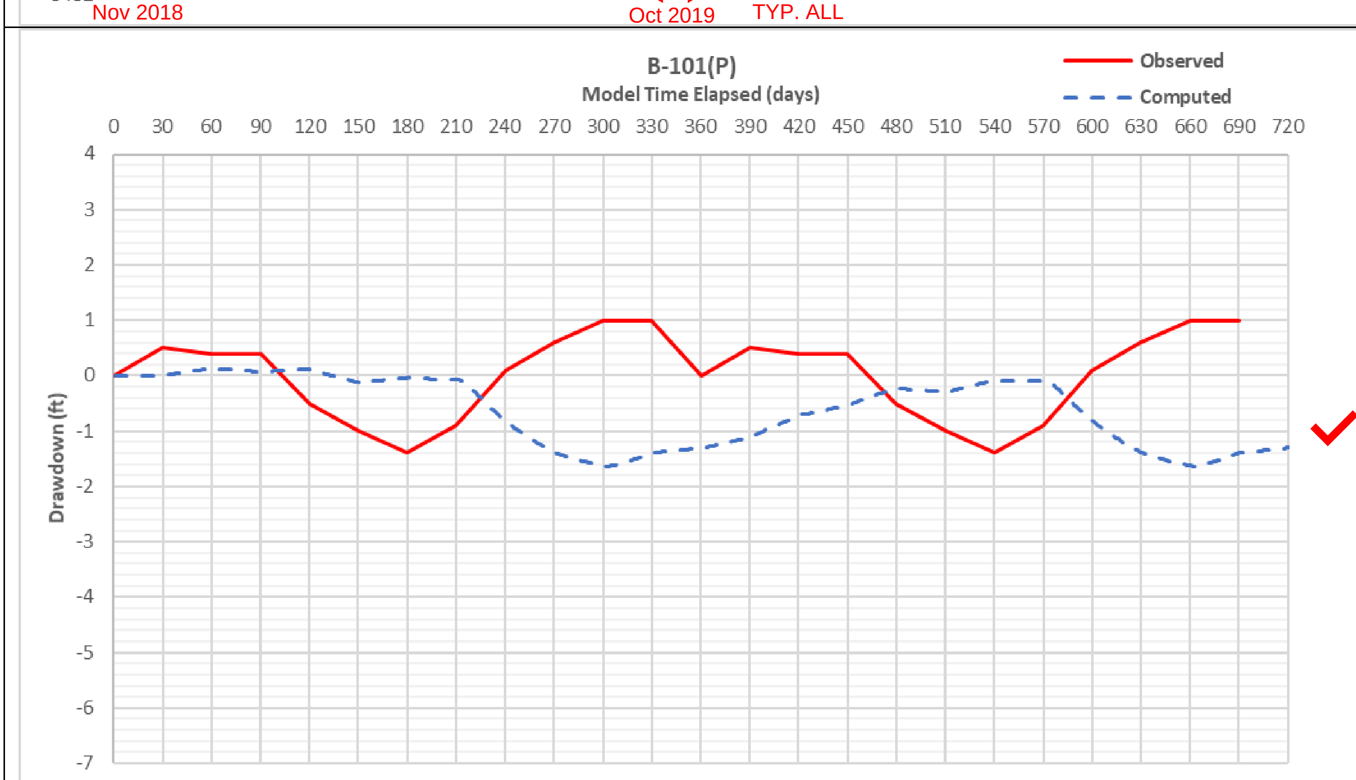
Approved	10/16/20	By	ABP

Client City of Boulder

Subject Well Results





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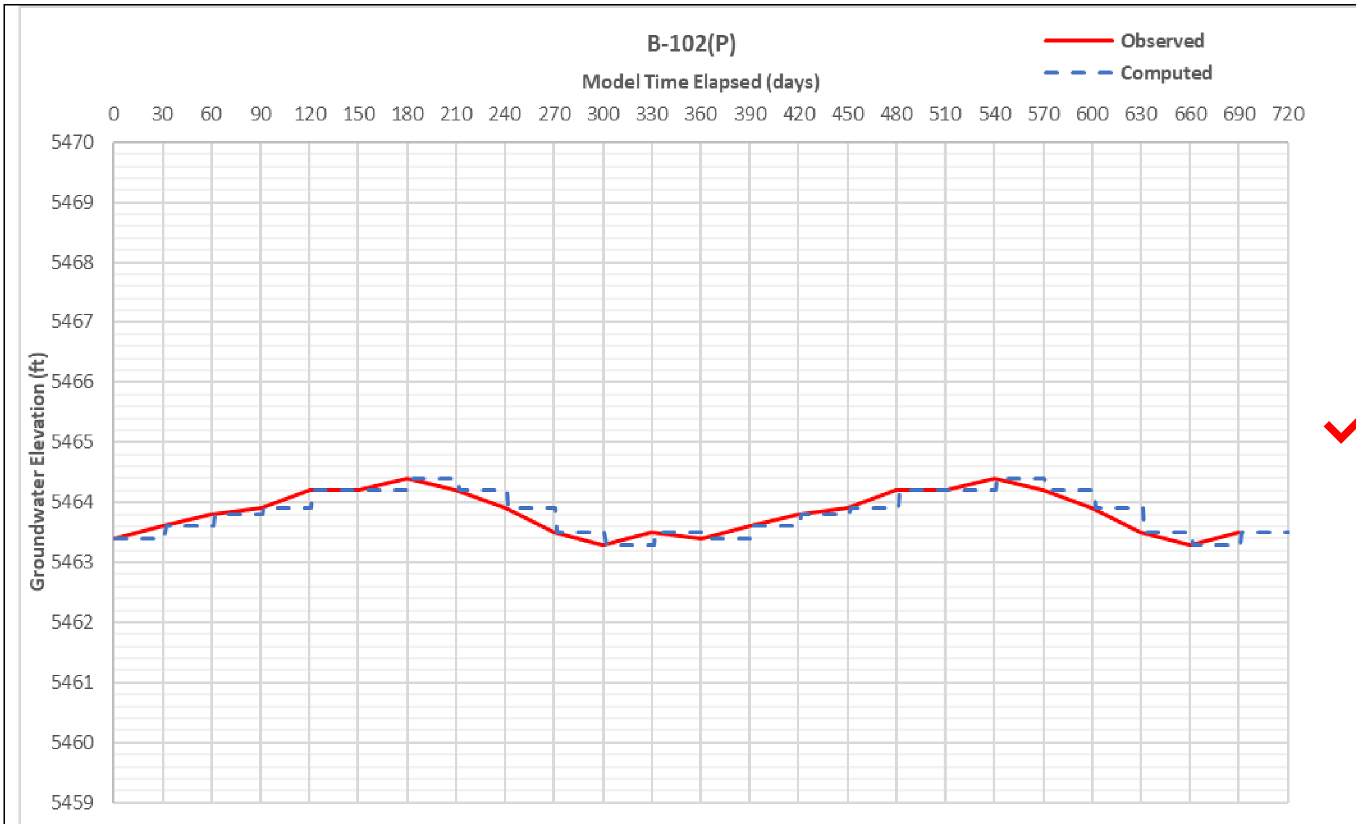
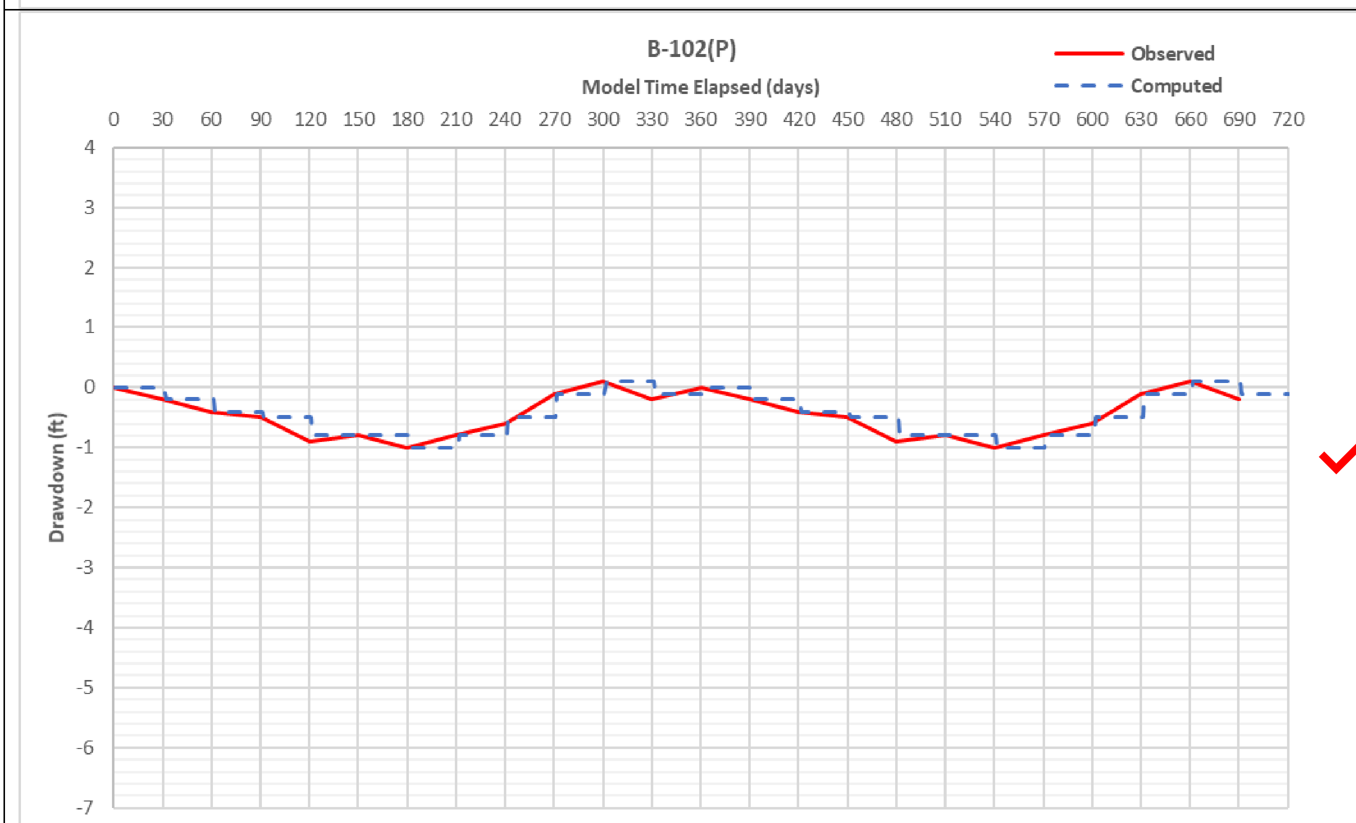
Client: City of Boulder	Checked	10/16/2020	By	JNH
Subject: Well Results	Approved	10/16/20	By	ABP





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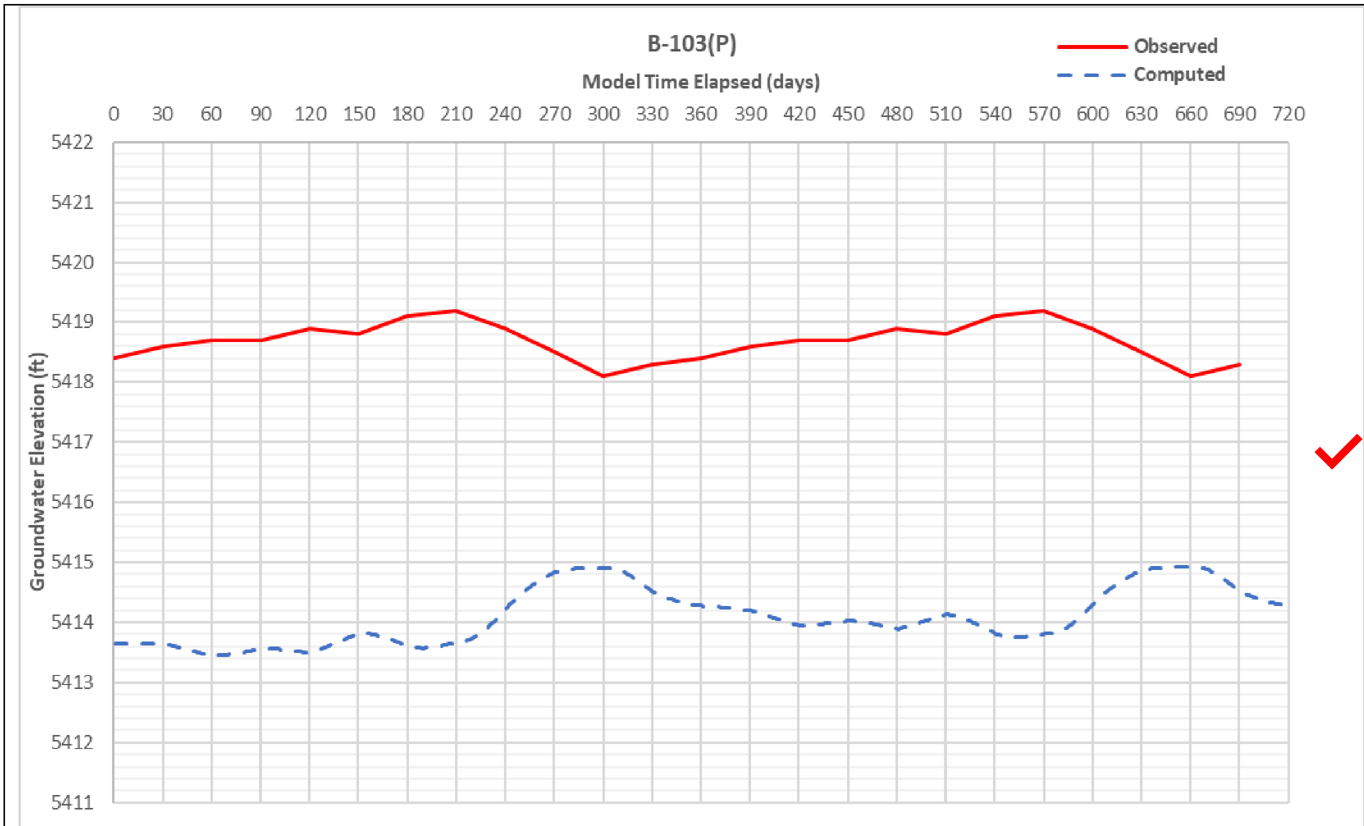
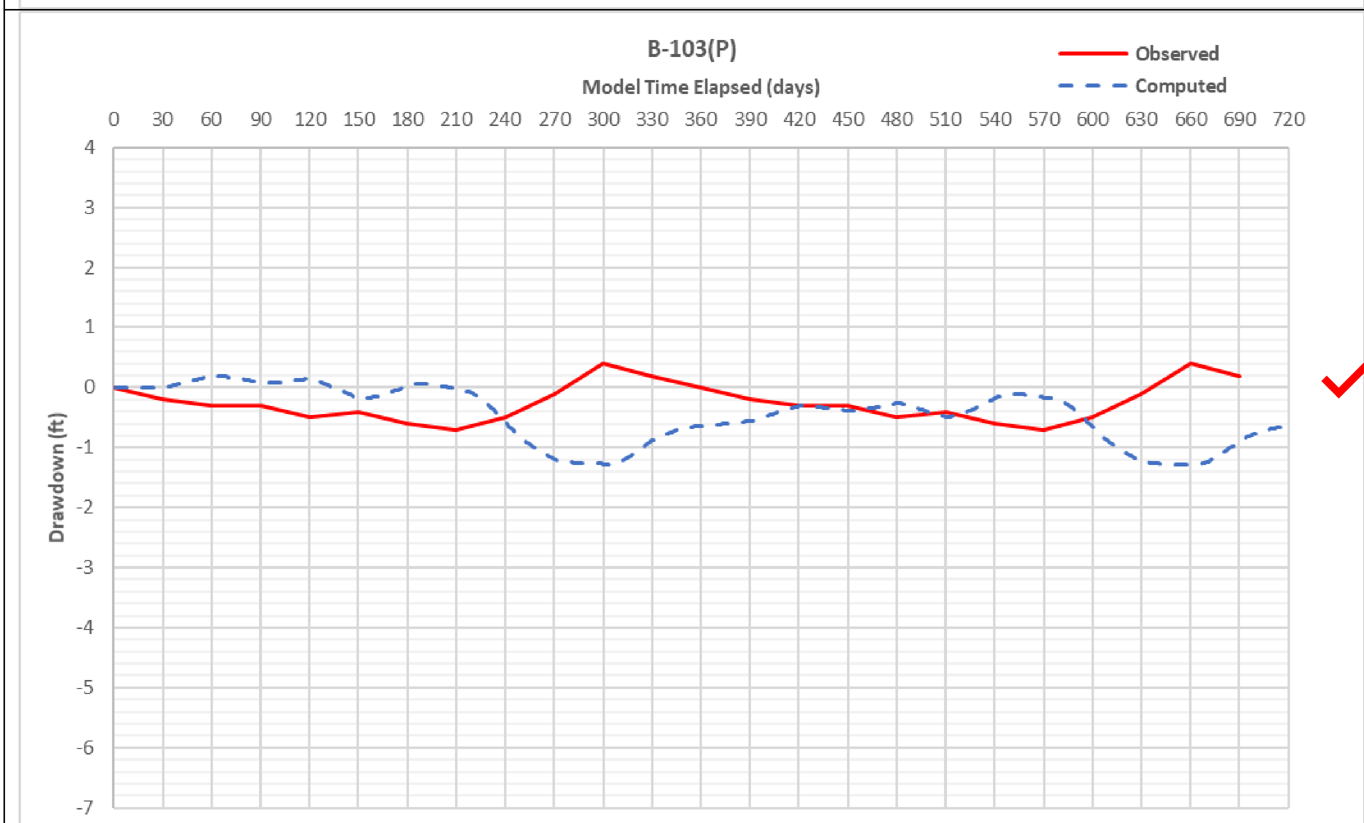
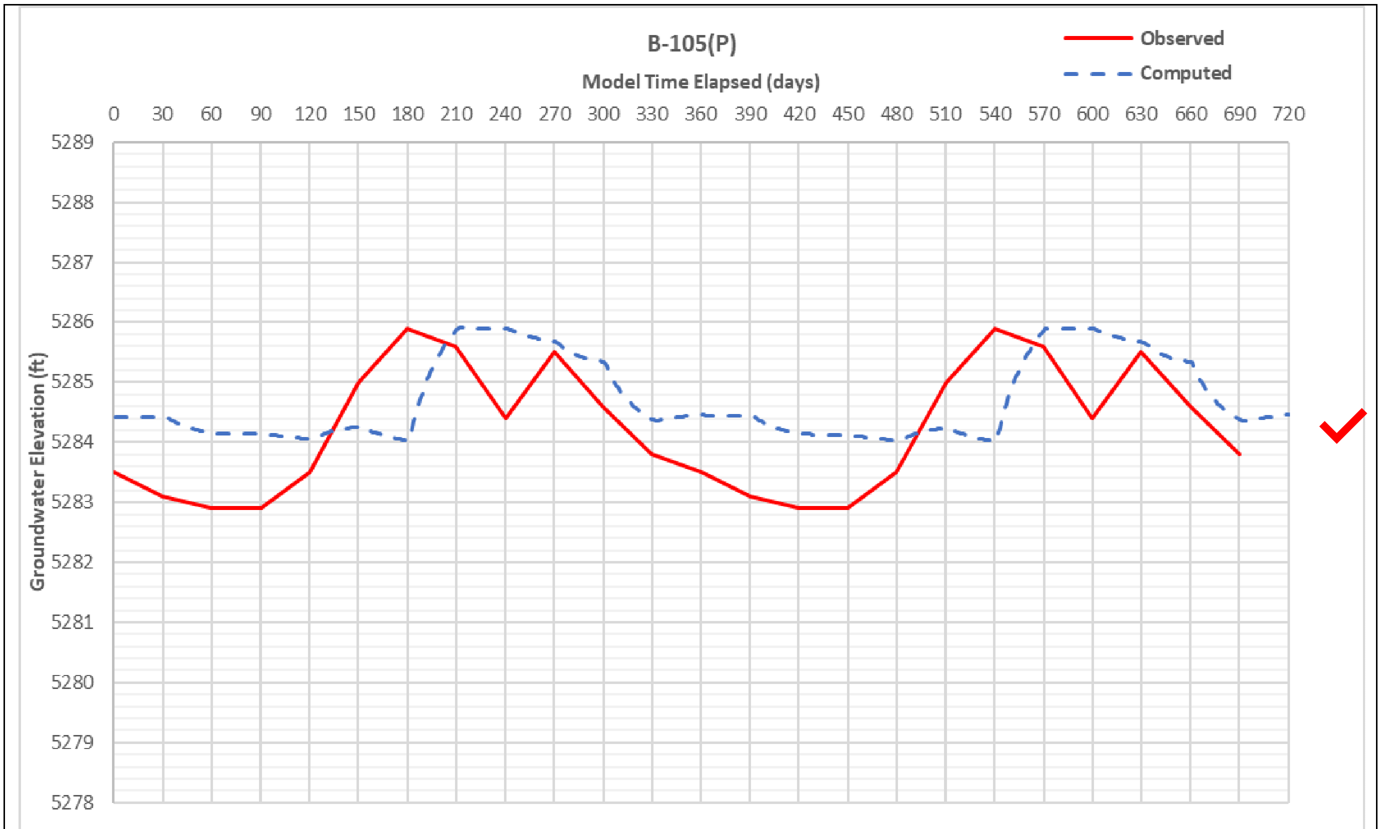
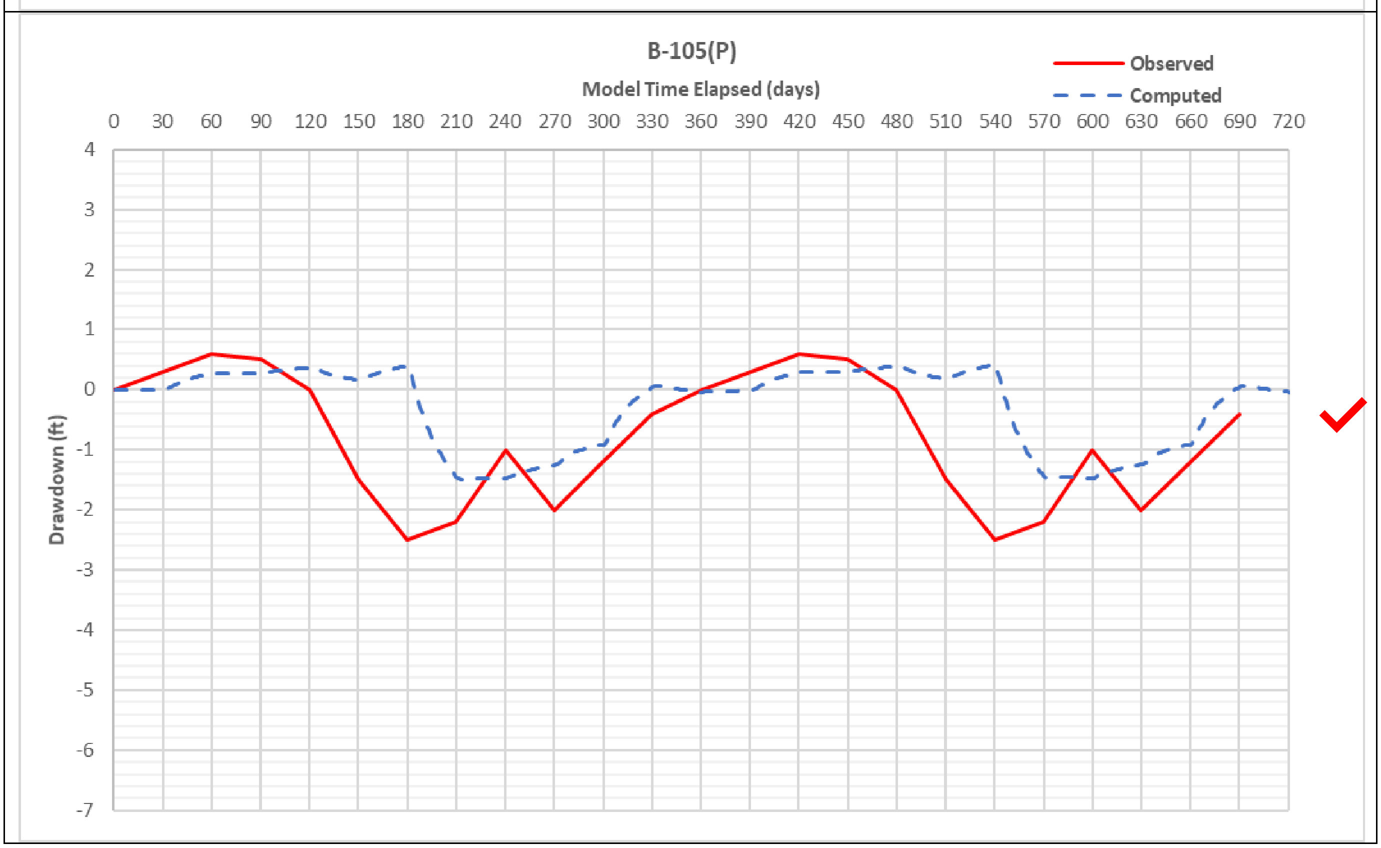
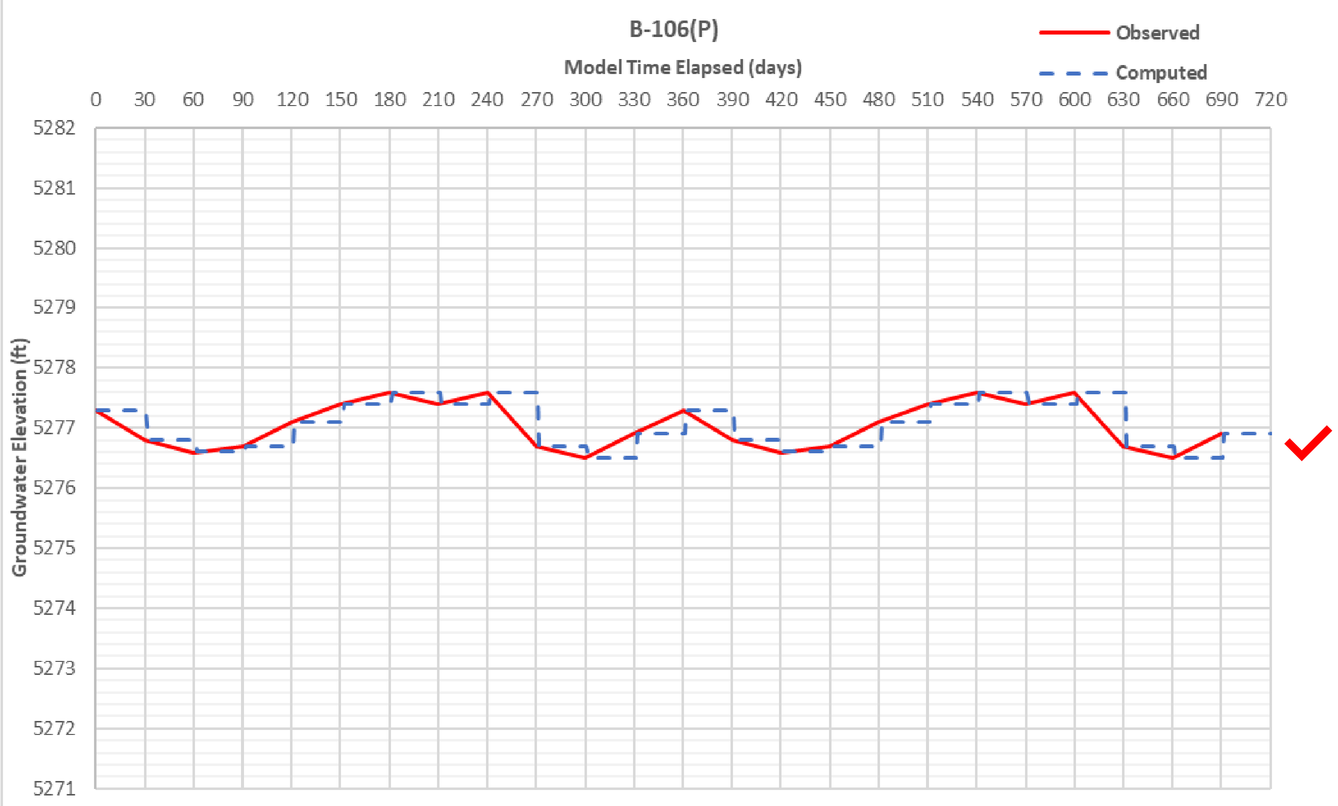
Client: City of Boulder	Checked	10/16/2020	By	JNH
Subject: Well Results	Approved	10/16/20	By	ABP

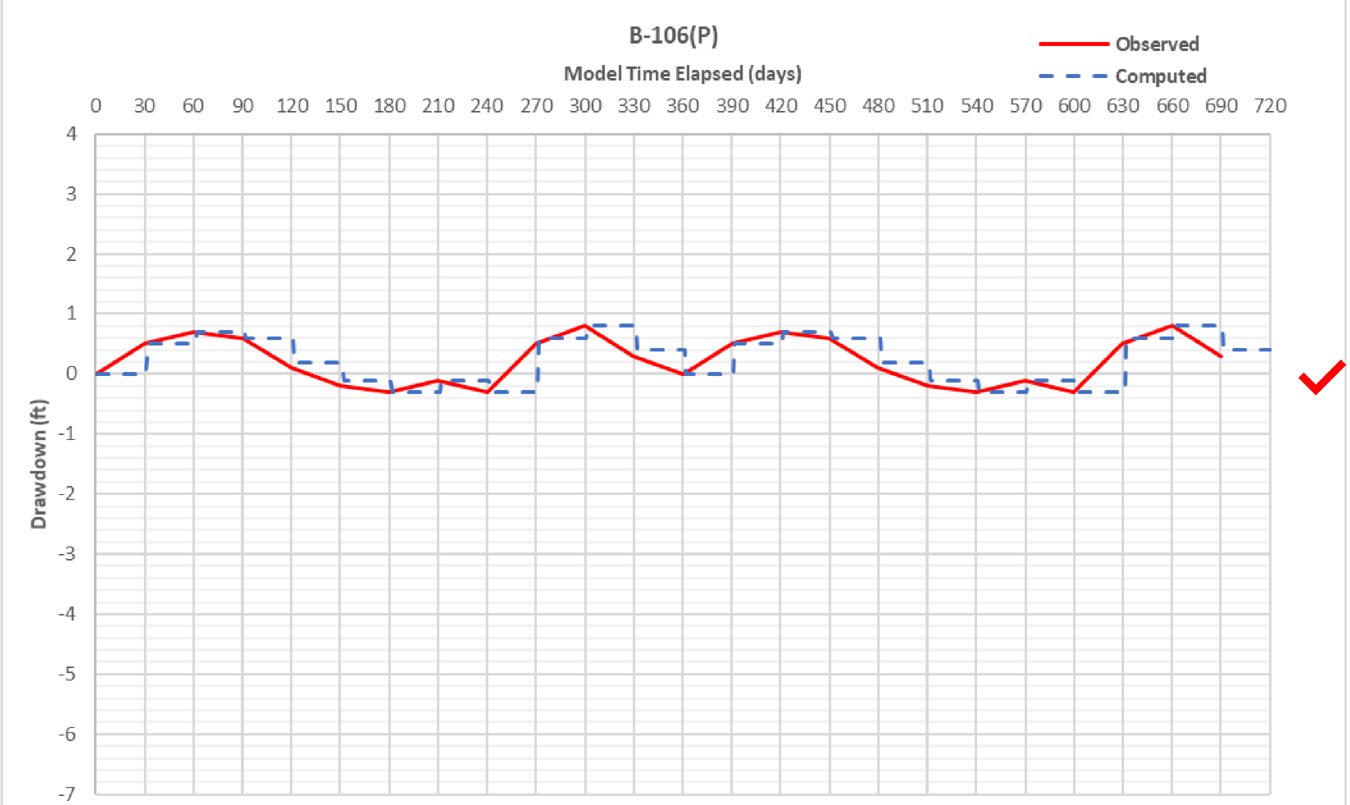





B-105(P)
Model Time Elapsed (days)
Observed
Computed
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
5289
5288
5287
5286
5285
5284
5283
5282
5281
5280
5279
5278
Groundwater Elevation (ft)


B-105(P)
Model Time Elapsed (days)
Observed
Computed
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
Drawdown (ft)


B-106(P)
Model Time Elapsed (days)
Observed
Computed
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
Groundwater Elevation (ft)
5282 5281 5280 5279 5278 5277 5276 5275 5274 5273 5272 5271


B-106(P)
Model Time Elapsed (days)
Observed
Computed
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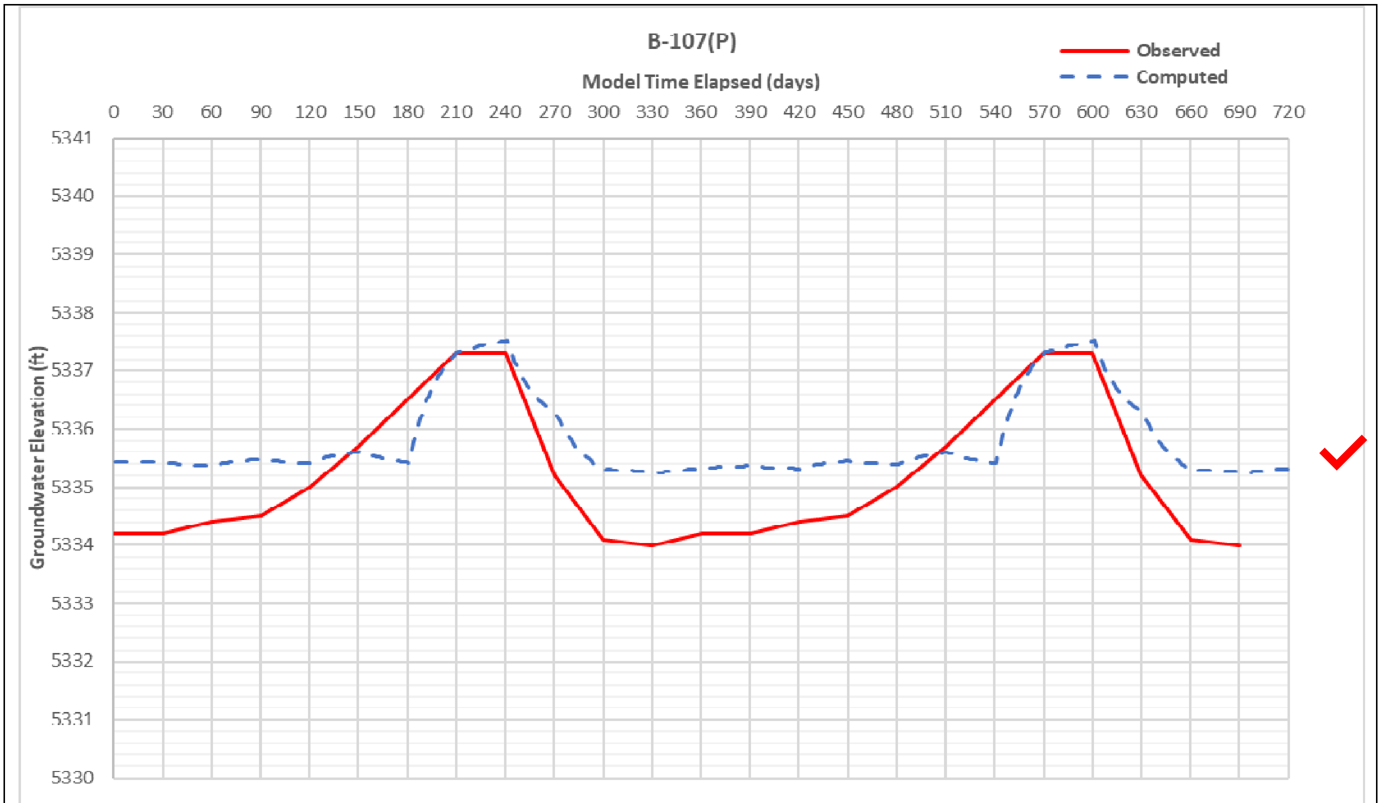
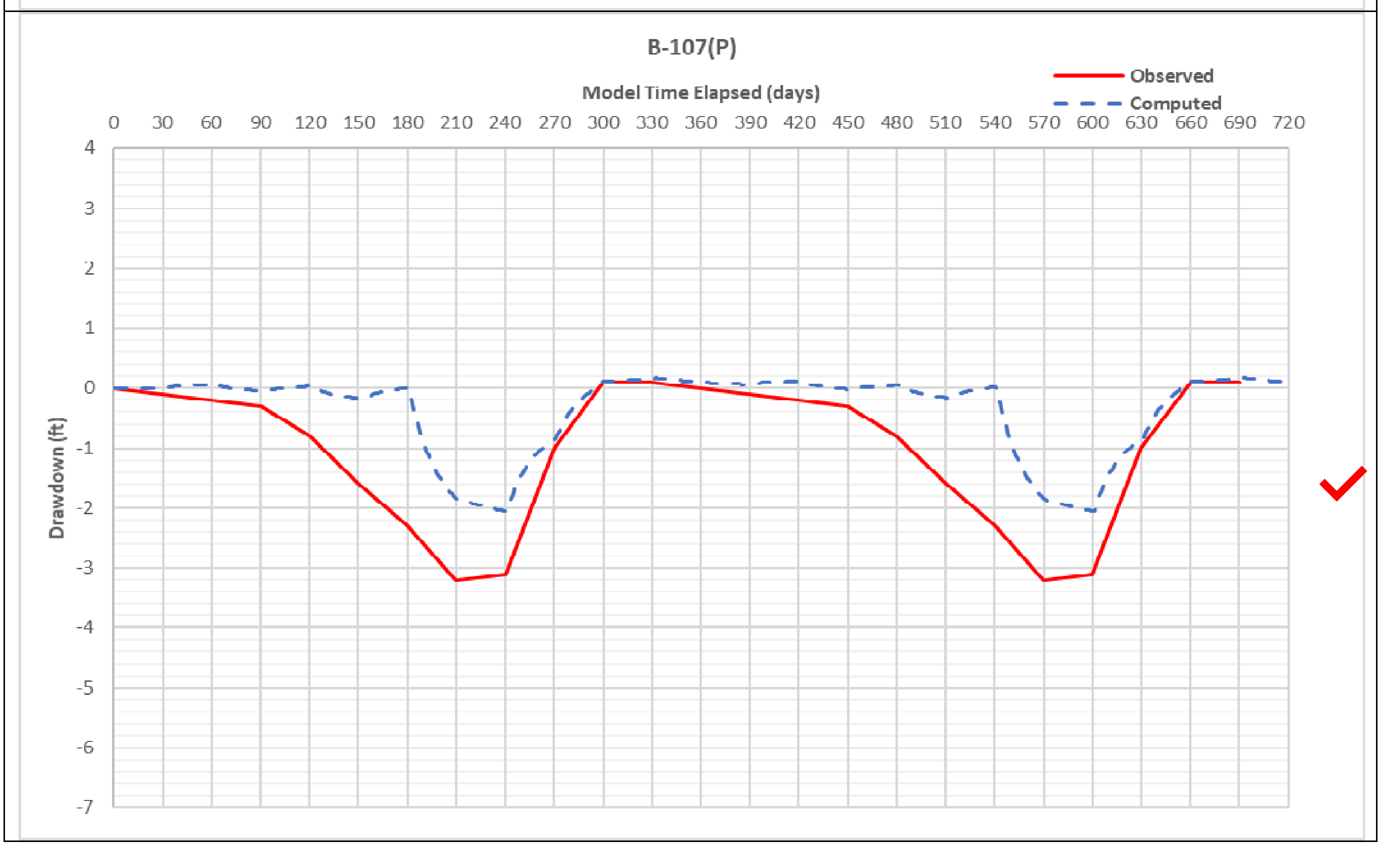
Drawdown (ft)
4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7


B-107(P)
Model Time Elapsed (days)
Observed
Computed
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
5341
5340
5339
5338
5337
5336
5335
5334
5333
5332
5331
5330
Groundwater Elevation (ft)


B-107(P)
Model Time Elapsed (days)
Observed
Computed
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
Drawdown (ft)

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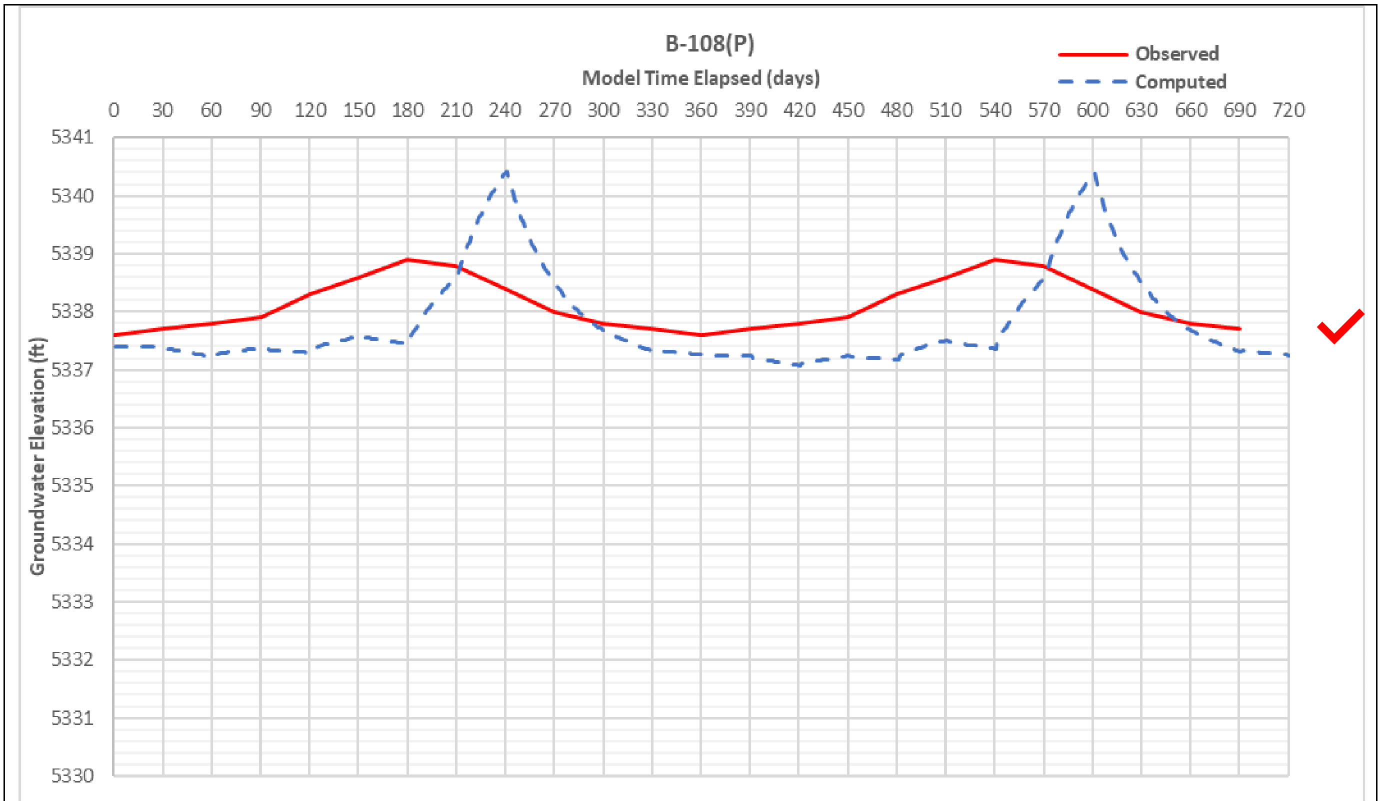
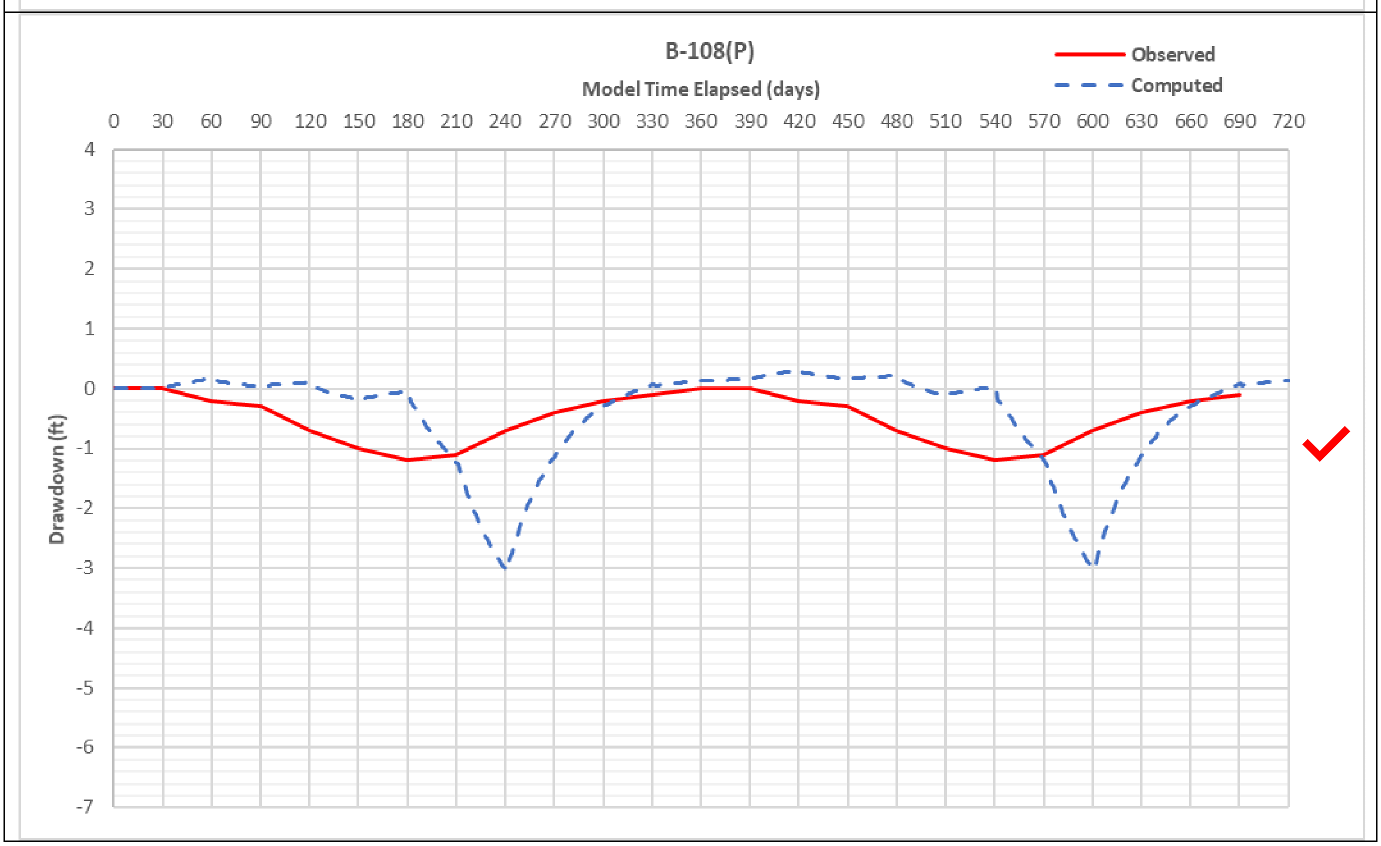
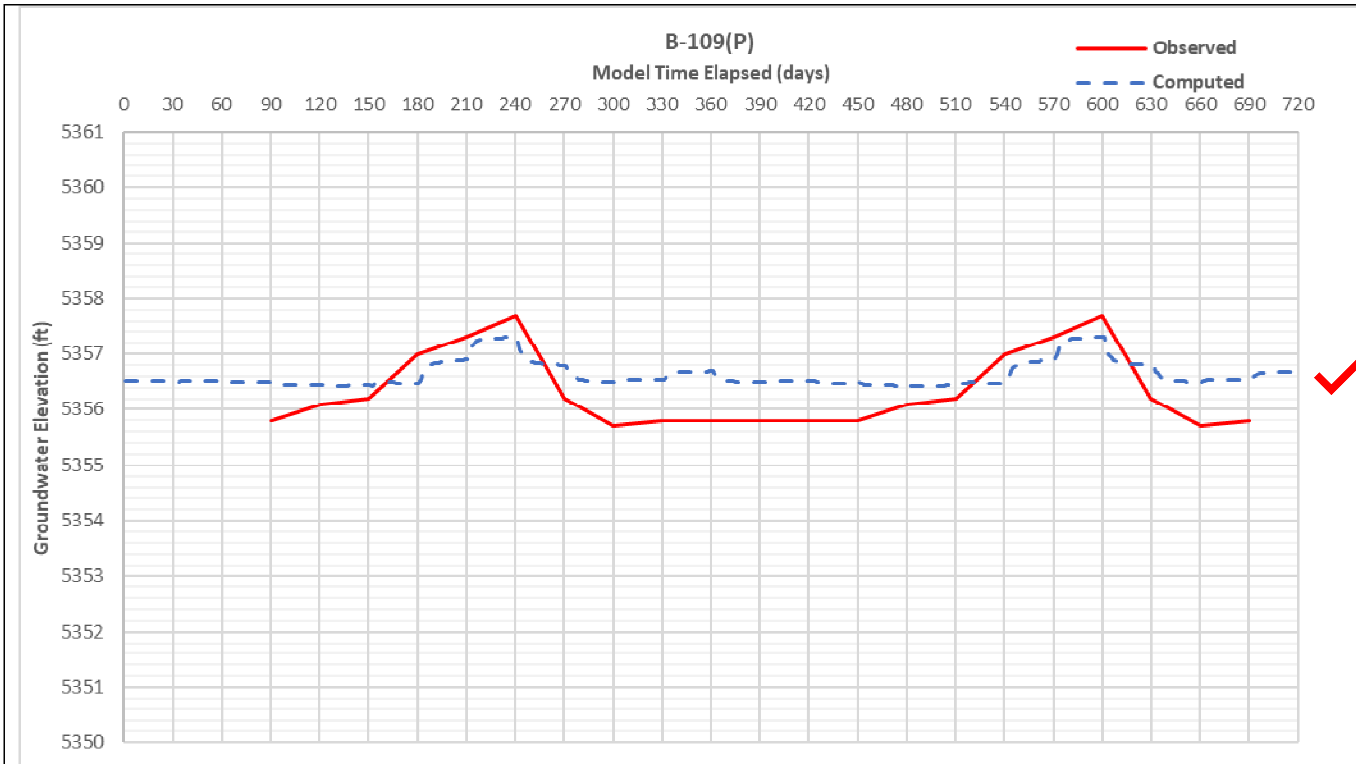
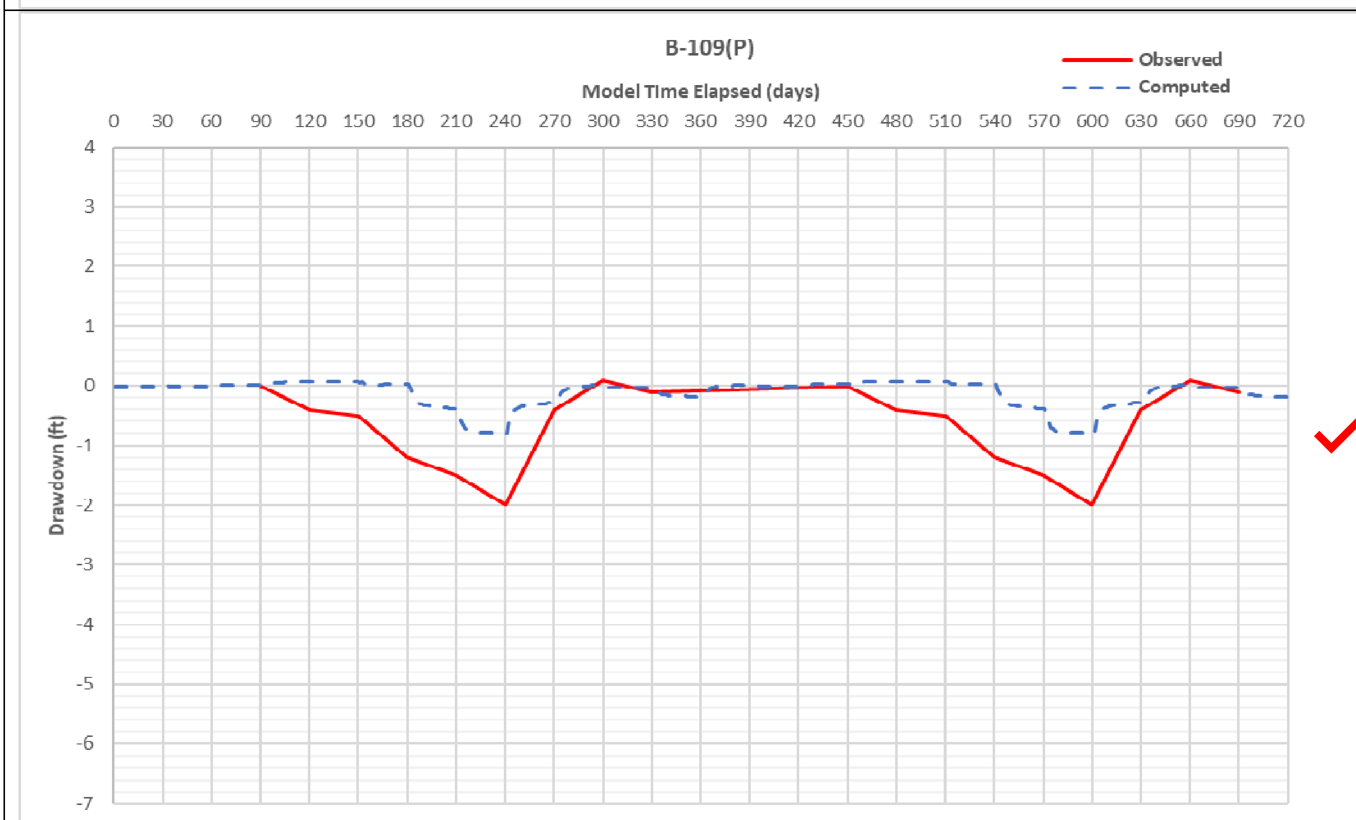





B-109(P)
Model Time Elapsed (days)
Observed
Computed
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
5361 5360 5359 5358 5357 5356 5355 5354 5353 5352 5351 5350
Groundwater Elevation (ft)


B-109(P)
Model Time Elapsed (days)
Observed
Computed
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7
Drawdown (ft)

		Project	16134	Page	10/33
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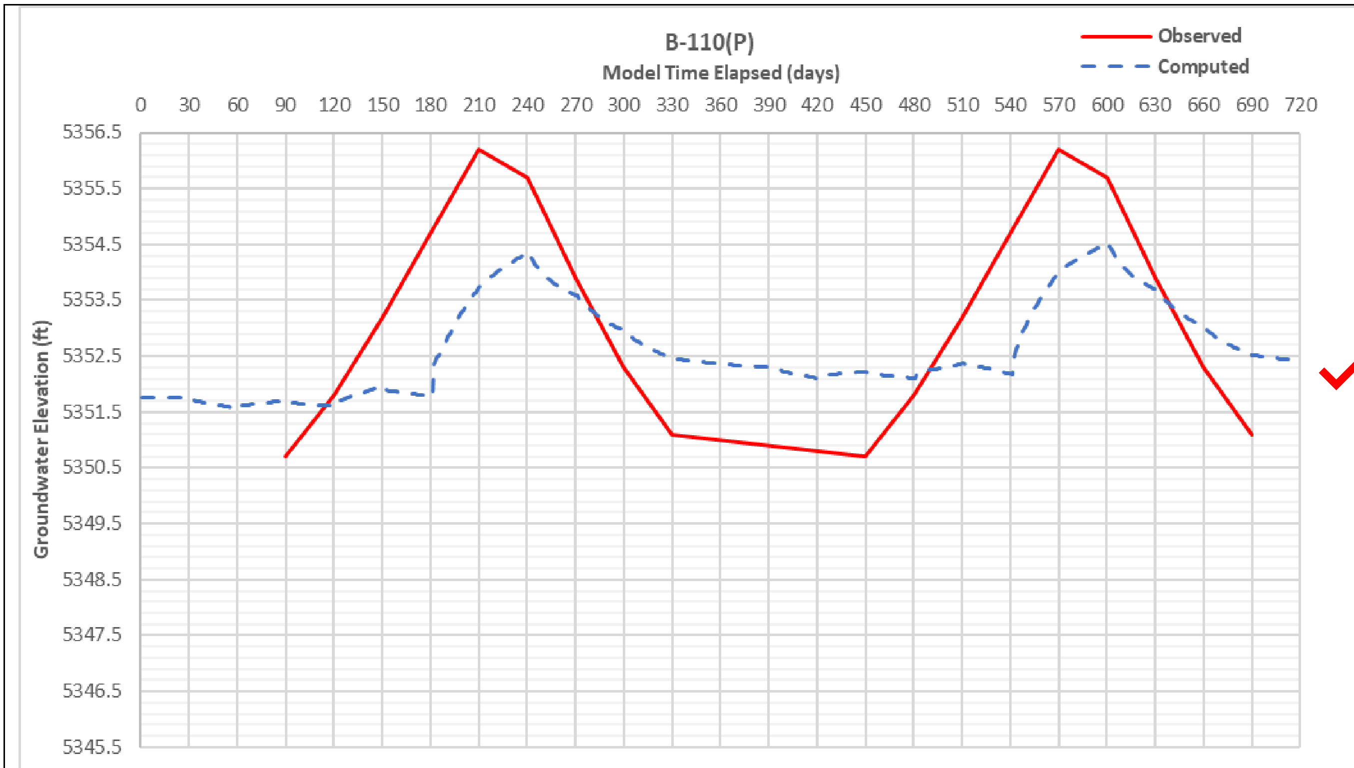

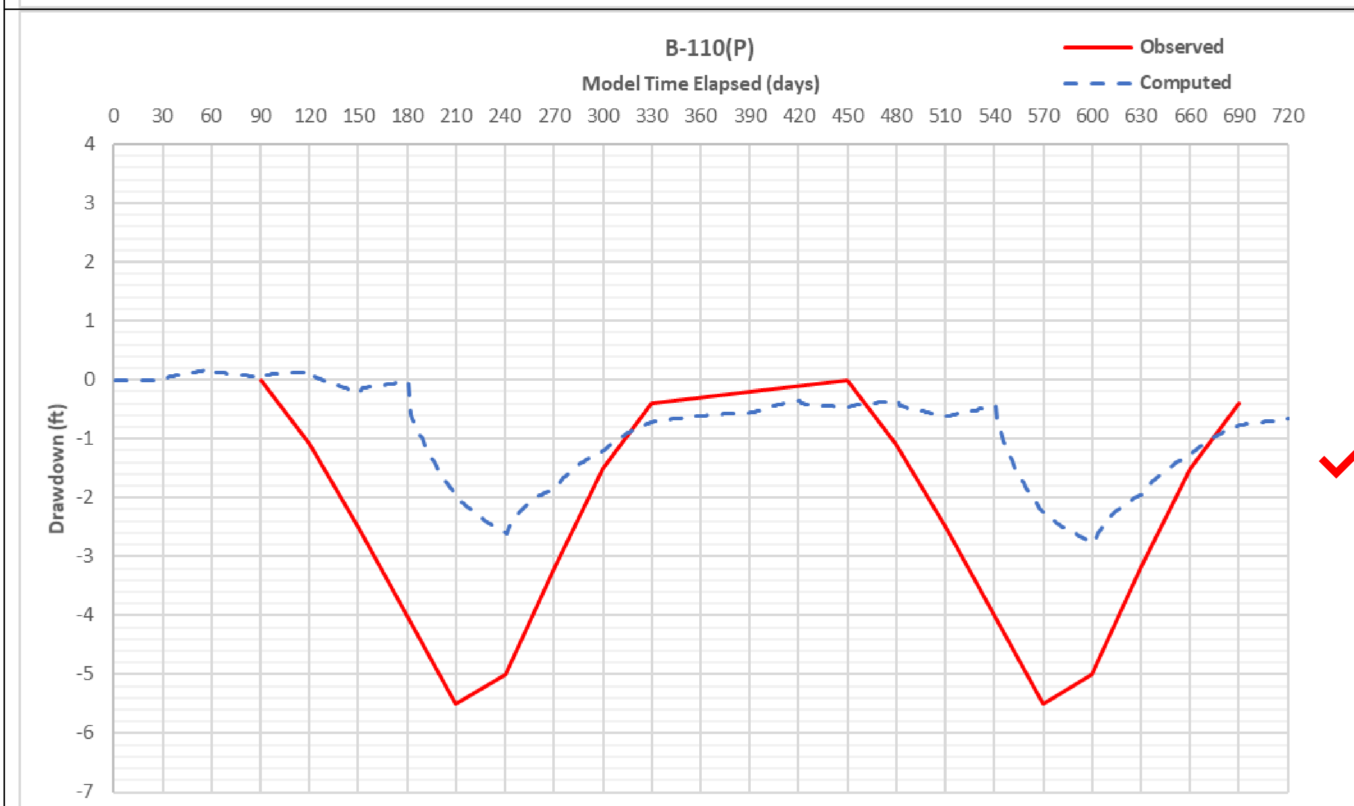

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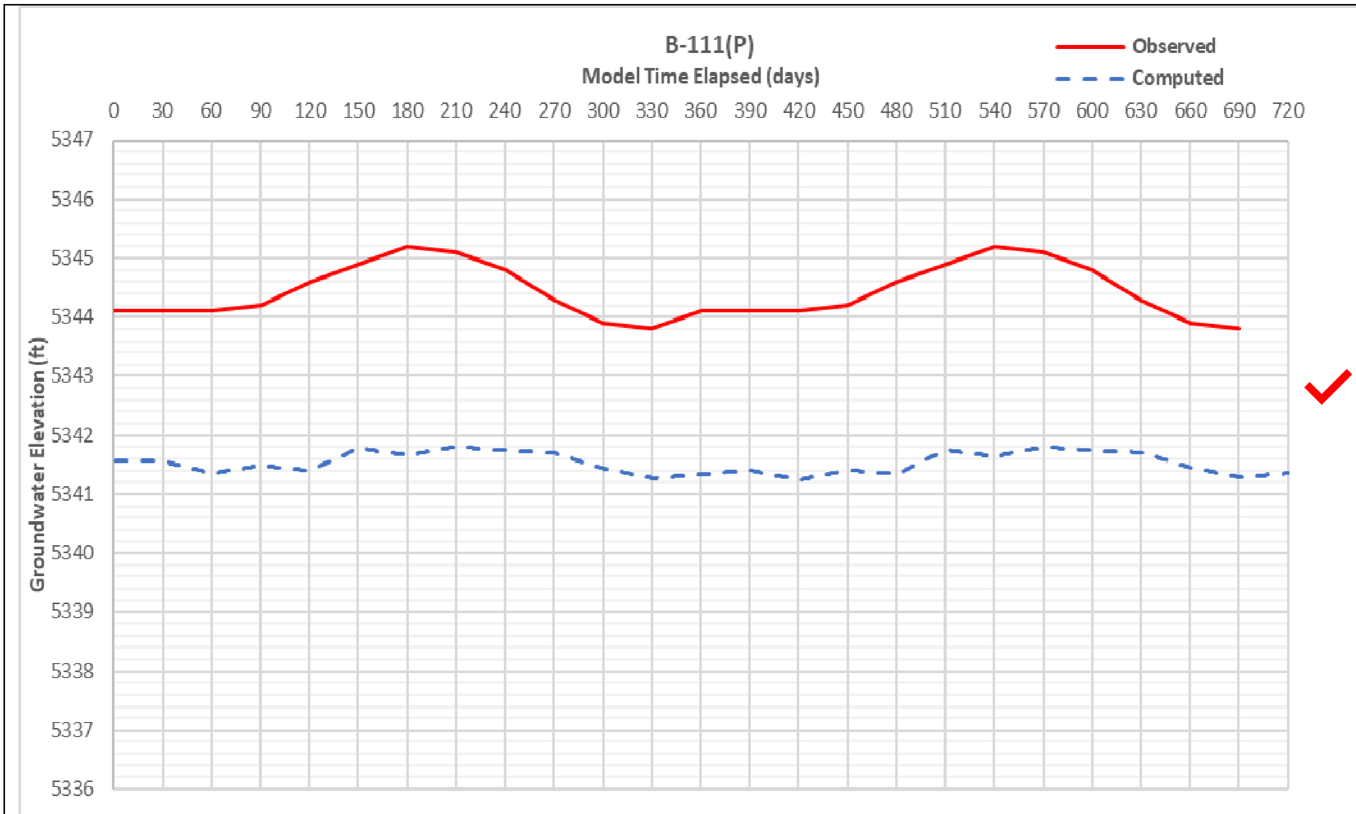
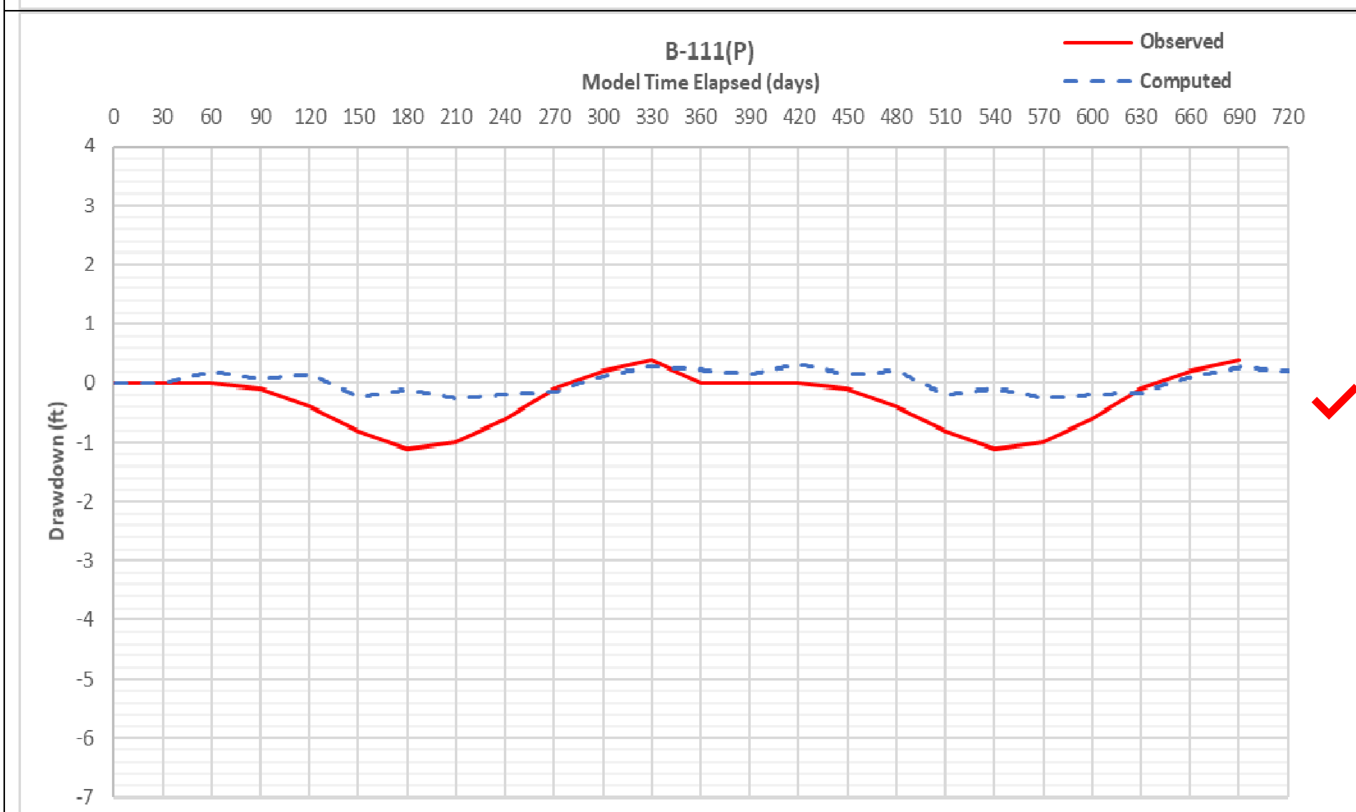
Subject	Well Results	Approved	10/16/20	By	ABP





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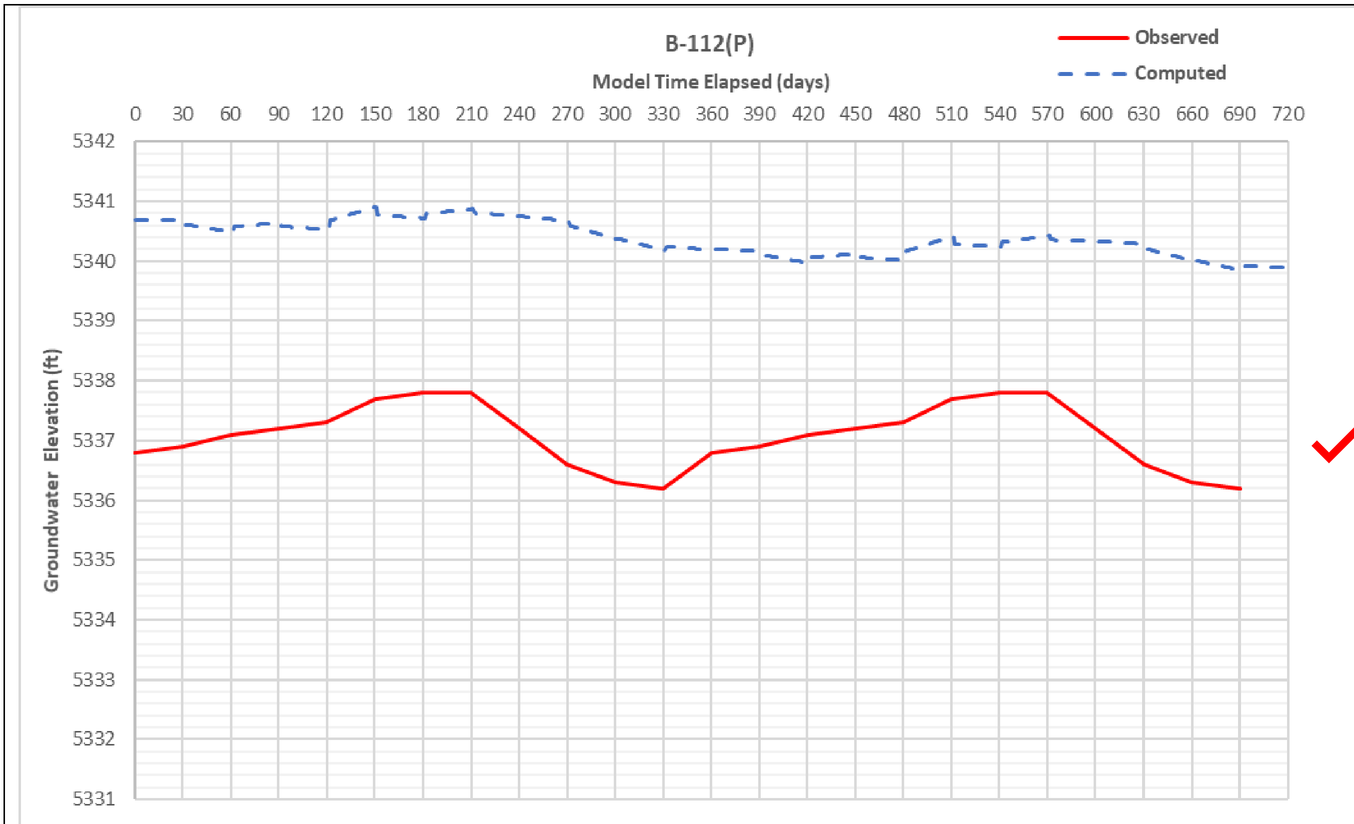
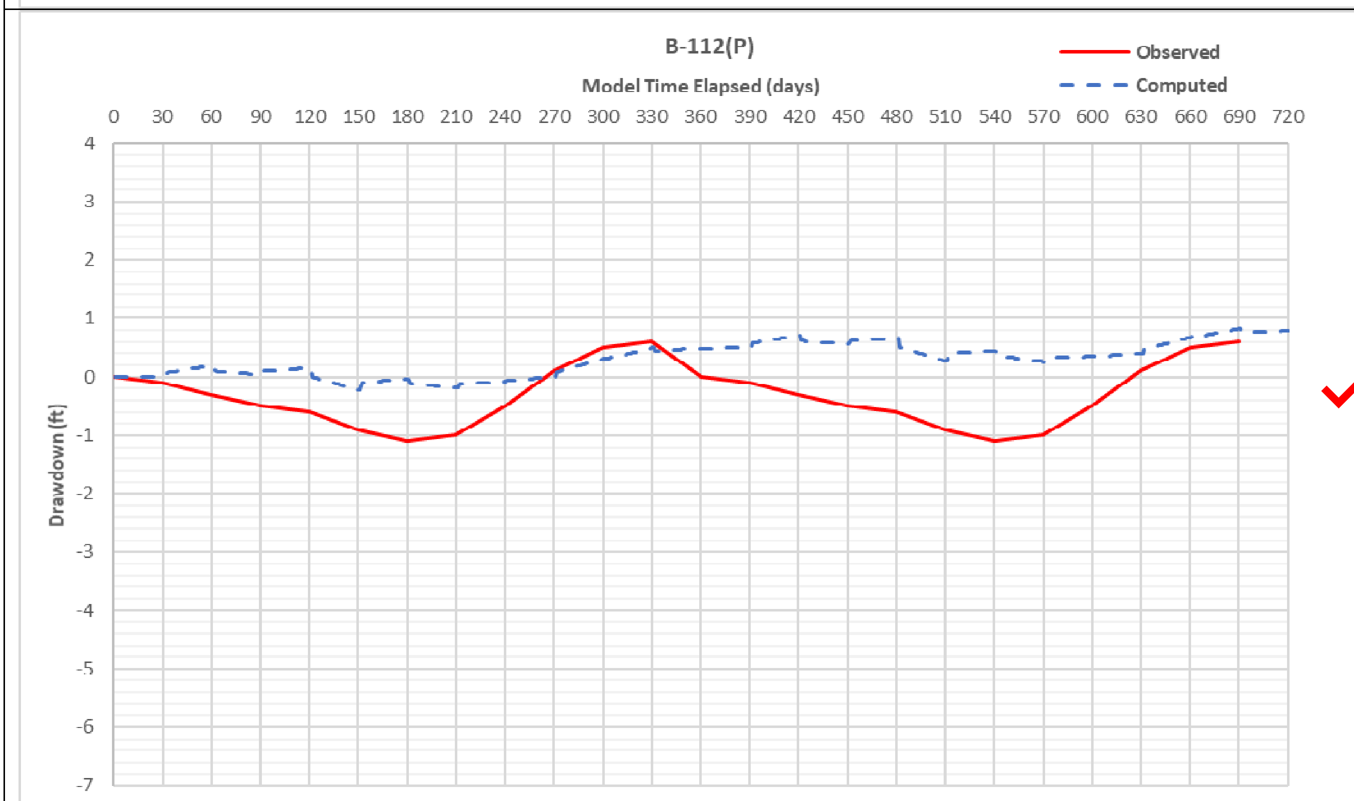
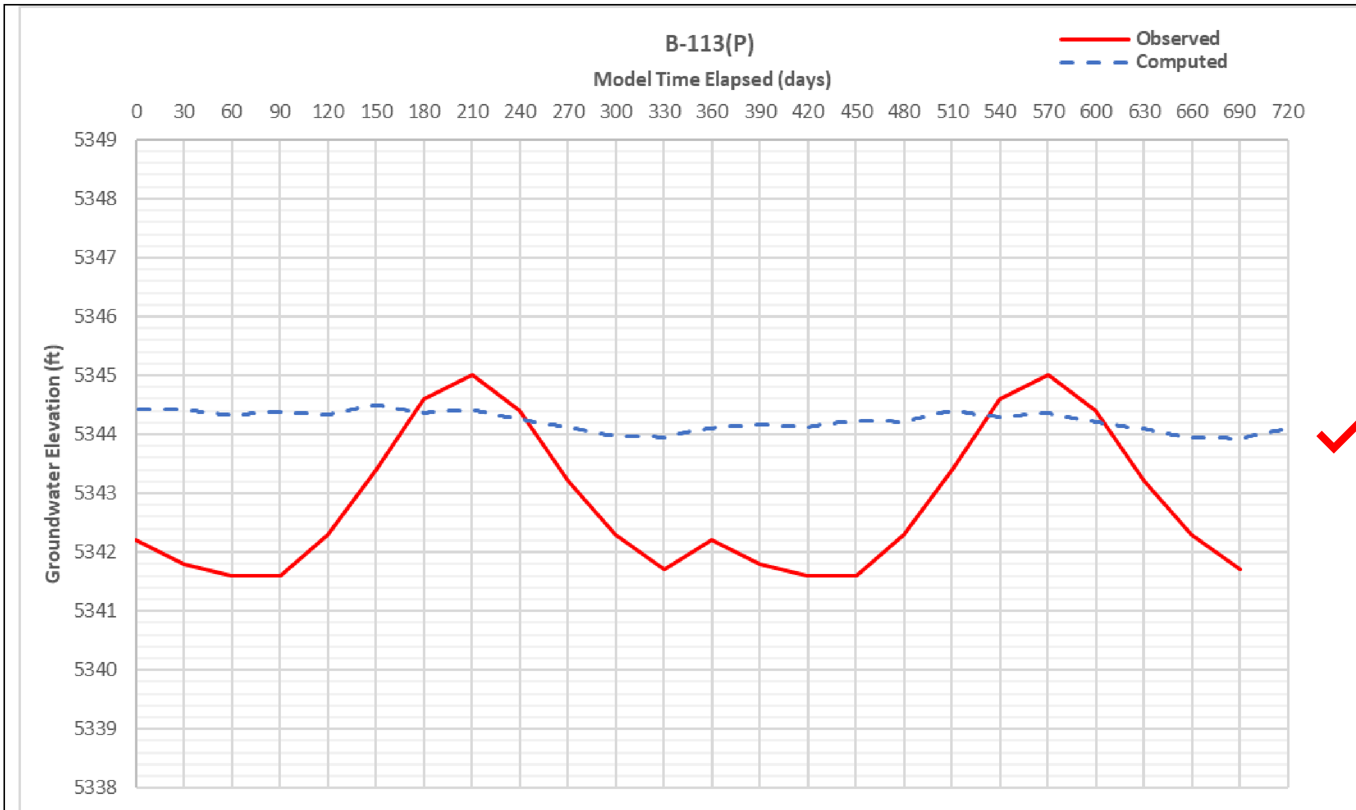
Subject Well Results	Approved	10/16/20	By	ABP







B-113(P)
Model Time Elapsed (days)
Observed
Computed
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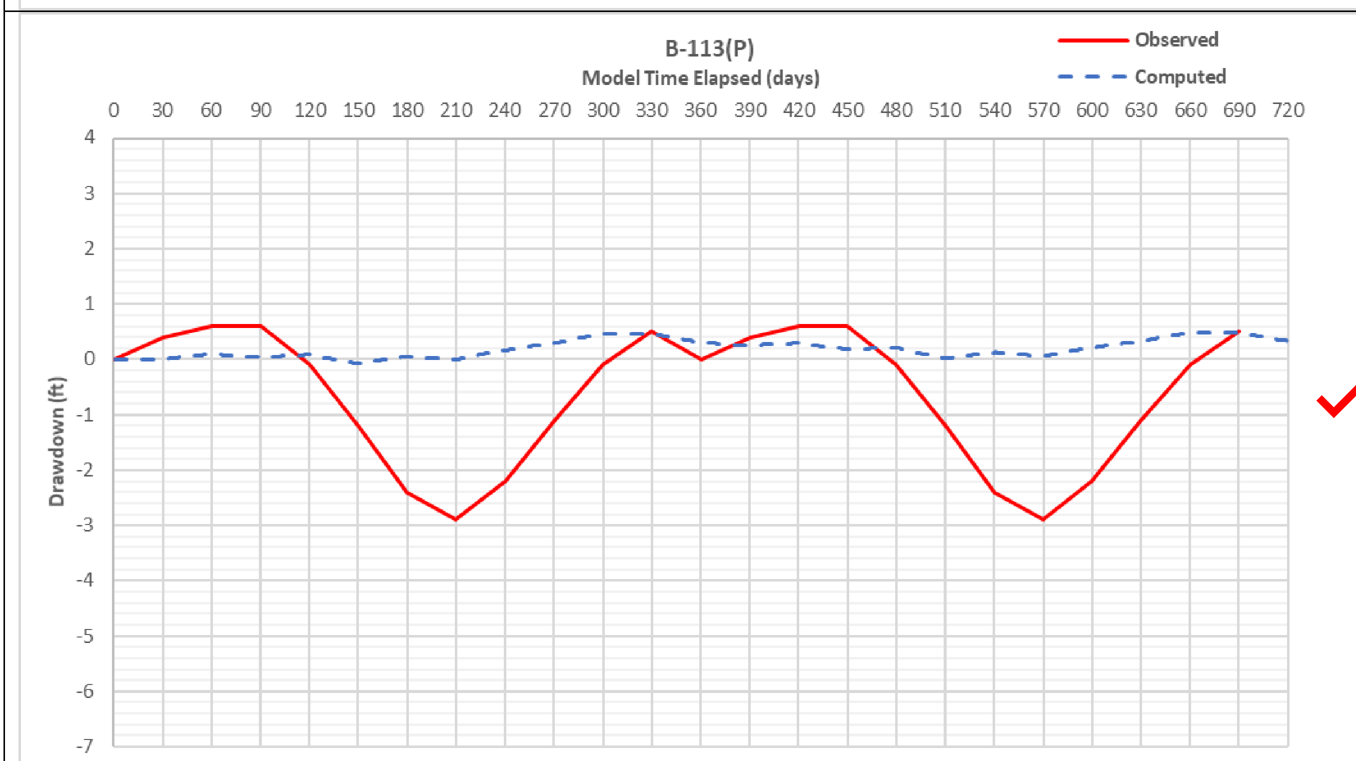
Groundwater Elevation (ft)



B-113(P)
Model Time Elapsed (days)
Observed
Computed
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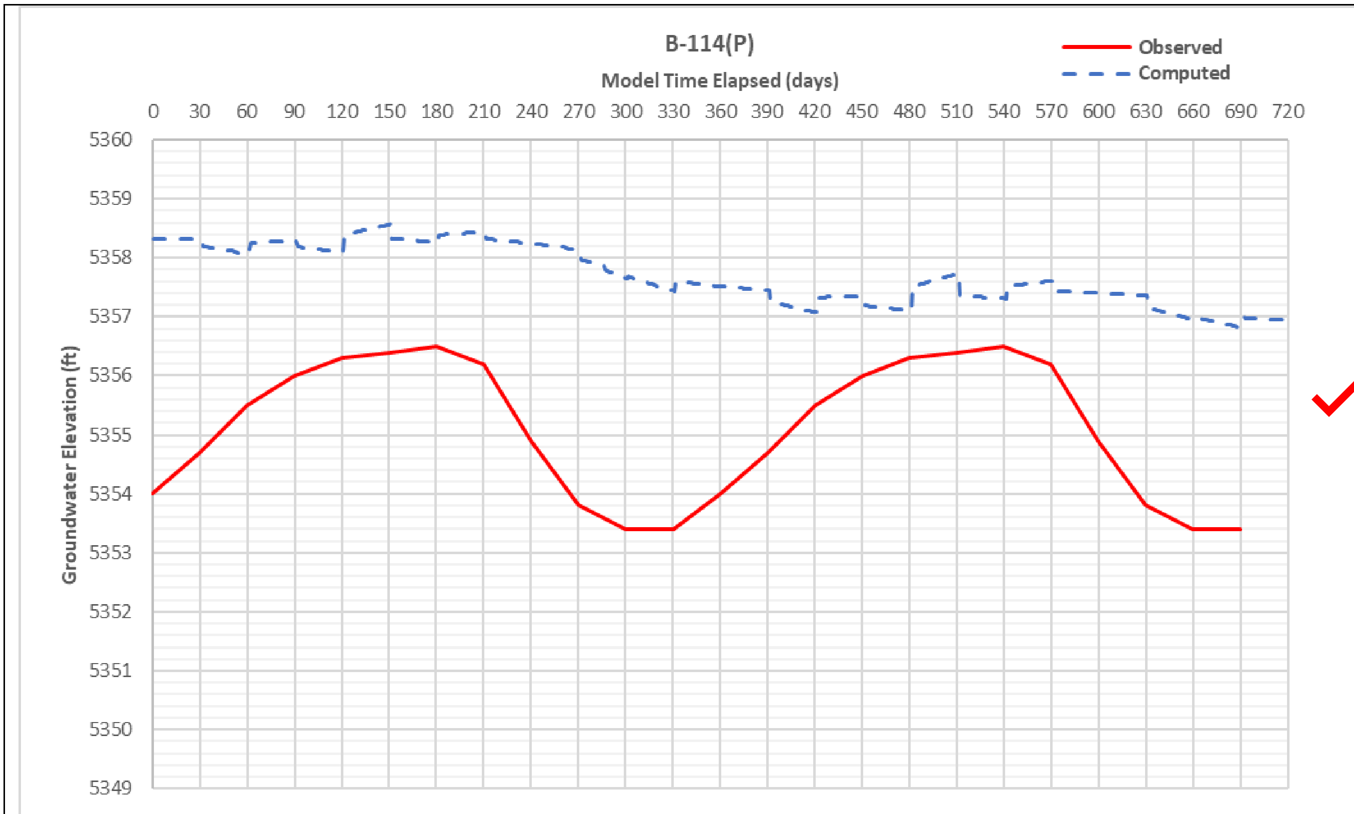
4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7
Drawdown (ft)


B-114(P)
Model Time Elapsed (days)
Observed
Computed
Groundwater Elevation (ft)
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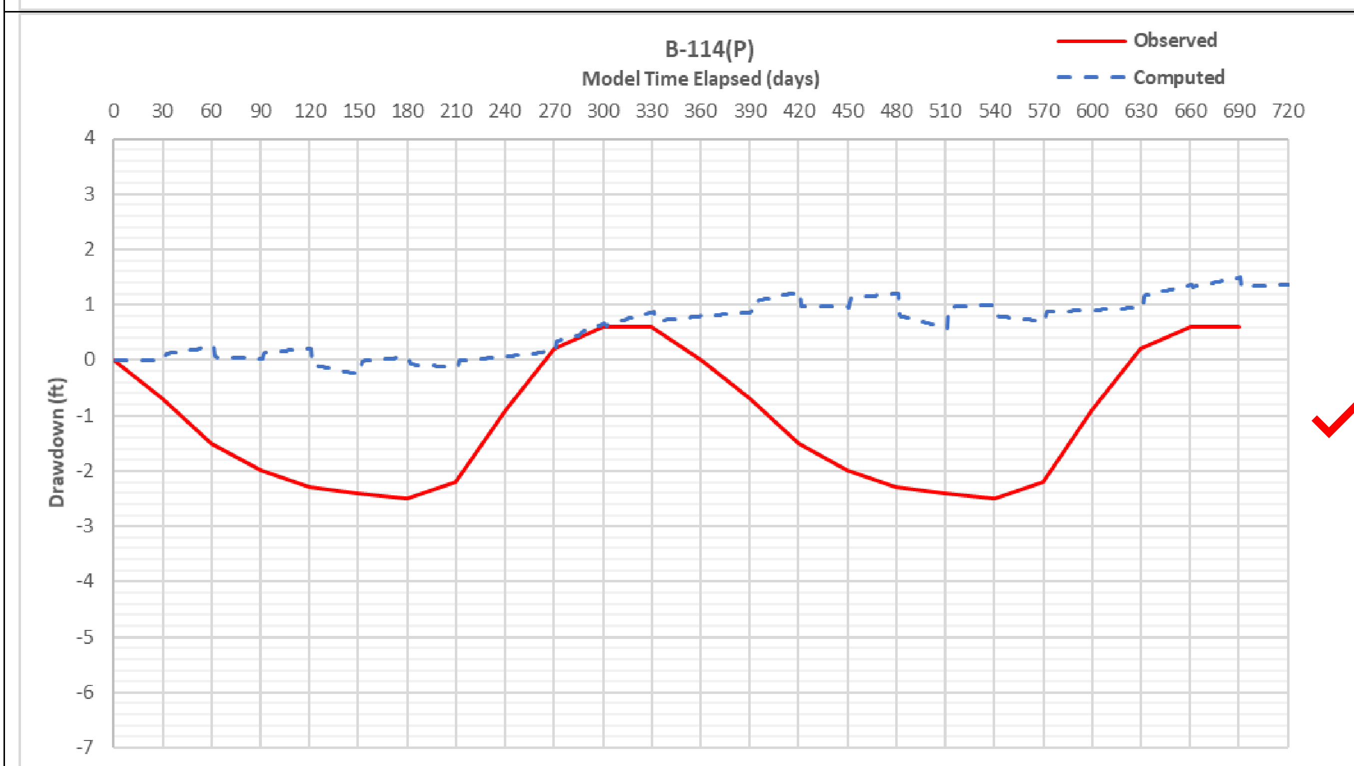
5360 5359 5358 5357 5356 5355 5354 5353 5352 5351 5350 5349


B-114(P)
Model Time Elapsed (days)
Observed
Computed
Drawdown (ft)
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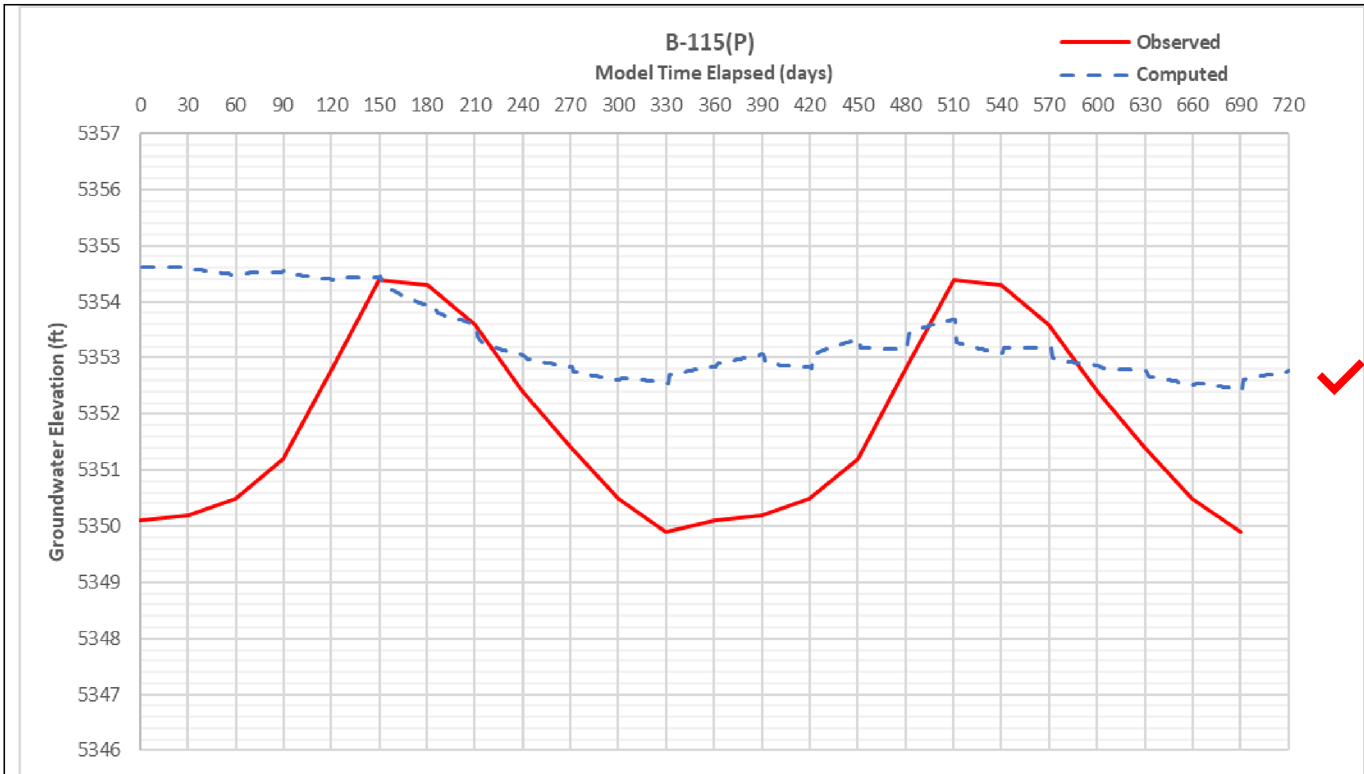
4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7



B-115(P)
Model Time Elapsed (days)
Observed
Computed
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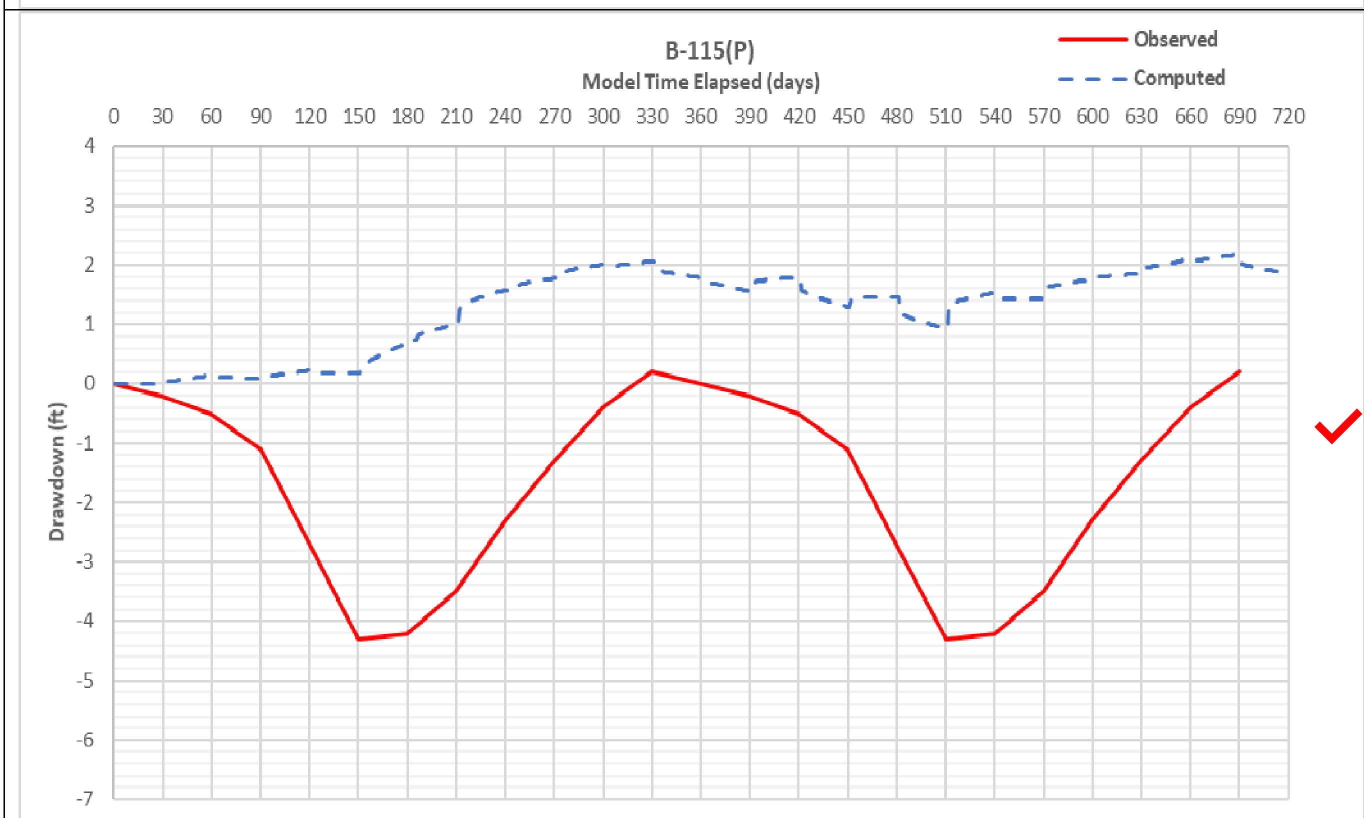
Groundwater Elevation (ft)



B-115(P)
Model Time Elapsed (days)
Observed
Computed
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4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7
Drawdown (ft)

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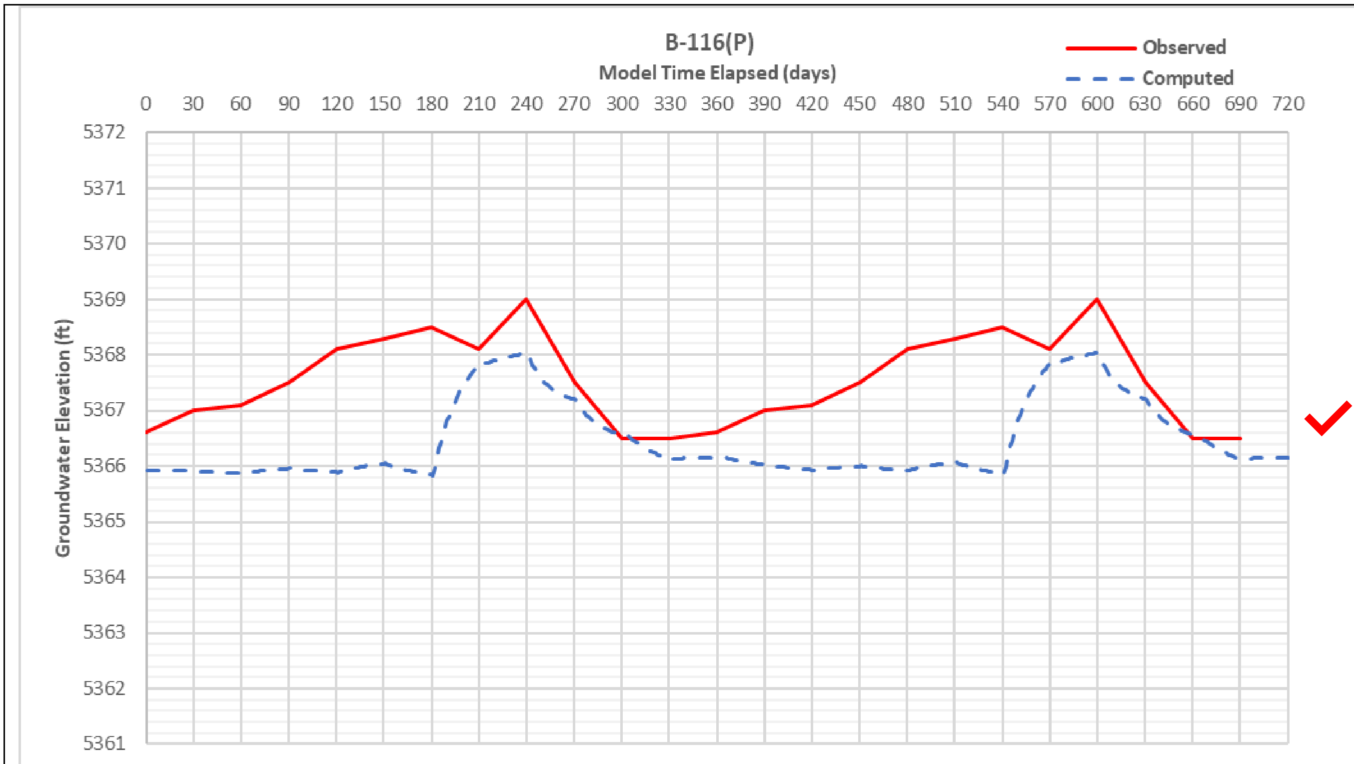

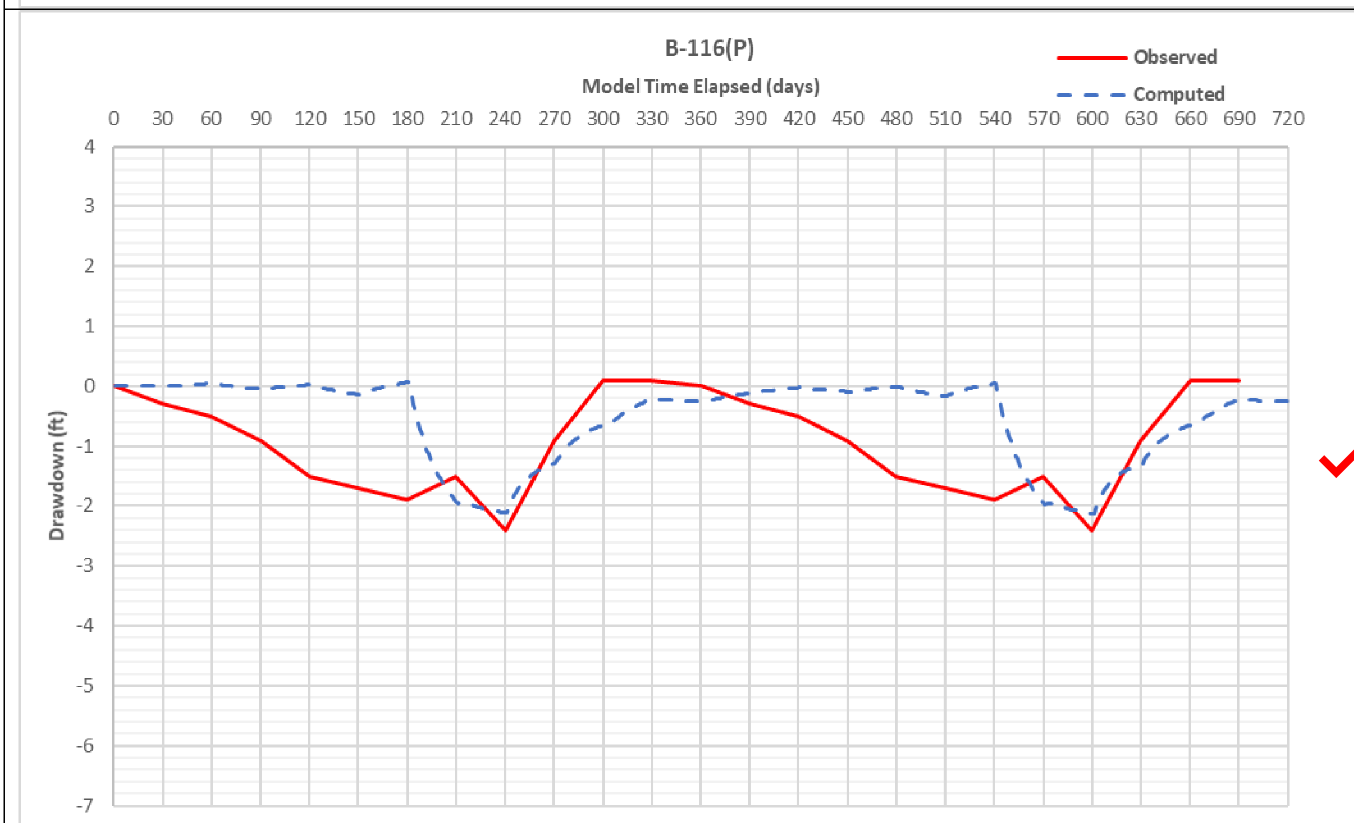

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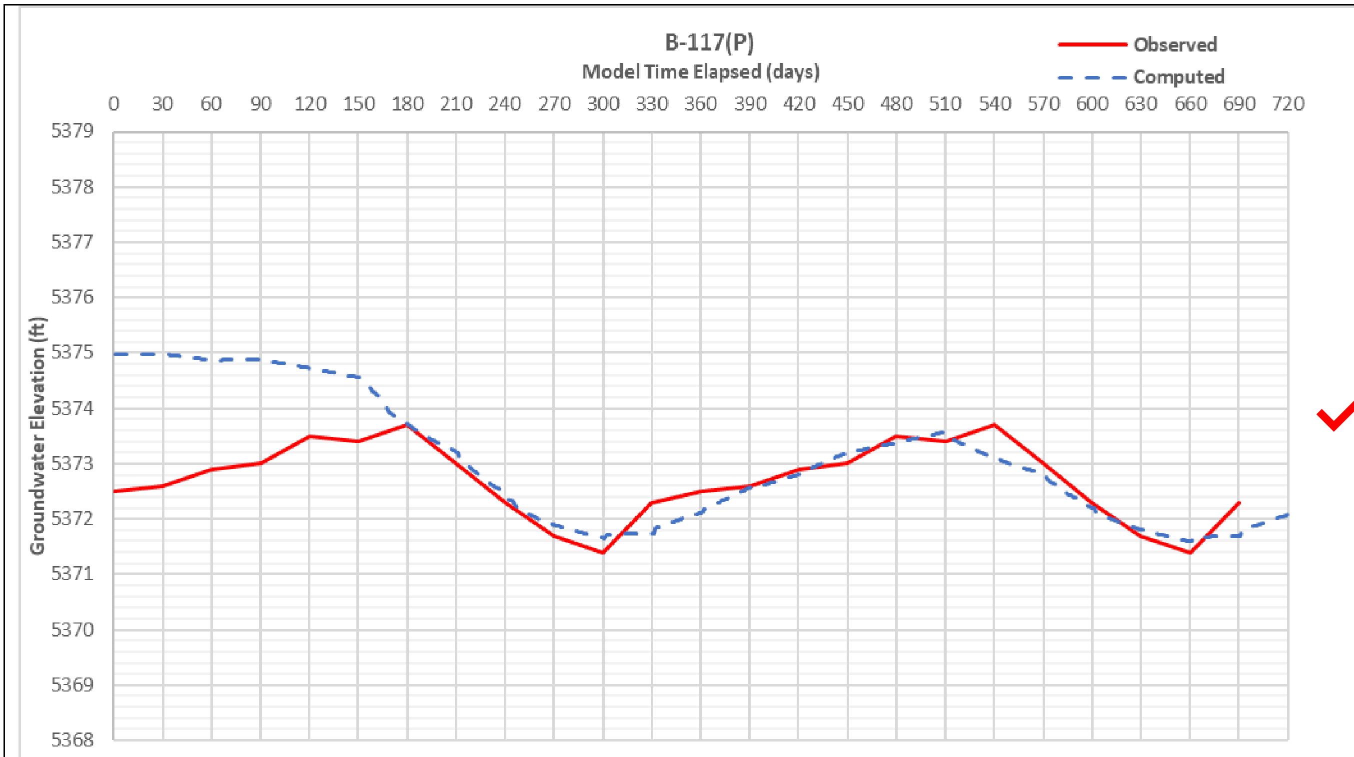
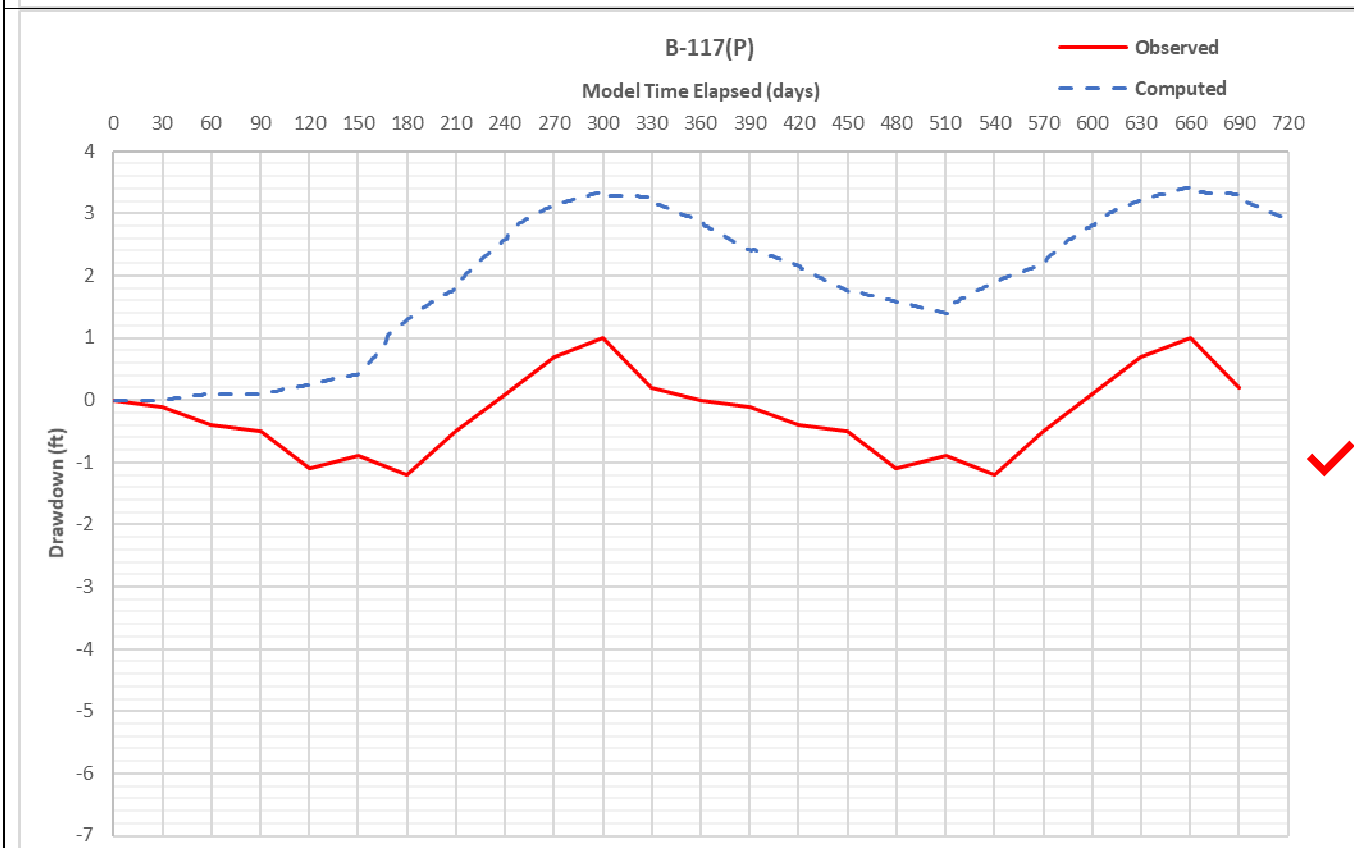
Approved	10/16/20	By	ABP

Client City of Boulder

Subject Well Results





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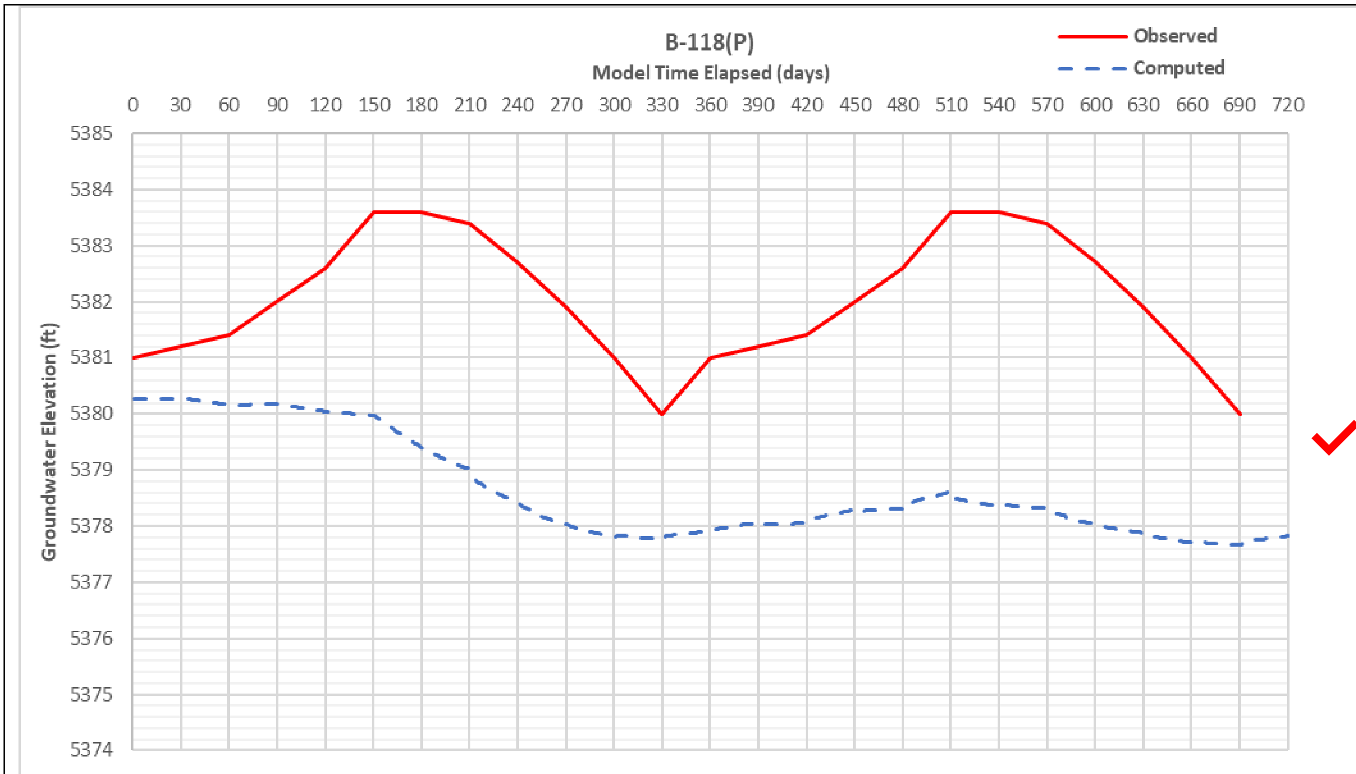
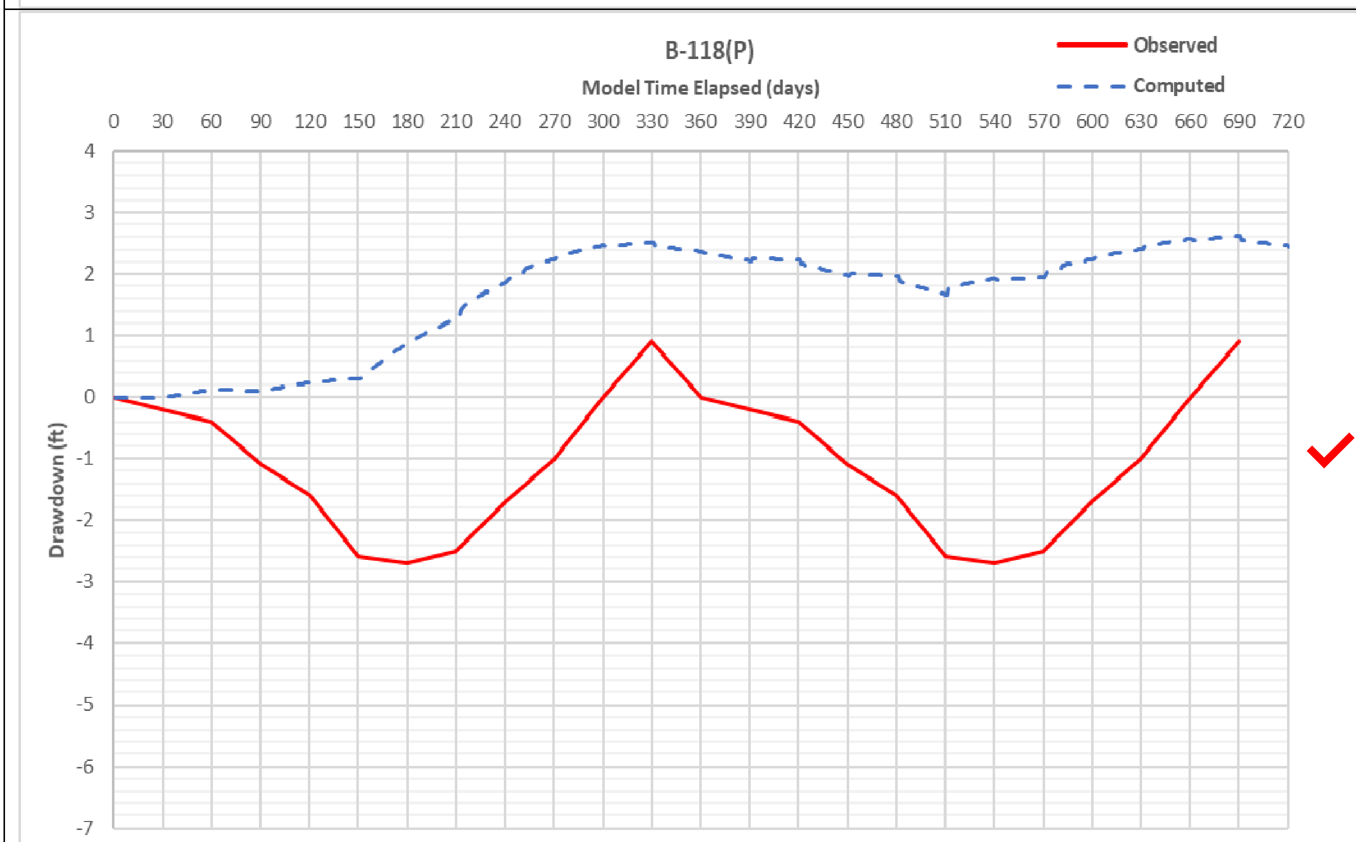
Approved	10/16/20	By	ABP

Client City of Boulder

Subject Well Results





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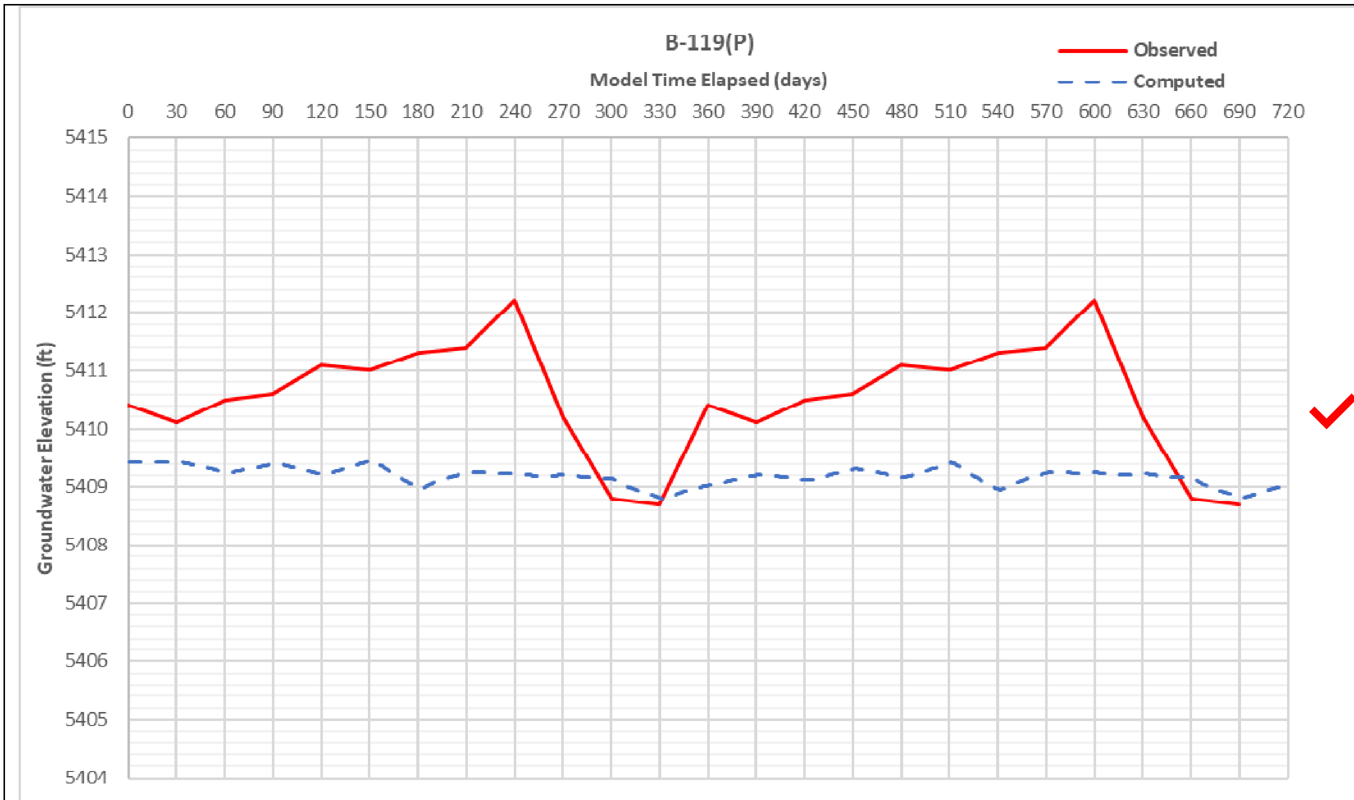

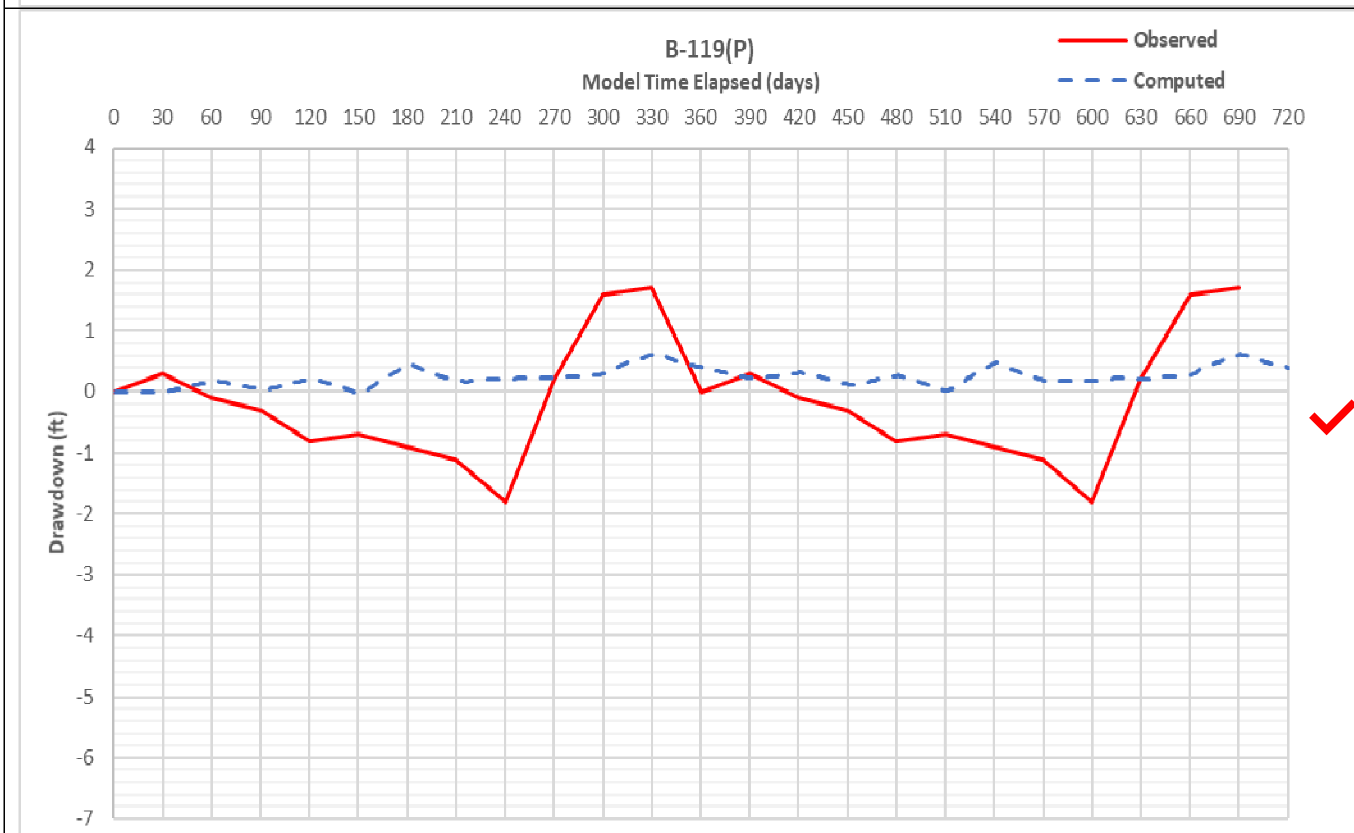

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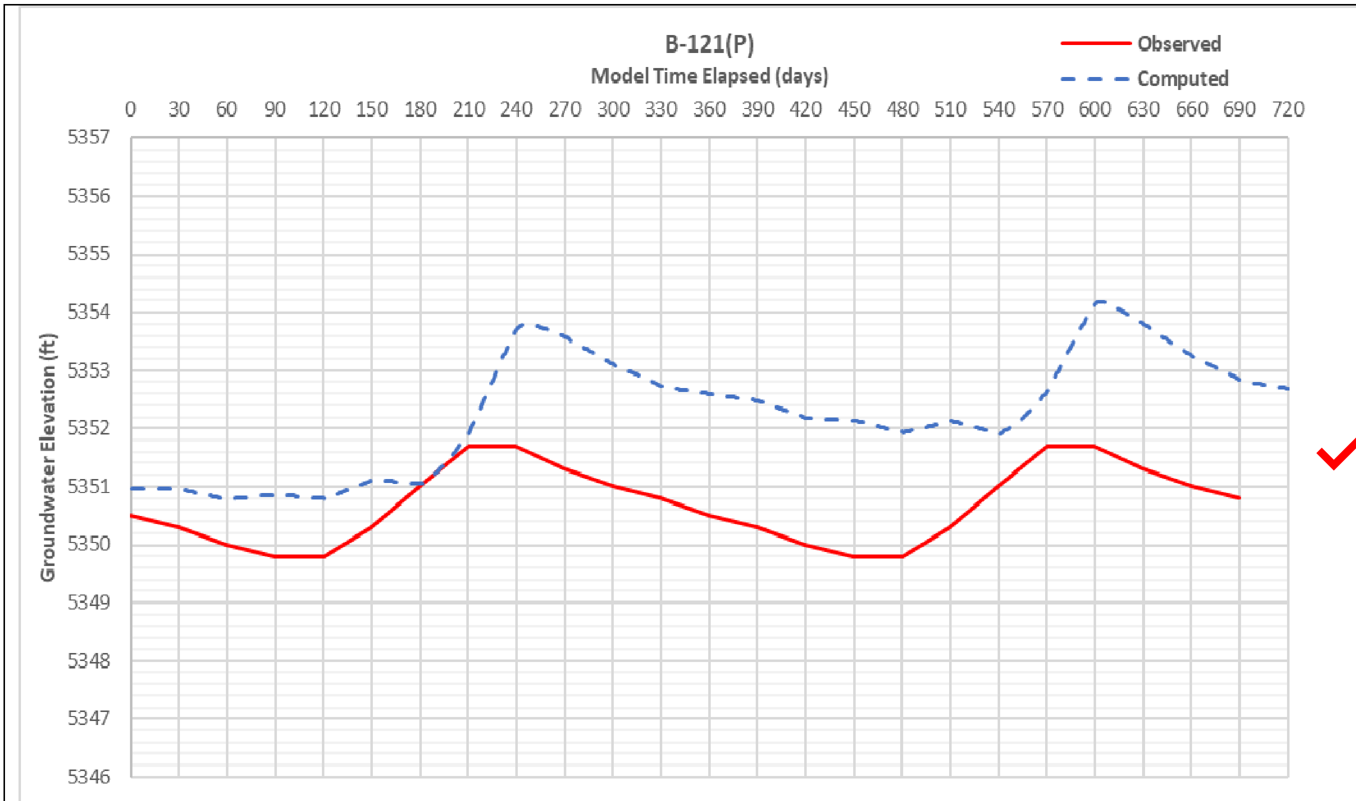
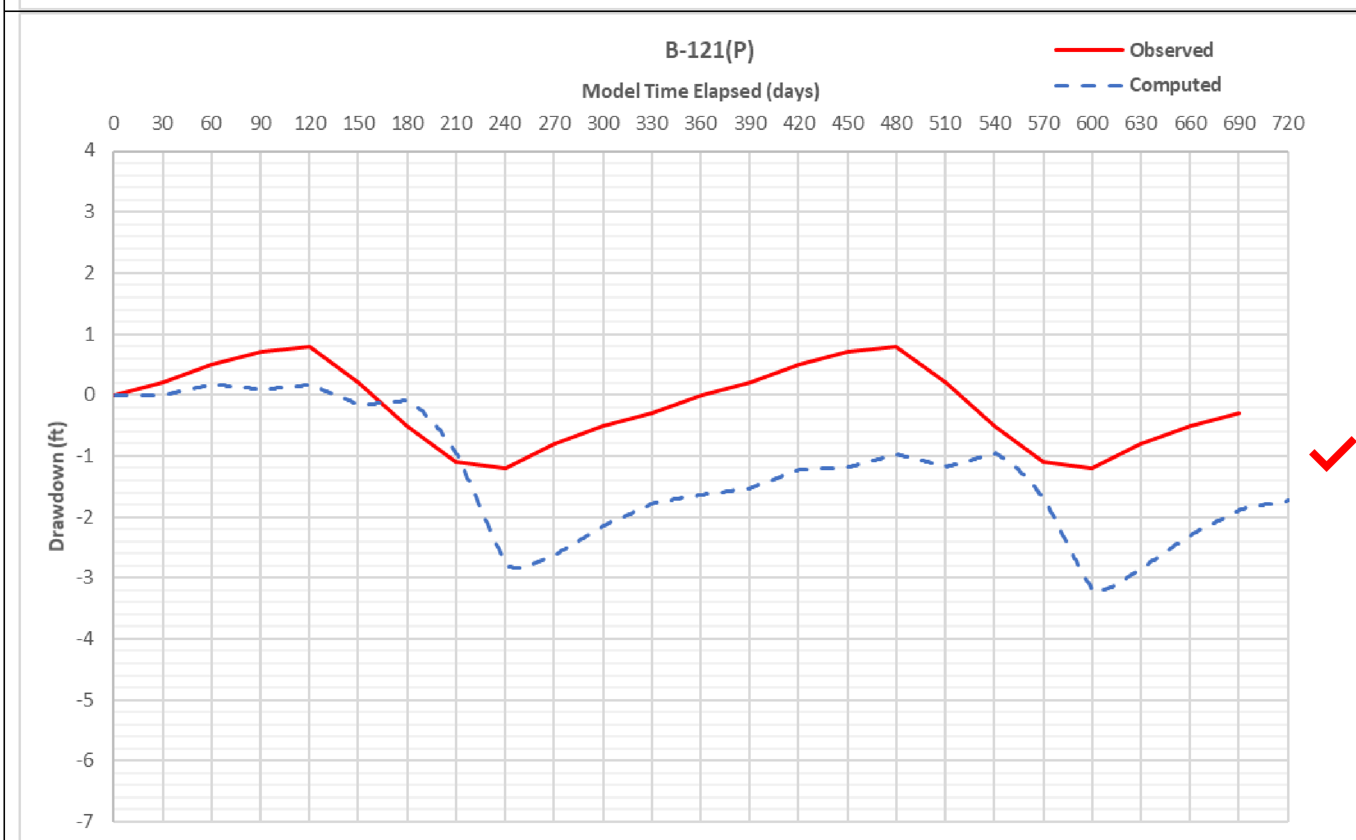
Approved	10/16/20	By	ABP

RJH CONSULTANTS, INC.

Client City of Boulder

Subject Well Results





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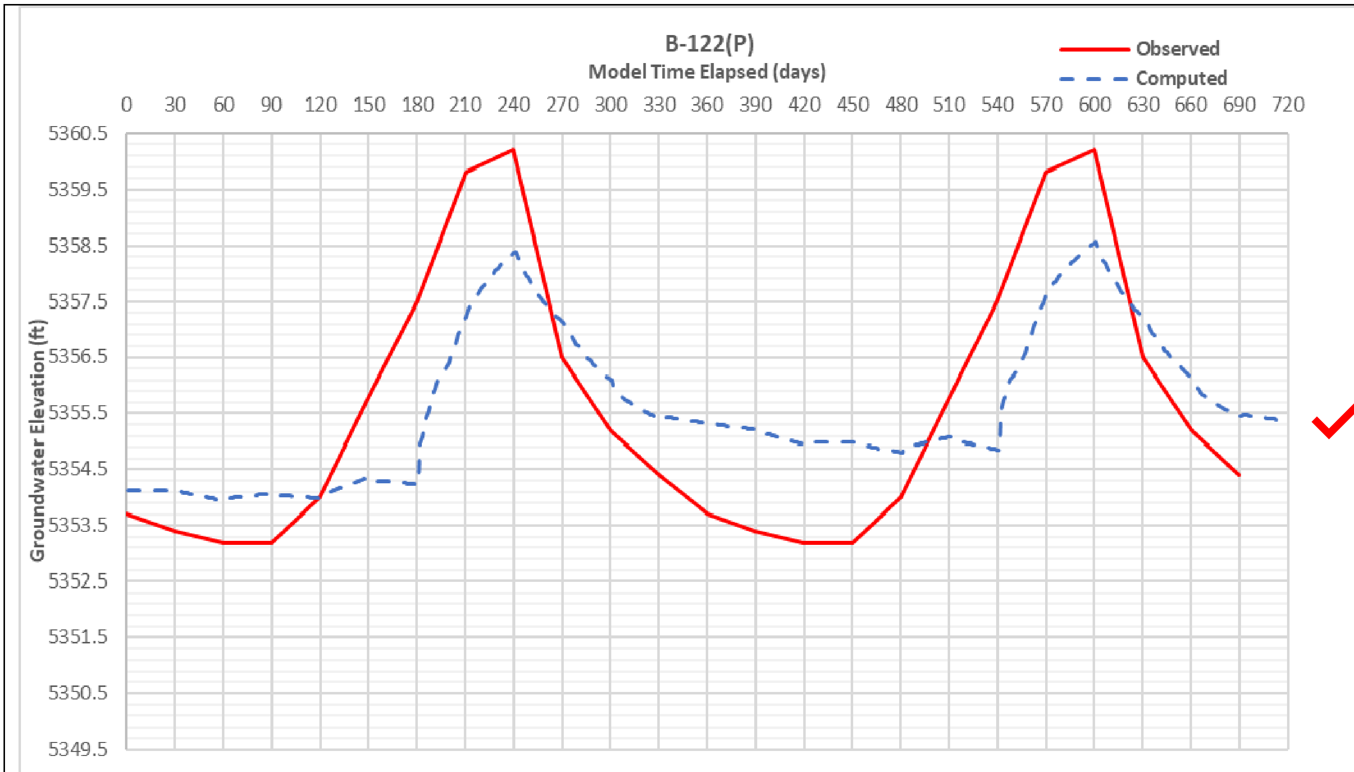
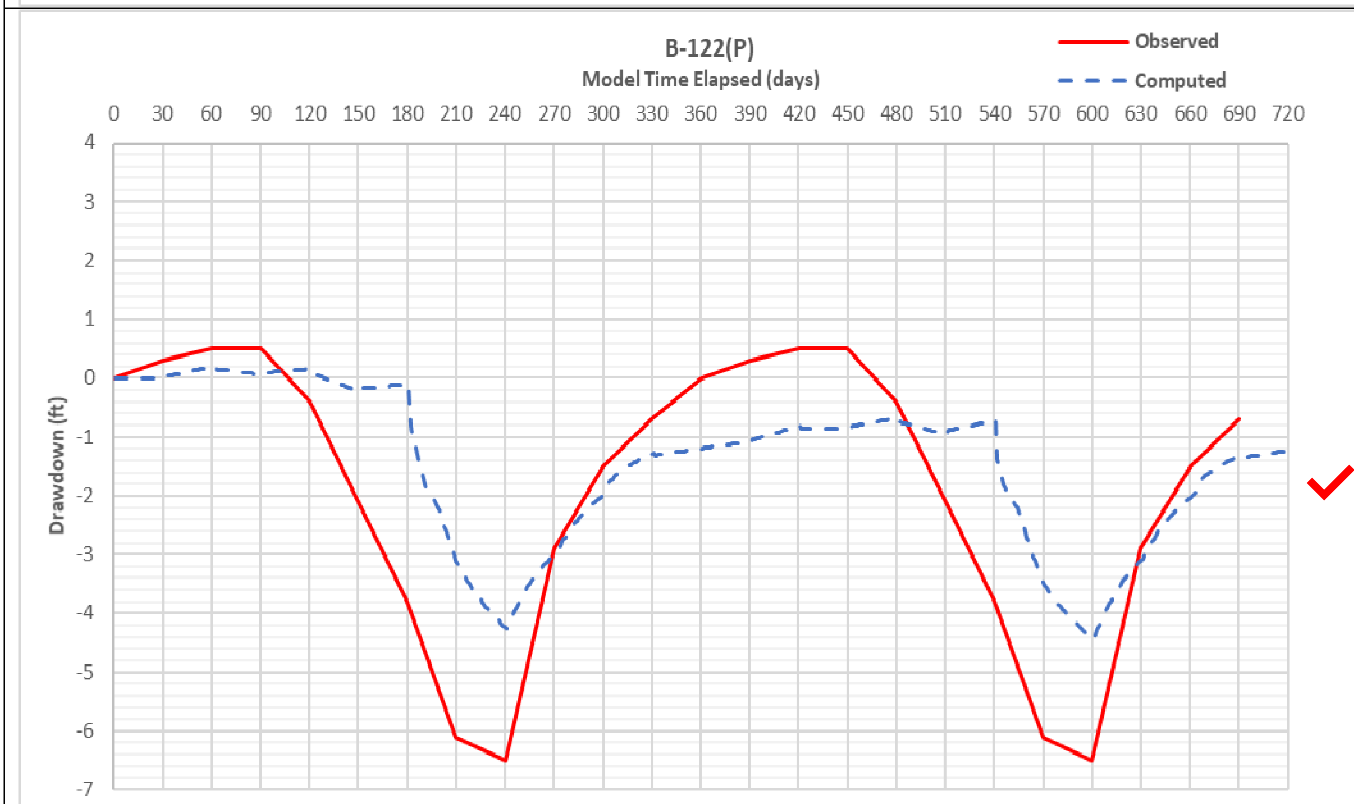
Date	10/11/2020	By	ATMerook
Checked	10/16/2020	By	JNH
Approved	10/16/20	By	ABP

Client City of Boulder

Subject Well Results





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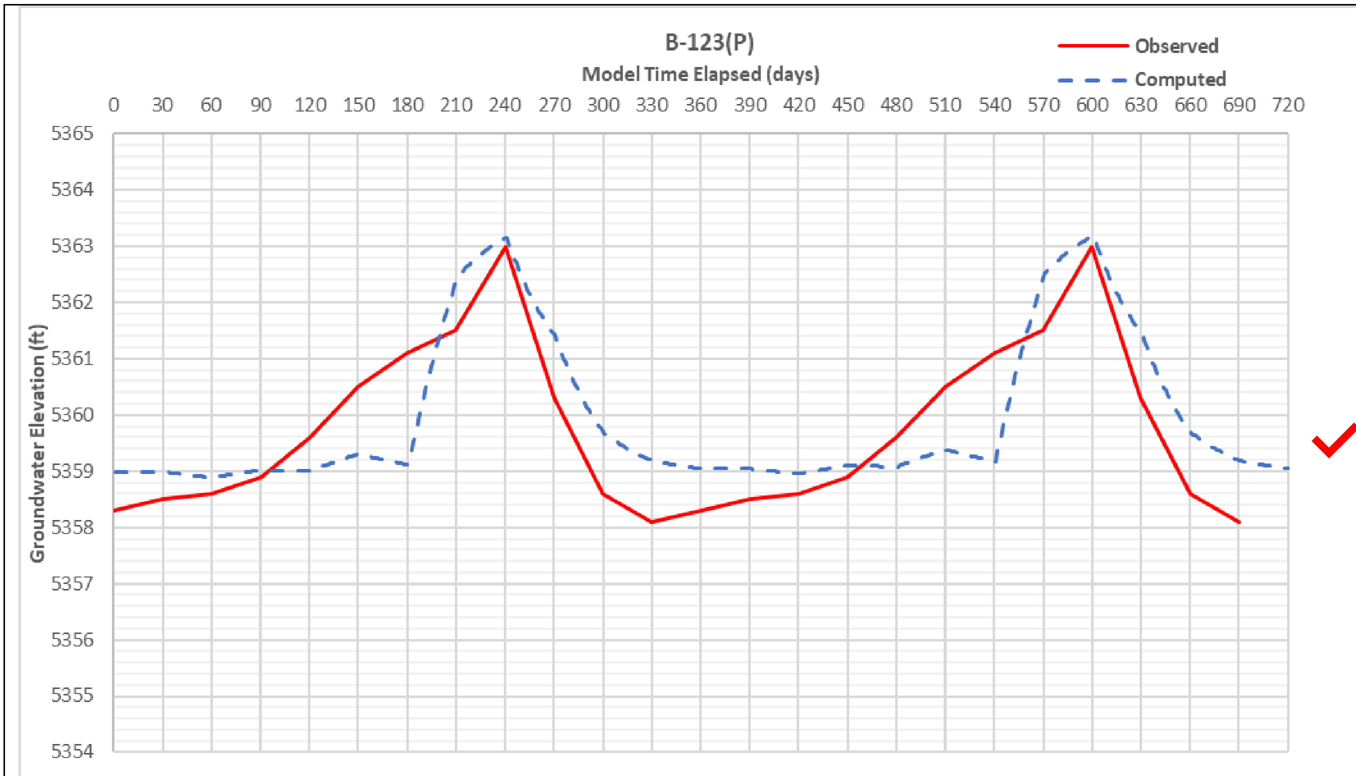
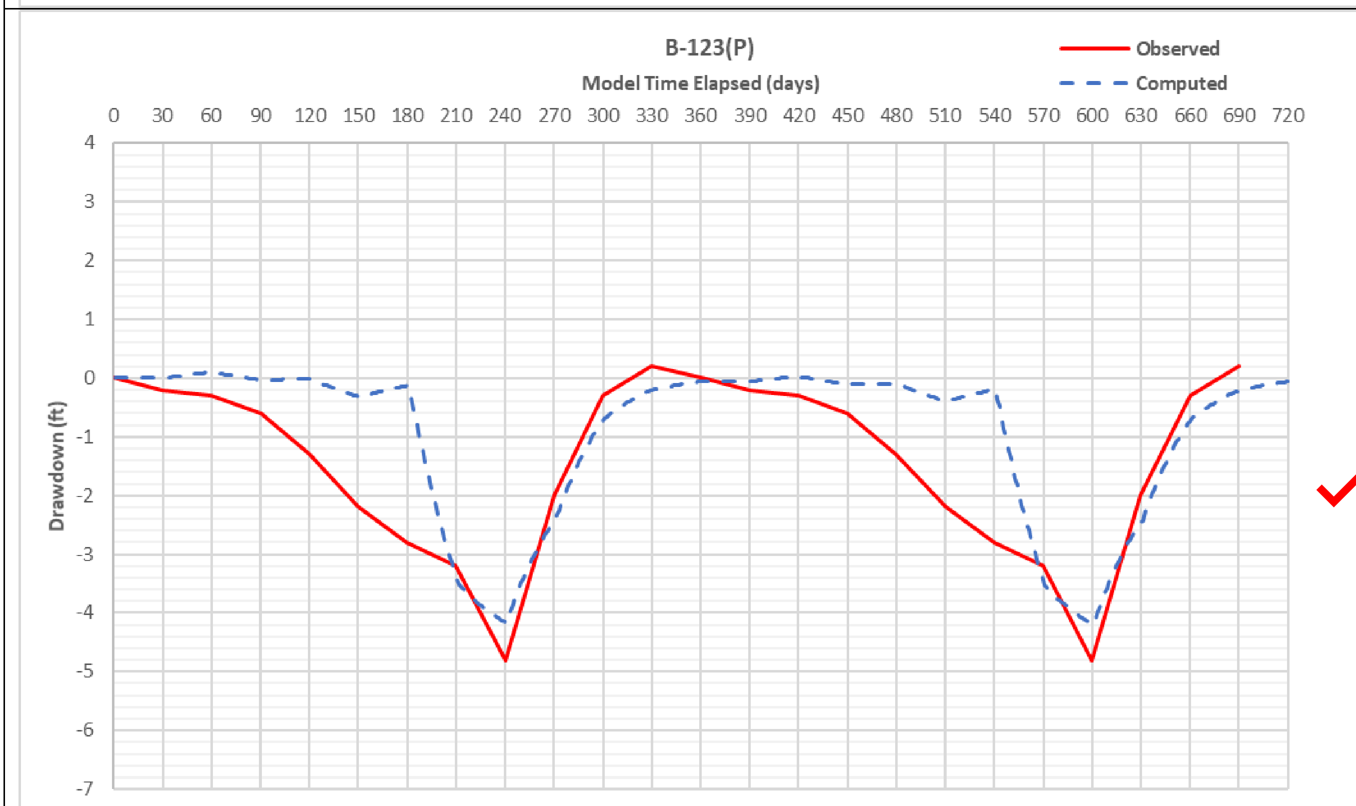
		Date	10/11/2020	By	ATMerook
Client	City of Boulder	Checked	10/16/2020	By	JNH
Subject	Well Results	Approved	10/16/20	By	ABP





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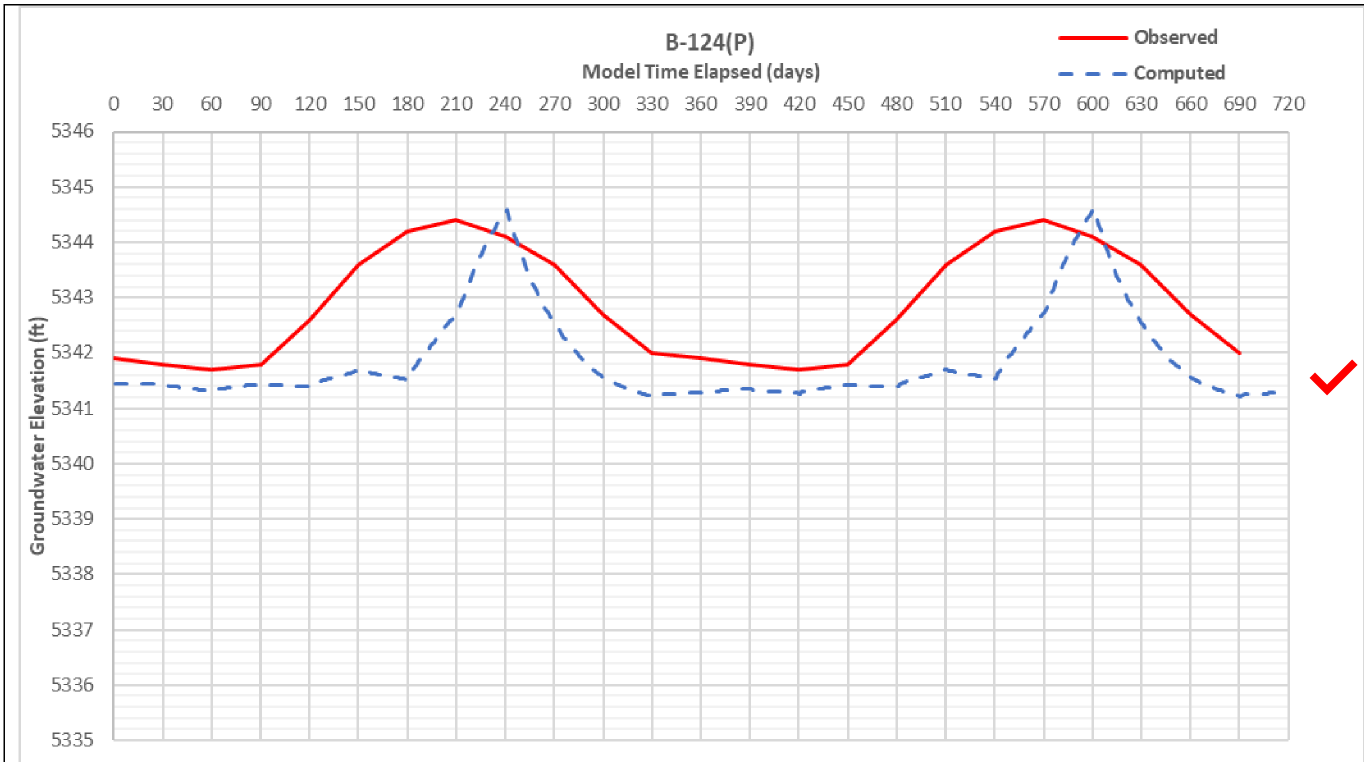
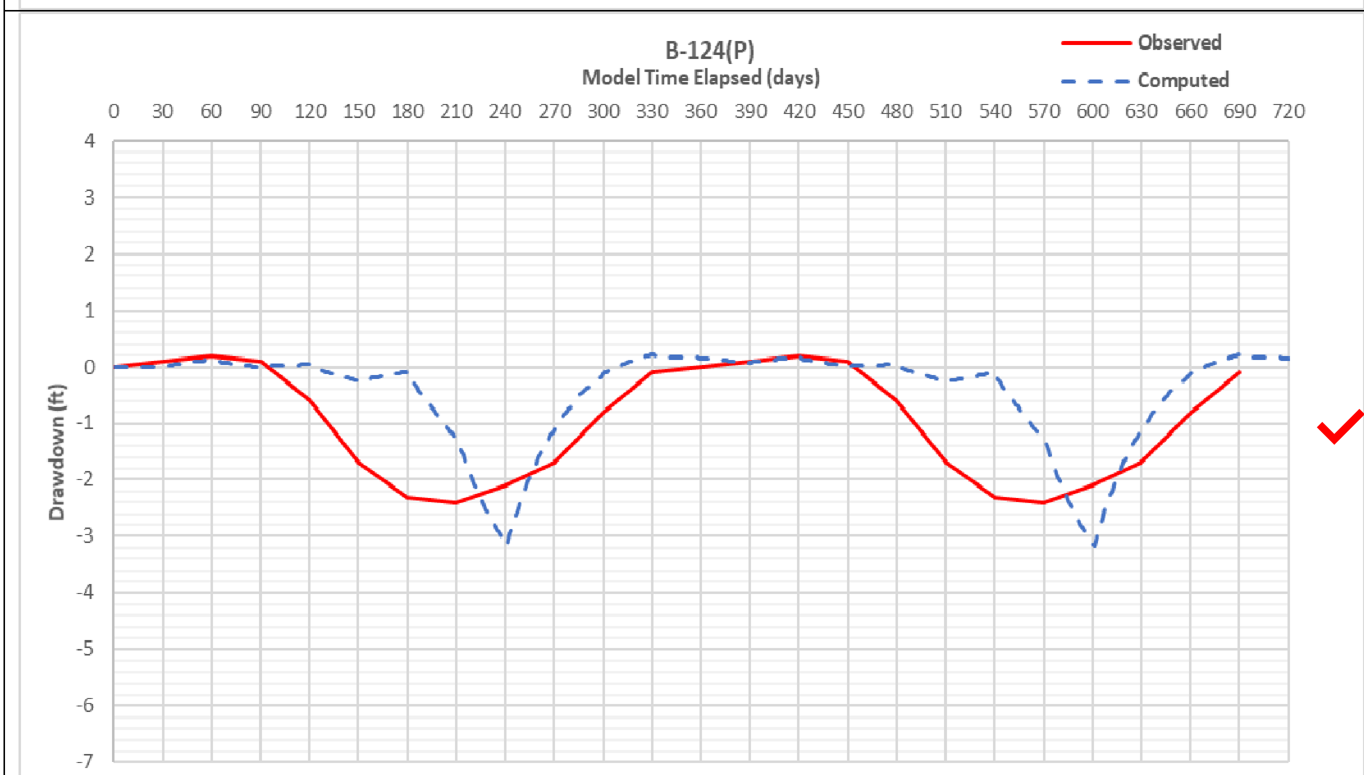
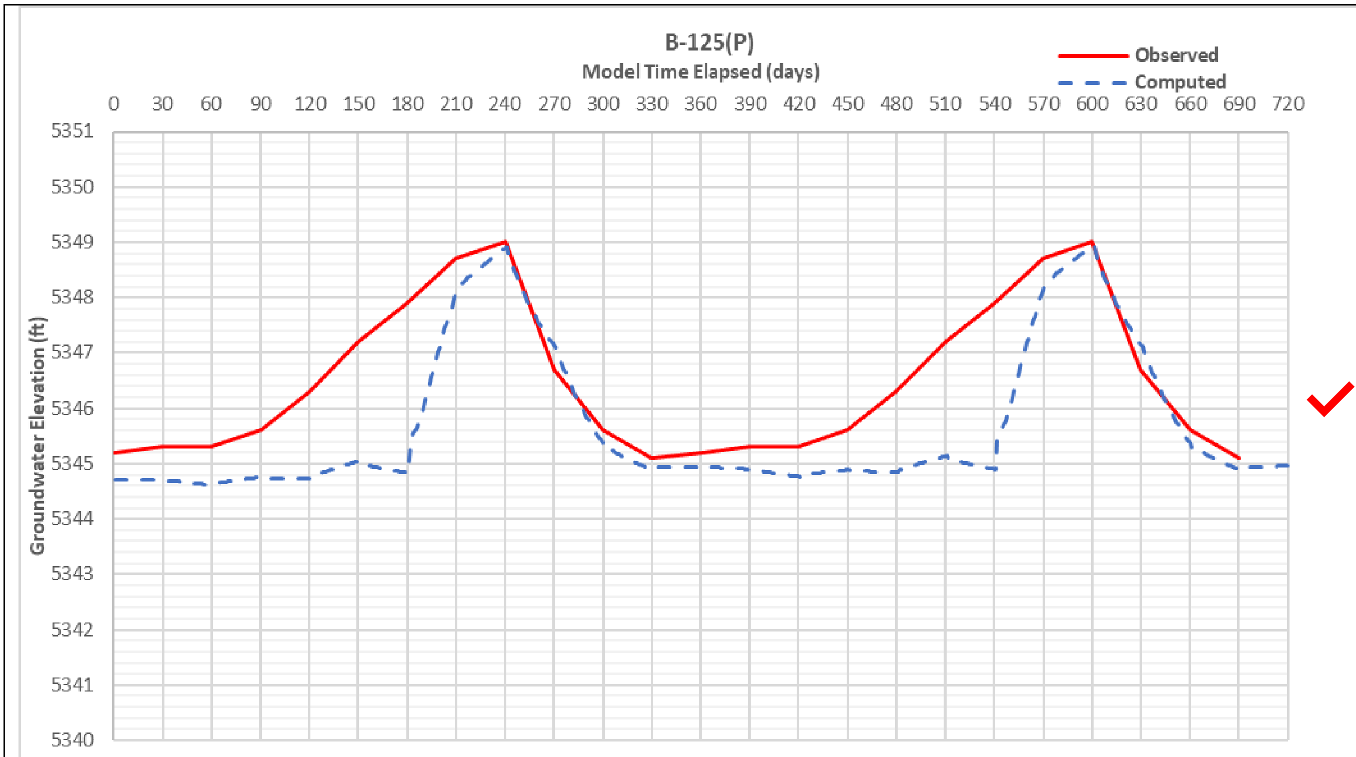
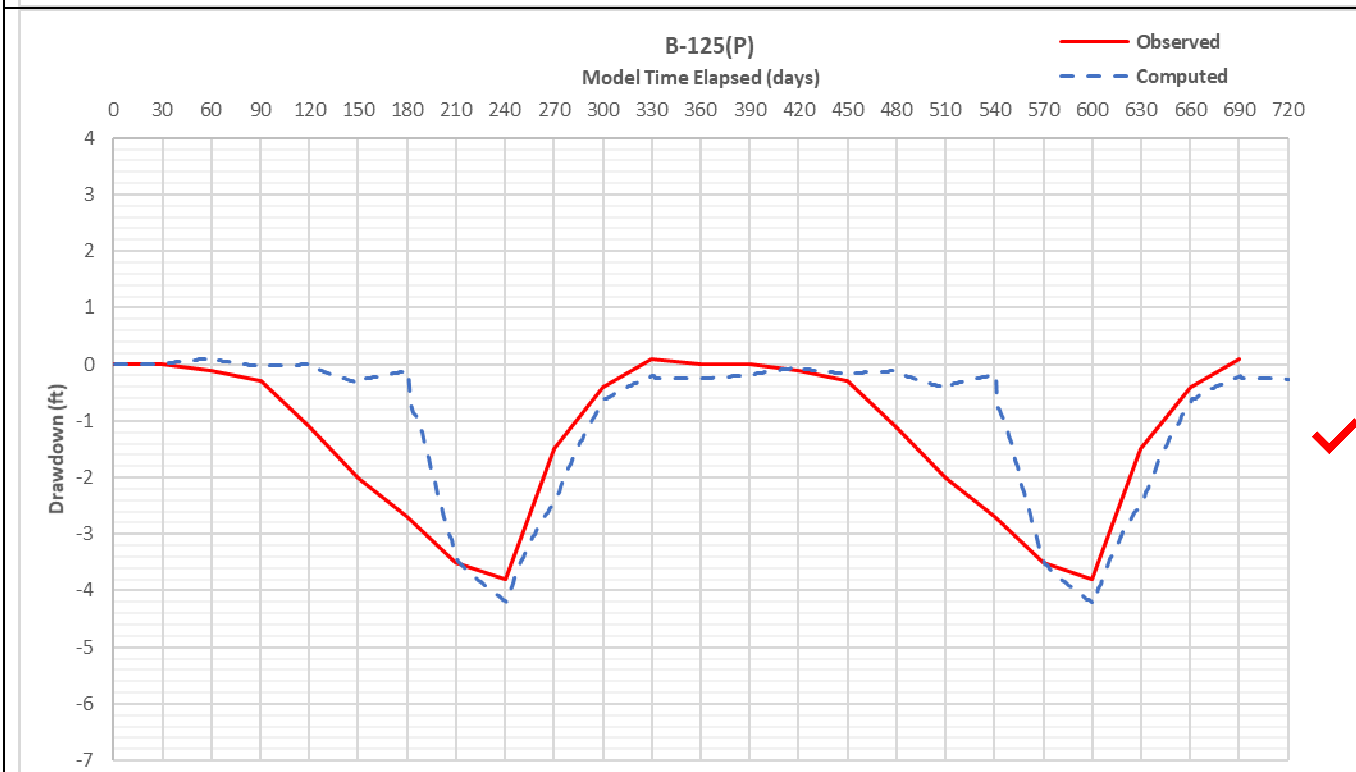
Client	City of Boulder	Checked	10/16/2020	By	JNH
Subject	Well Results	Approved	10/16/20	By	ABP







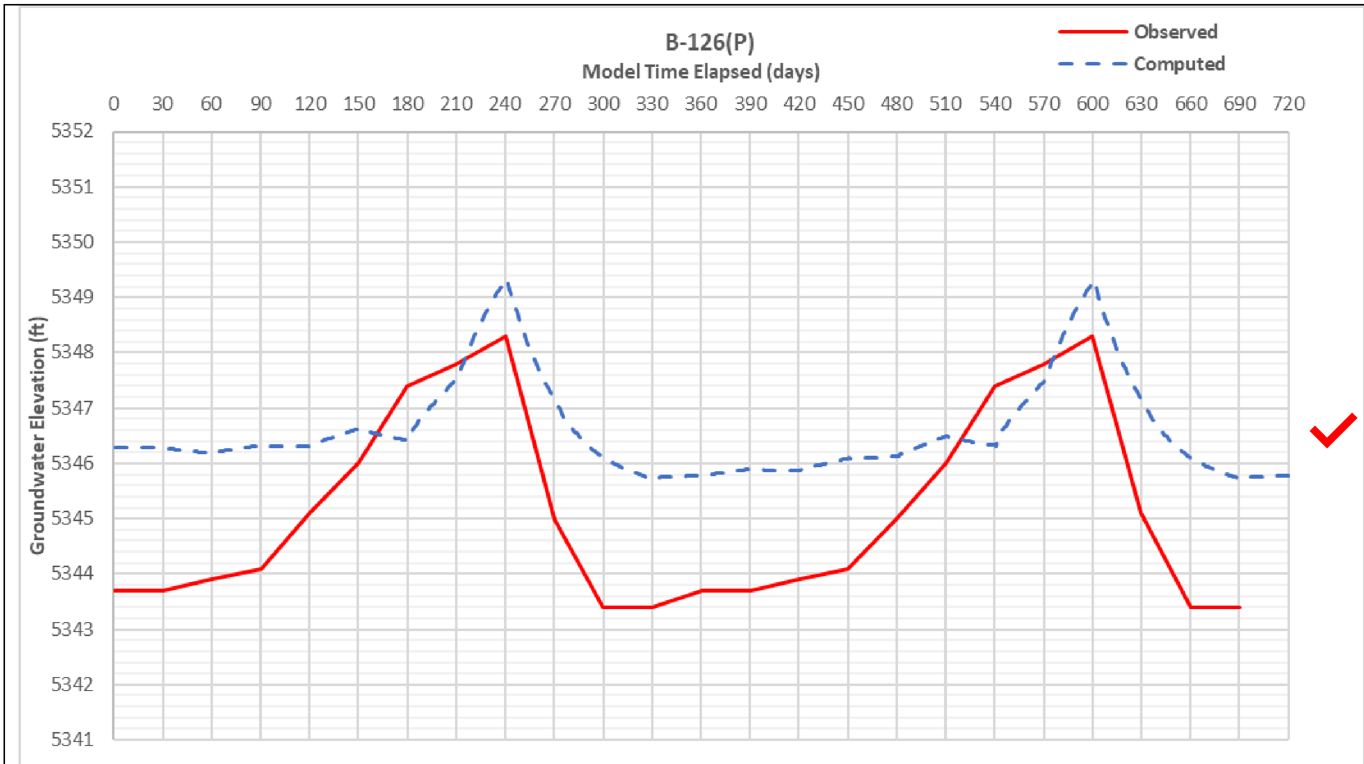
B-125(P)
Model Time Elapsed (days)
Observed
Computed
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
5351 5350 5349 5348 5347 5346 5345 5344 5343 5342 5341 5340
Groundwater Elevation (ft)

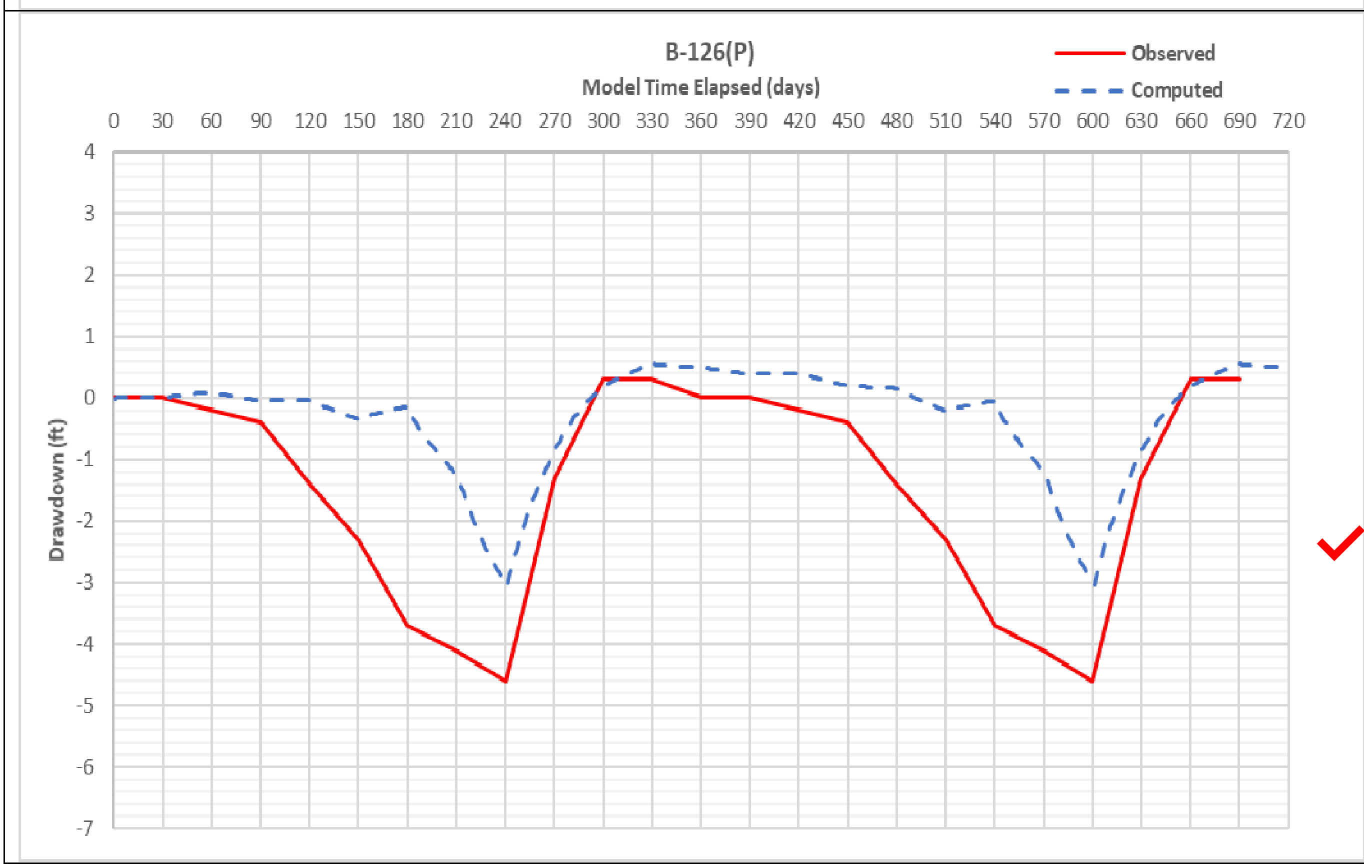


B-125(P)
Model Time Elapsed (days)
Observed
Computed
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7
Drawdown (ft)

Client City of Boulder

Subject Well Results





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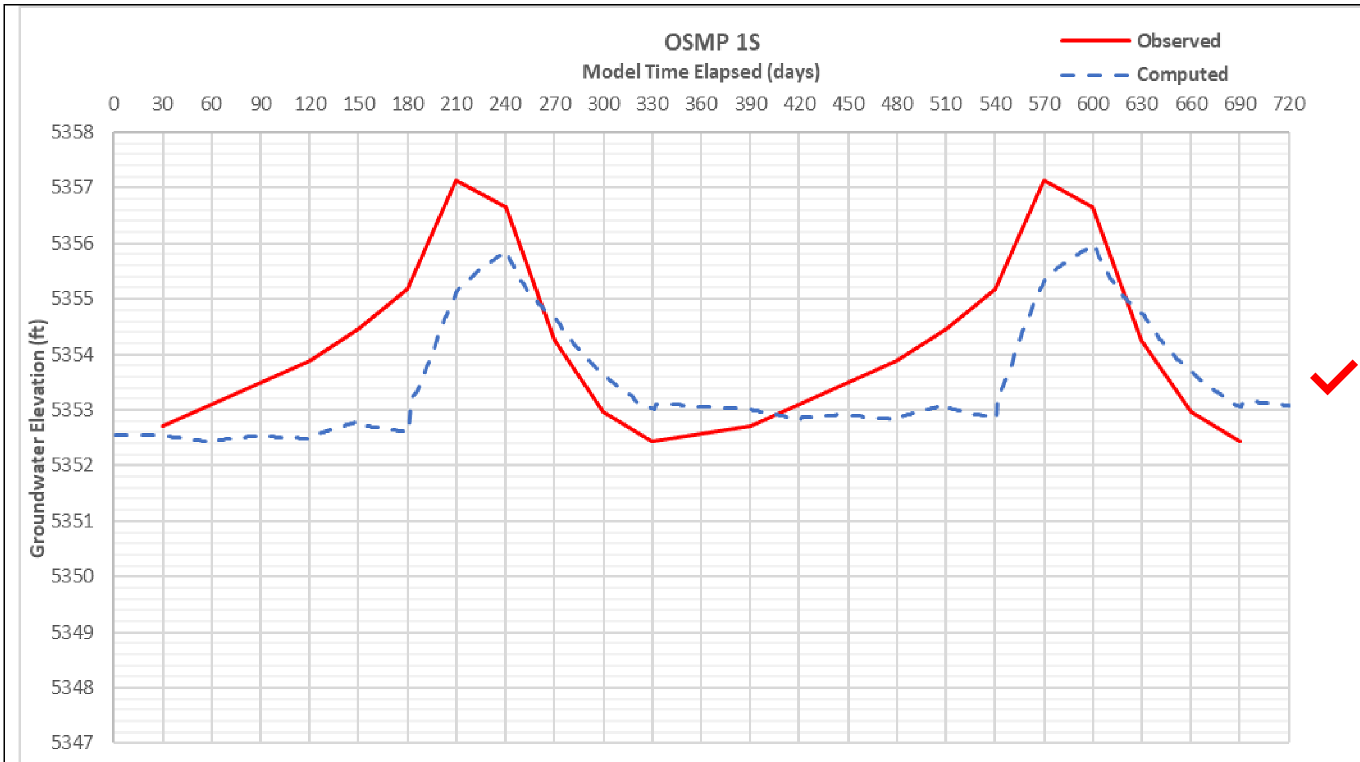
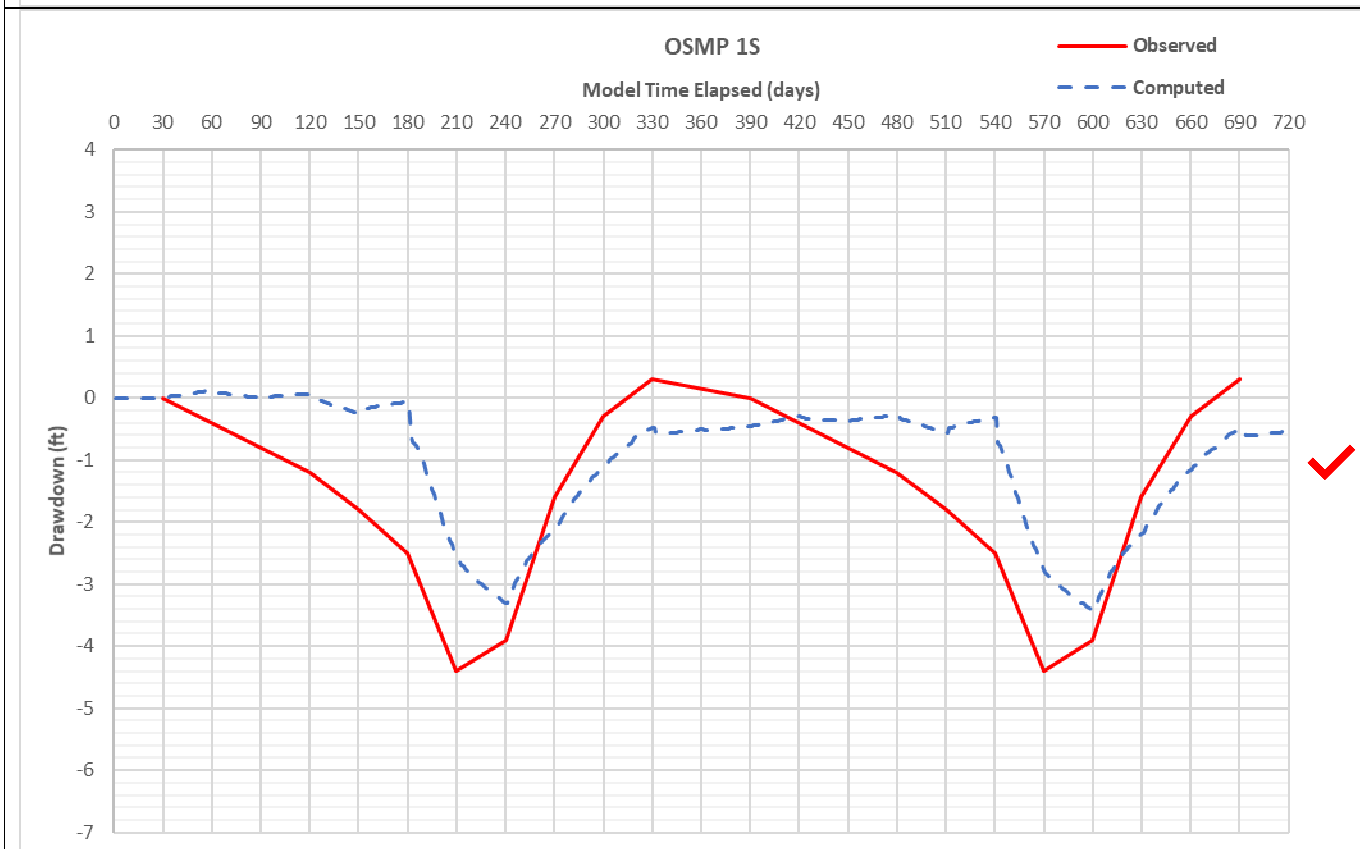
		Date	10/11/2020	By	ATMerook
Client	City of Boulder	Checked	10/16/2020	By	JNH
Subject	Well Results	Approved	10/16/20	By	ABP





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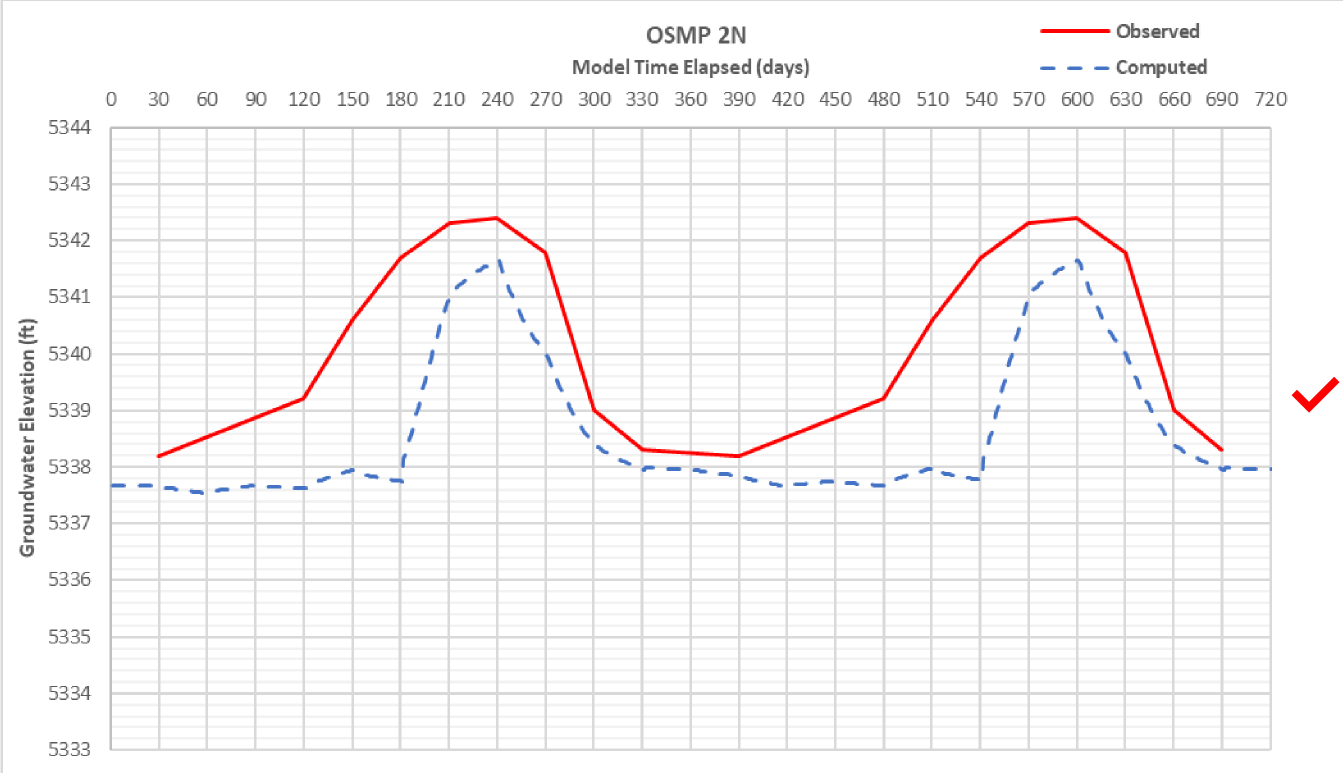
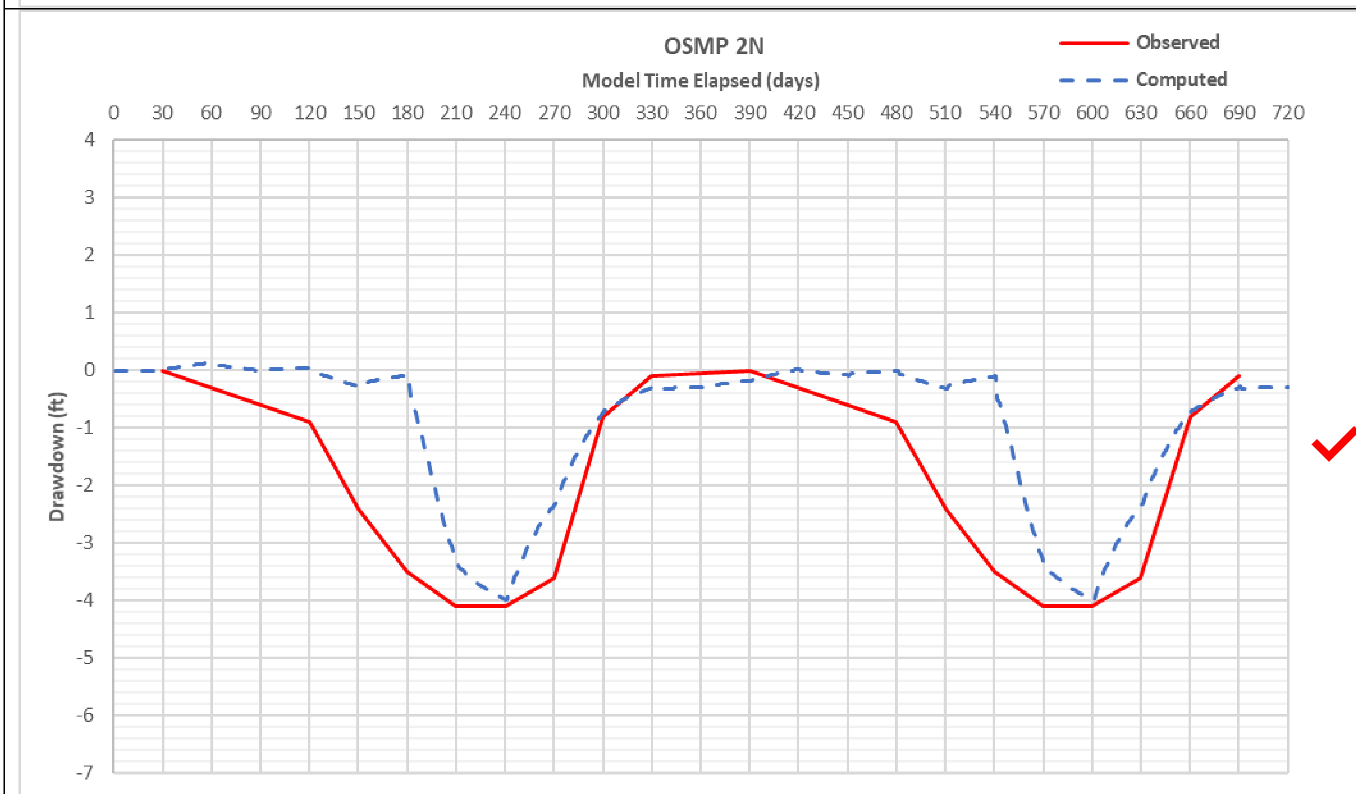
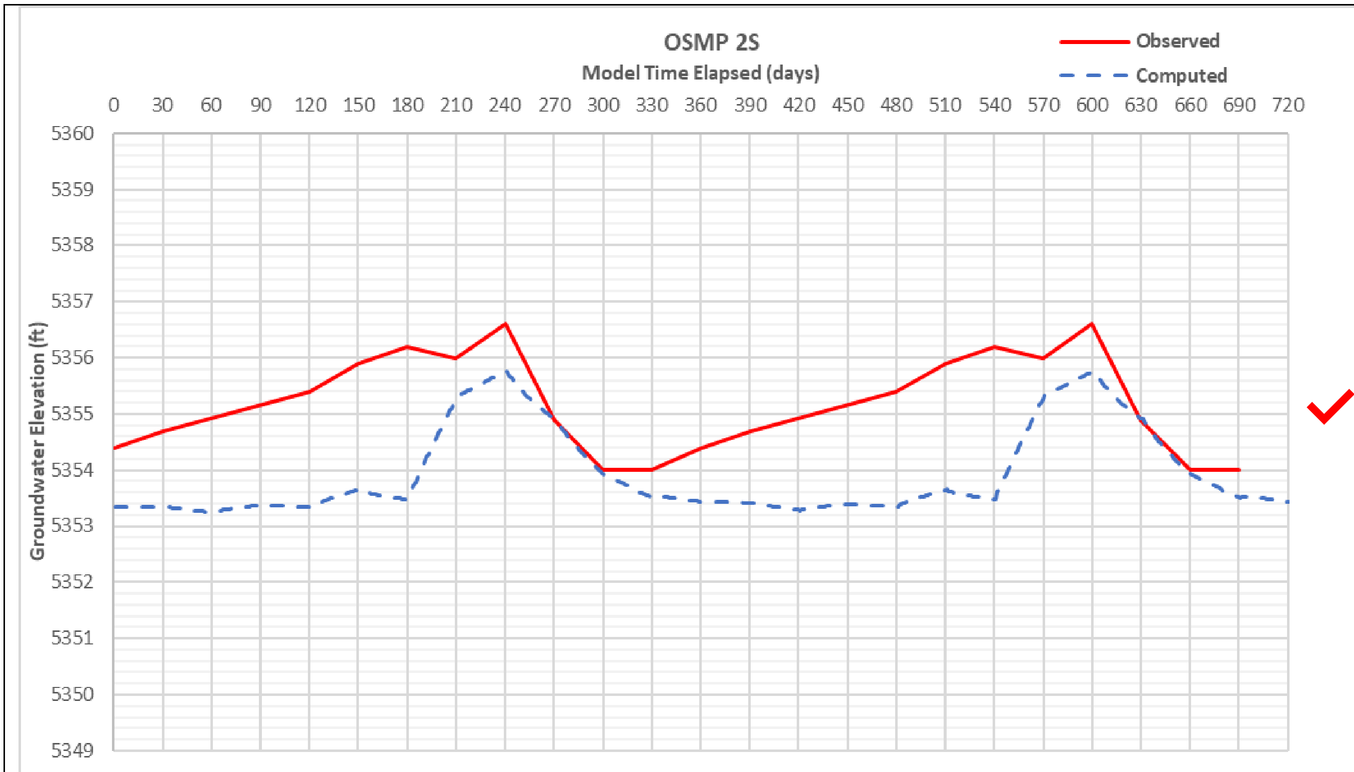
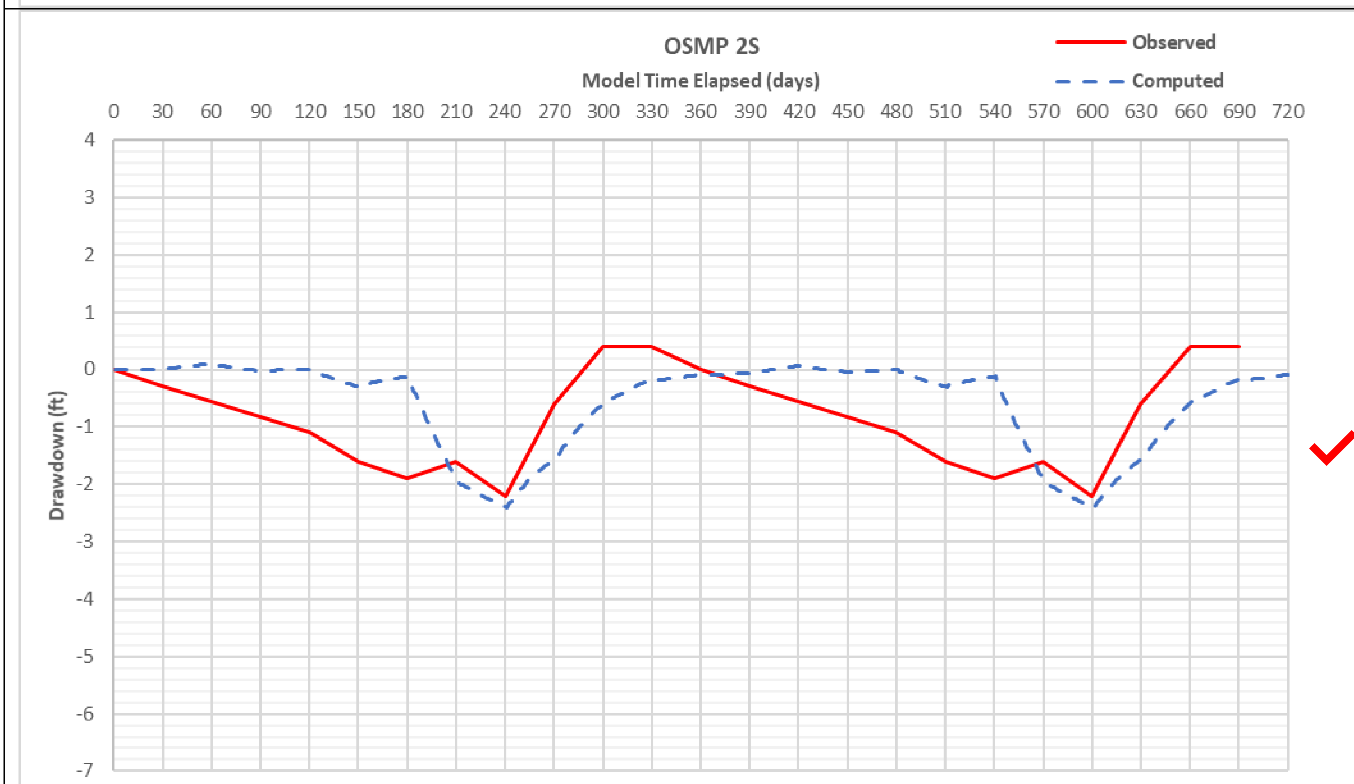
Client	City of Boulder	Checked	10/16/2020	By	JNH
Subject	Well Results	Approved	10/16/20	By	ABP





	Project	16134	Page	28/33
	Date	10/11/2020	By	ATMerook
Client: City of Boulder	Checked	10/16/2020	By	JNH
Subject: Well Results	Approved	10/16/20	By	ABP

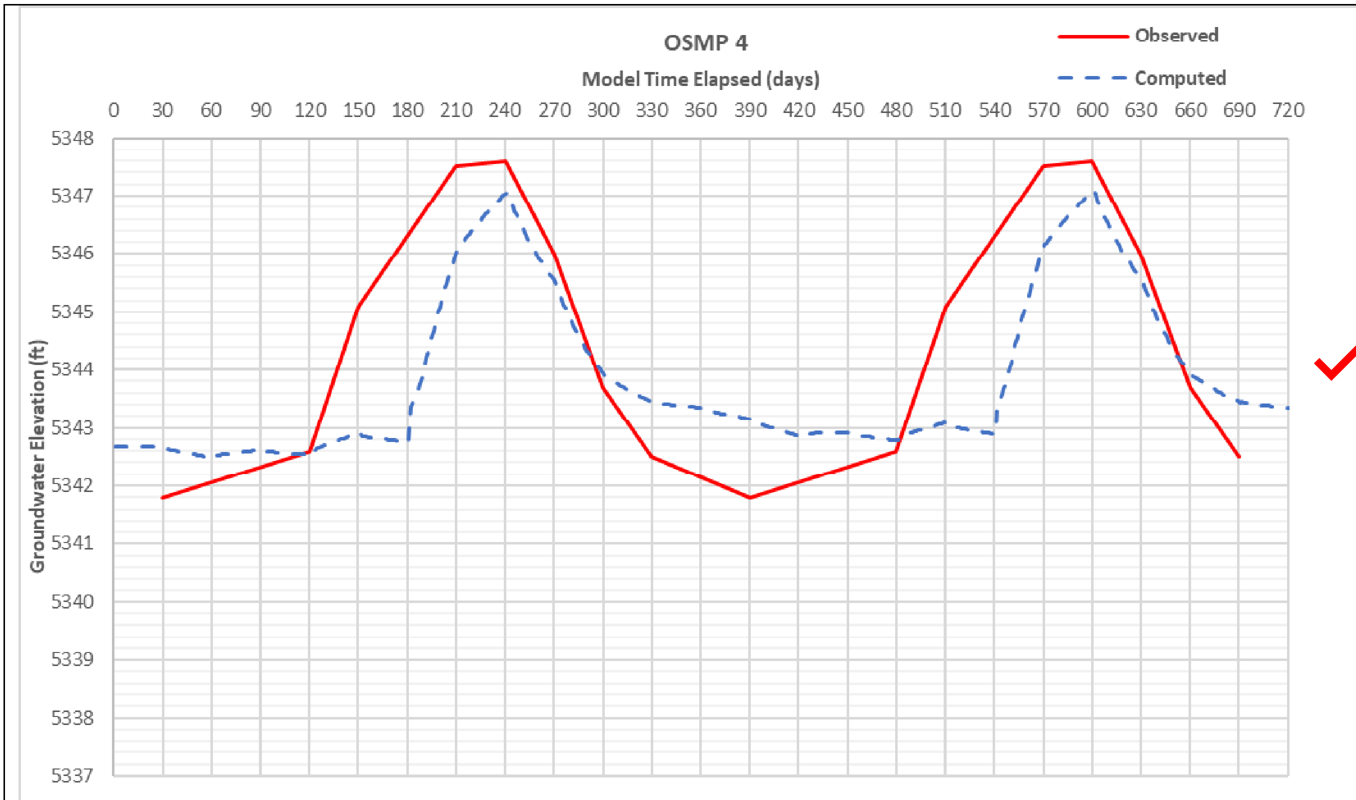


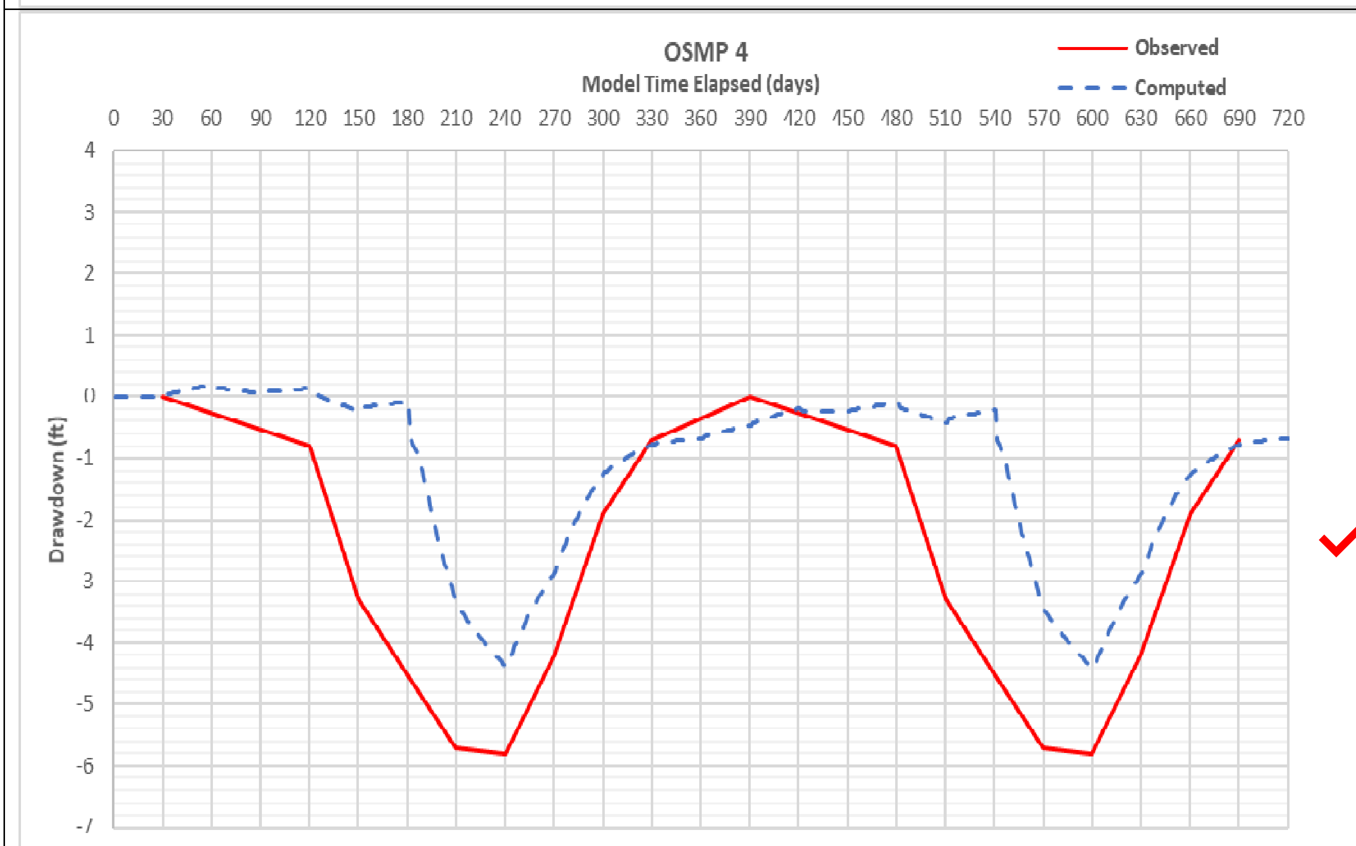


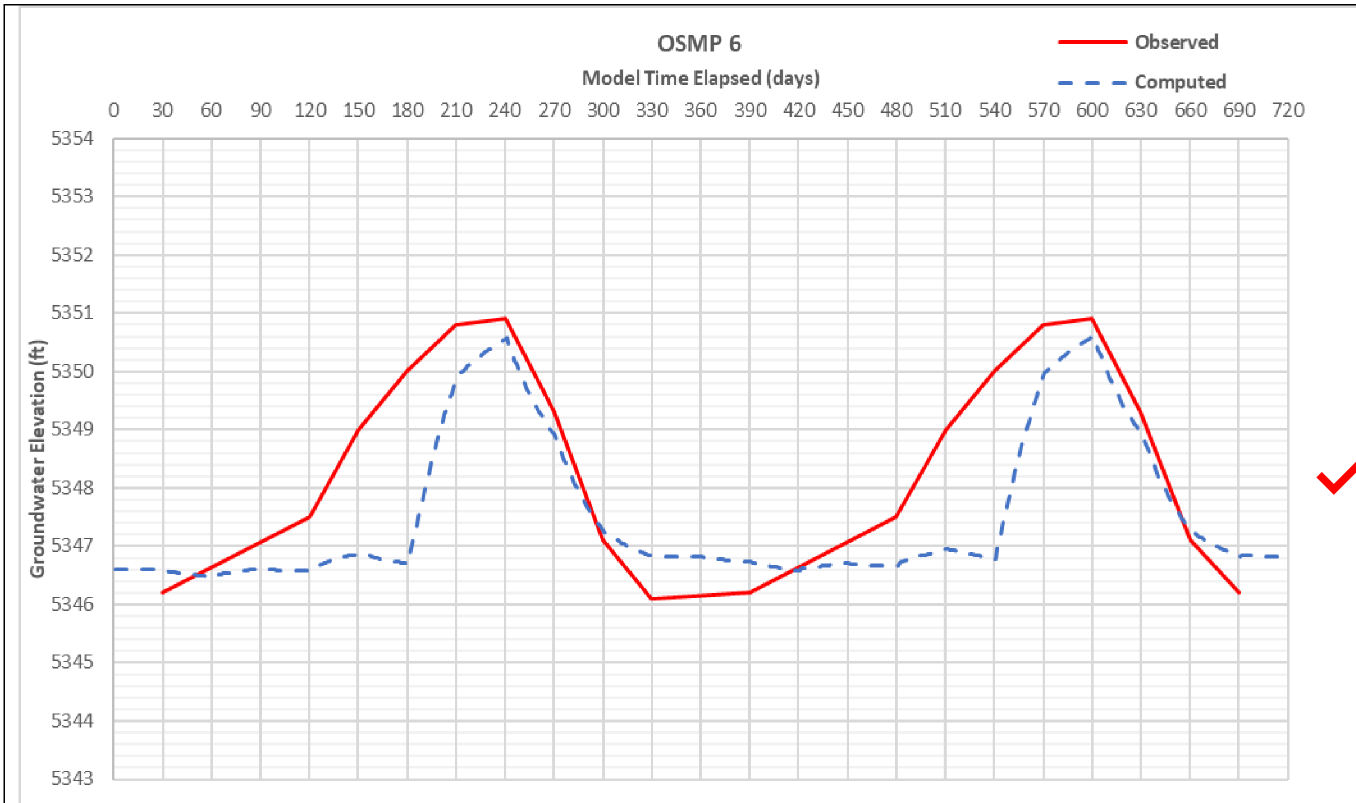
Project	16134	Page	29/33
Date	10/11/2020	By	ATMerook
Checked	10/16/2020	By	JNH
Approved	10/16/20	By	ABP

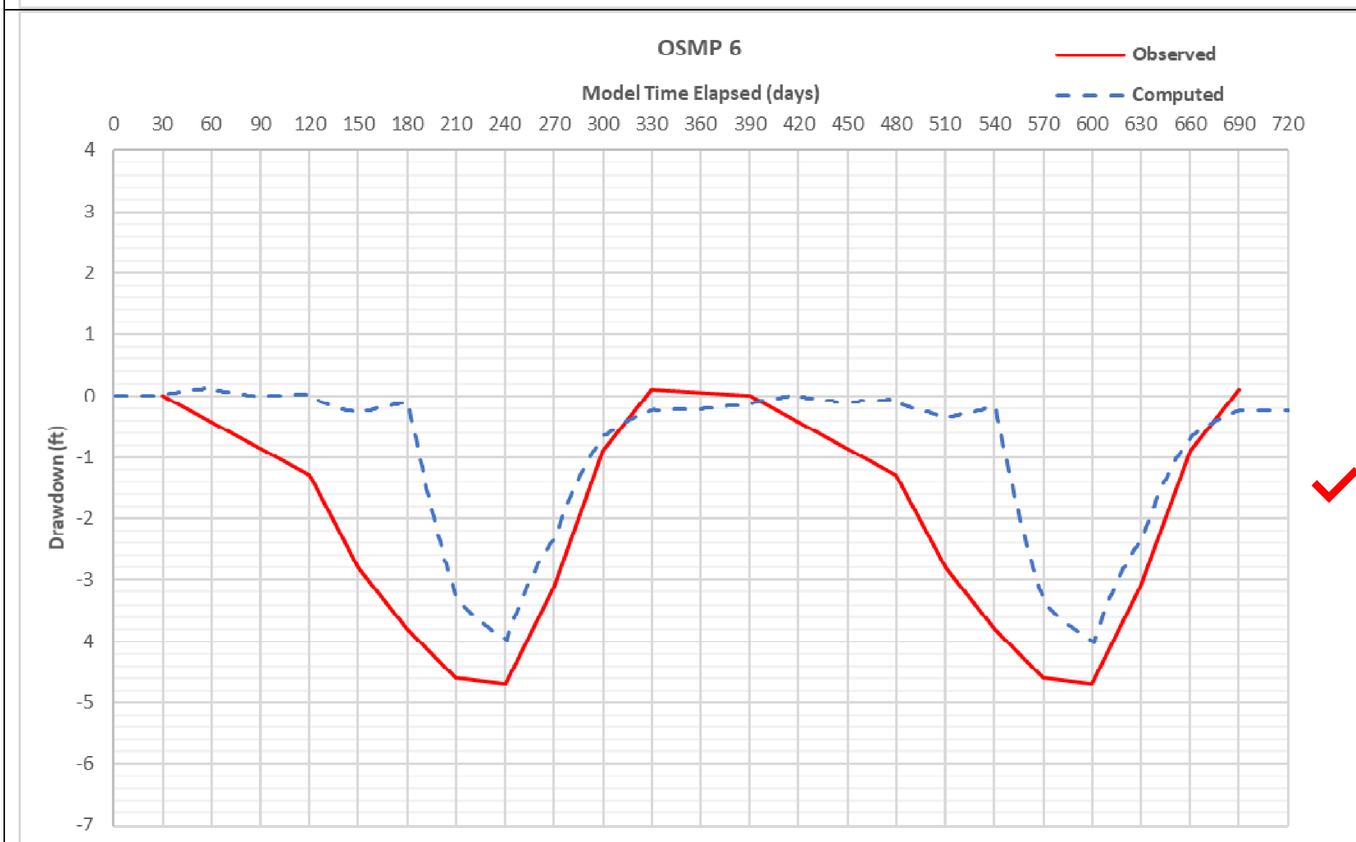
Client City of Boulder

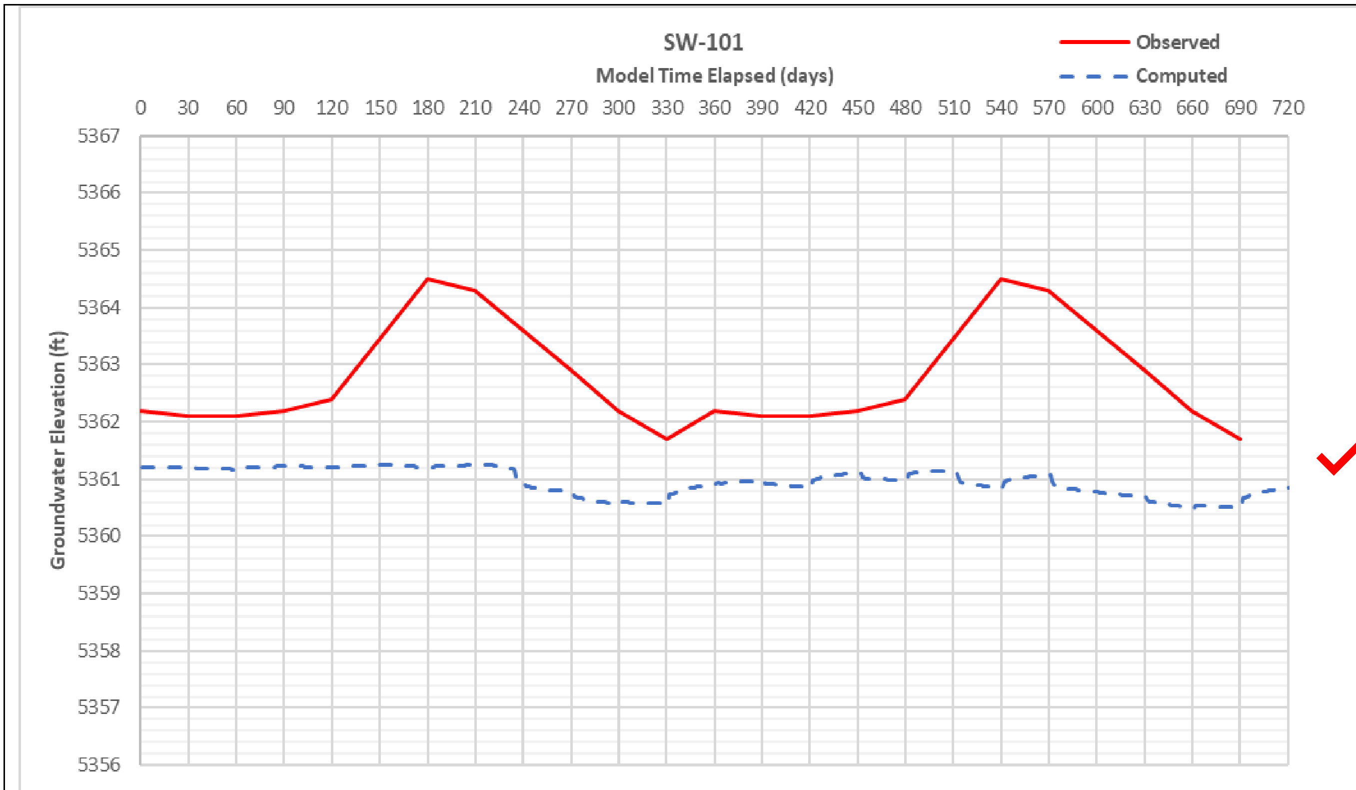
Subject Well Results






OSMP 6
Model Time Elapsed (days)
Observed
Computed
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
Groundwater Elevation (ft)
5354
5353
5352
5351
5350
5349
5348
5347
5346
5345
5344
5343


OSMP 6
Model Time Elapsed (days)
Observed
Computed
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
Drawdown (ft)
4
3
2
1
0
-1
-2
-3
4
-5
-6
-7


SW-101
Model Time Elapsed (days)
Observed
Computed
Groundwater Elevation (ft)
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
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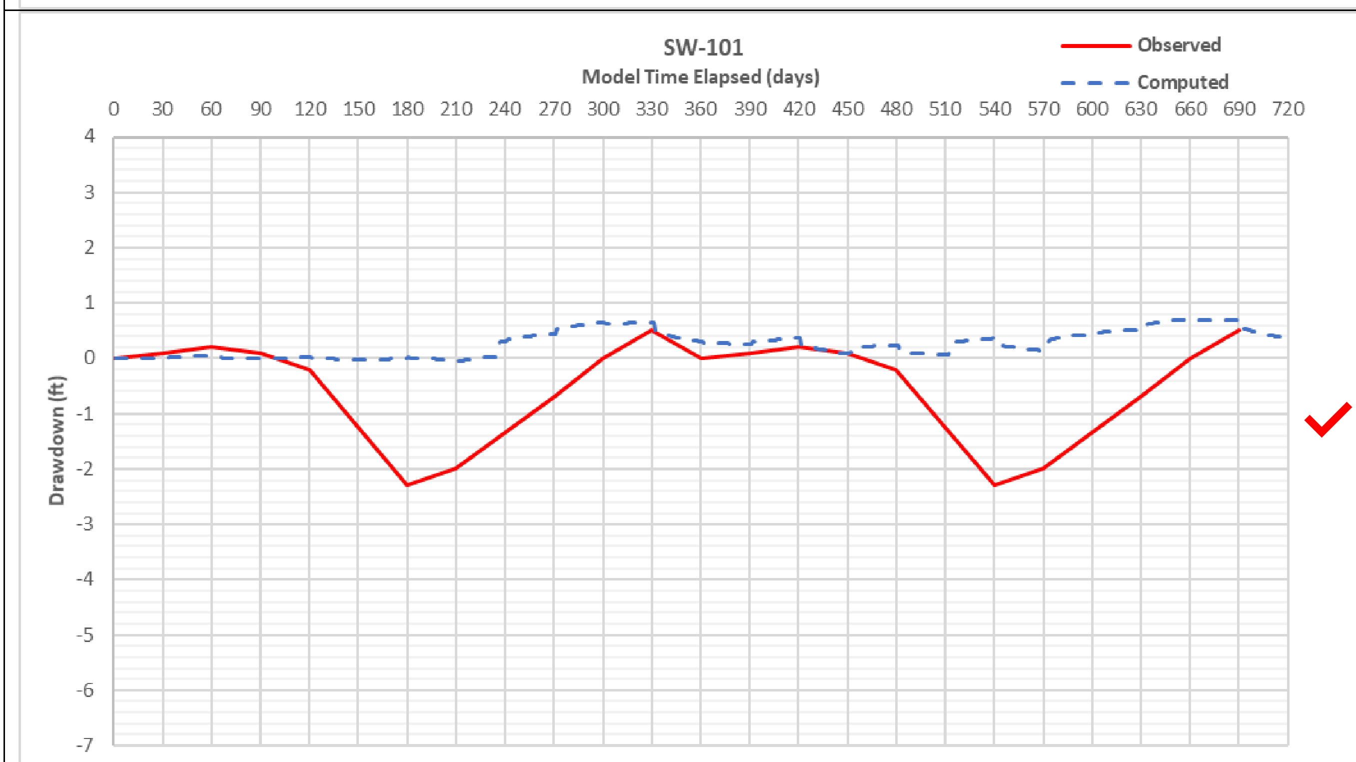
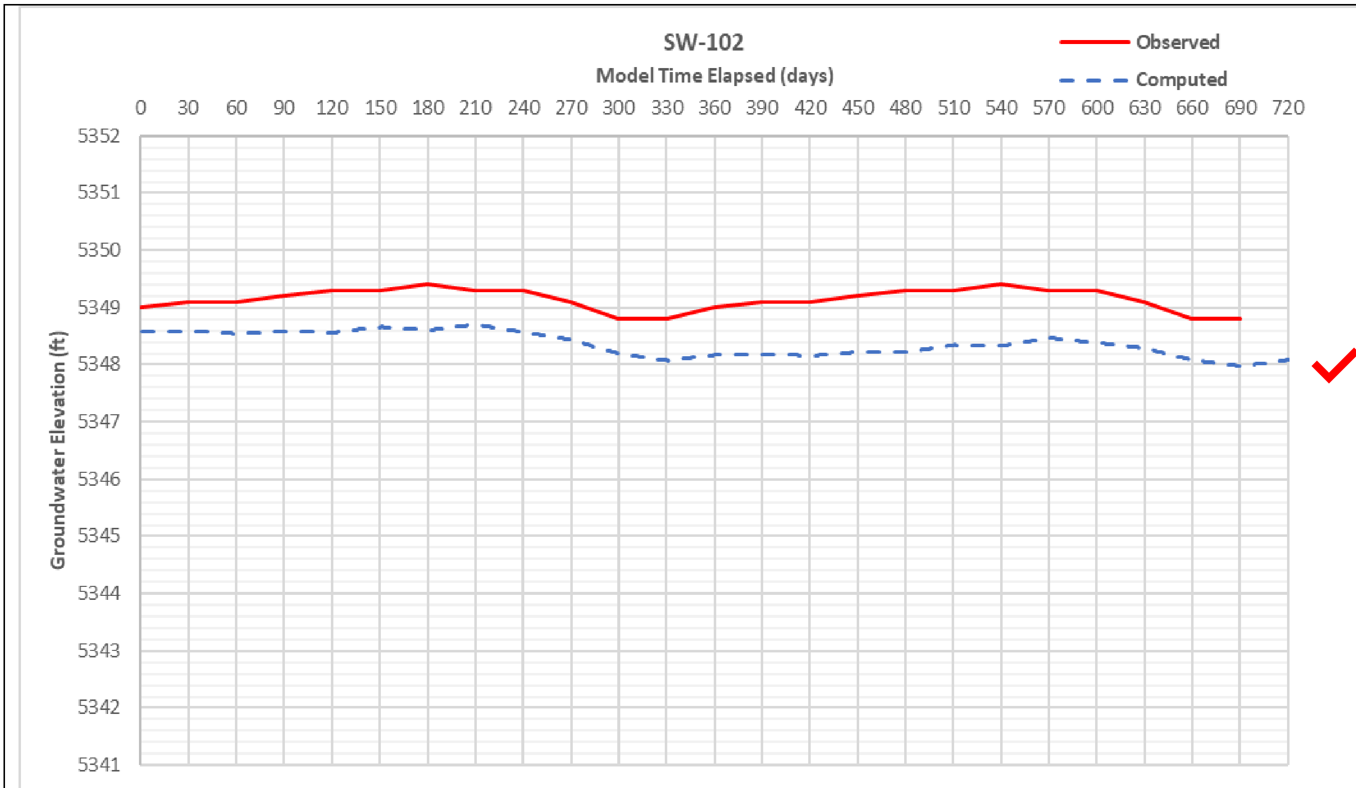
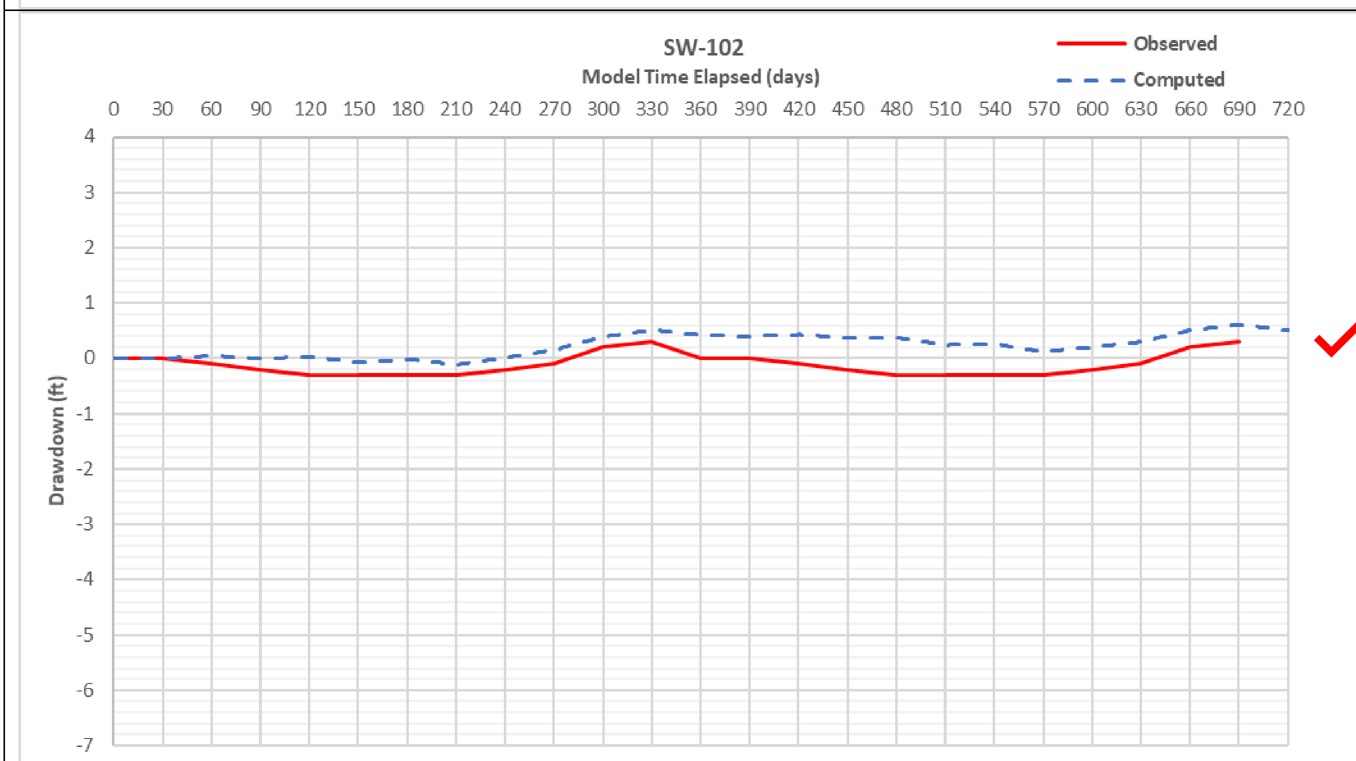
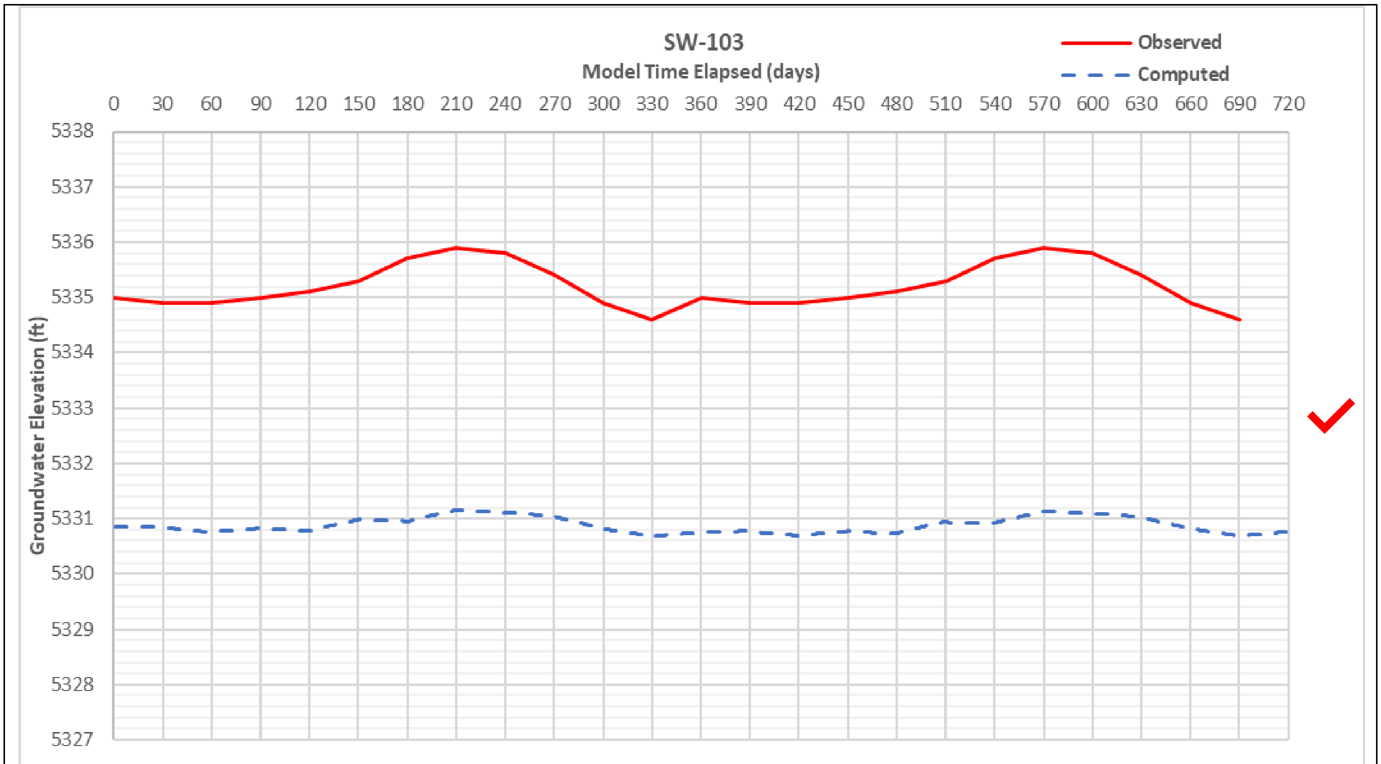
5365
5364
5363
5362
5361
5360
5359
5358
5357
5356

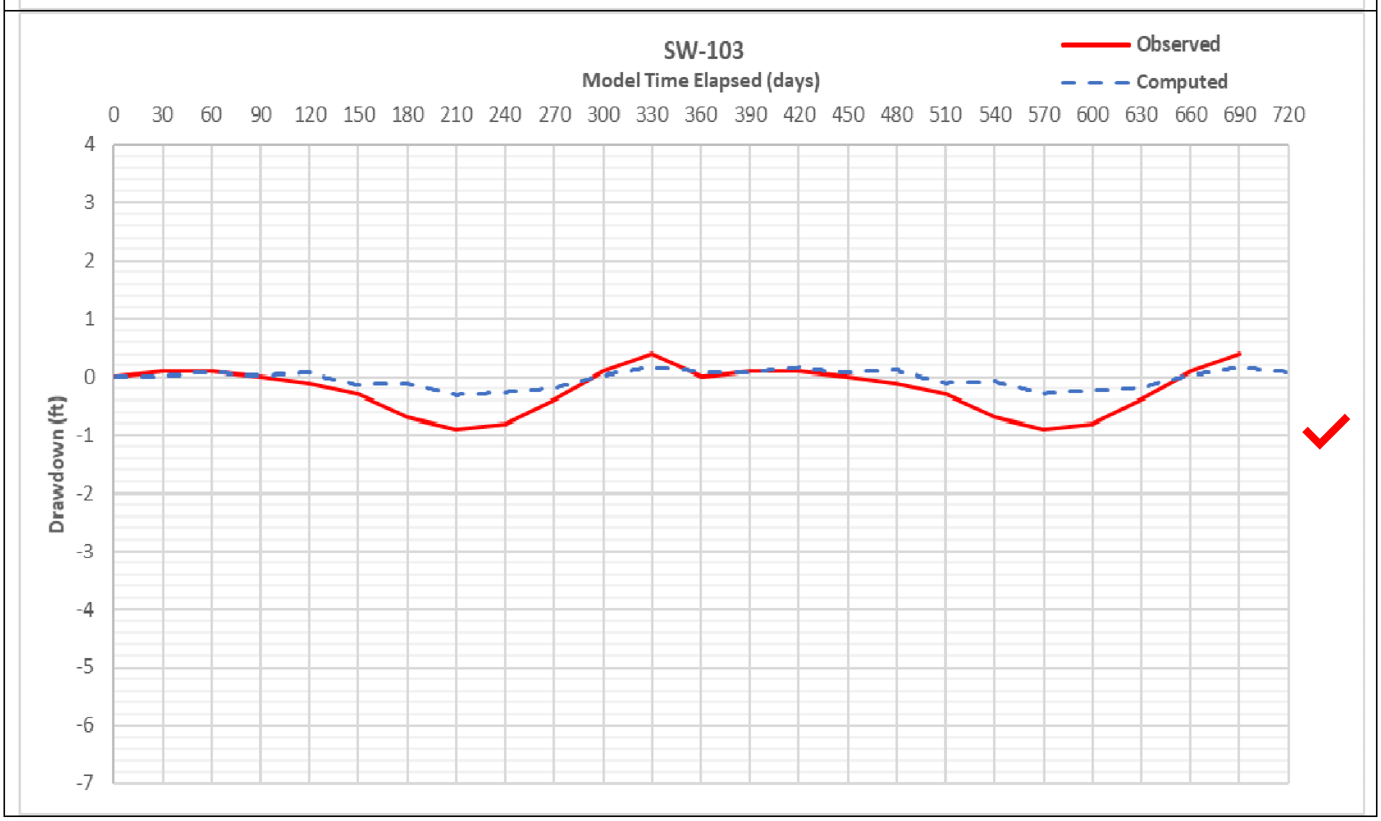

SW-101
Model Time Elapsed (days)
Observed
Computed
Drawdown (ft)
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7


SW-102
Model Time Elapsed (days)
Observed
Computed
Groundwater Elevation (ft)
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
5352 5351 5350 5349 5348 5347 5346 5345 5344 5343 5342 5341


SW-102
Model Time Elapsed (days)
Observed
Computed
Drawdown (ft)
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7

	Project	16134	Page	33/33
	Date	10/11/2020	By	ATMerook
Client City of Boulder	Checked	10/16/2020	By	JNH
Subject Well Results	Approved	10/16/20	By	ABP





APPENDIX K.4

FLOW CALCULATIONS

	Project	16134	Page	1/13
	Date	2/18/21	By	JNH
Client: City of Boulder	Checked	2/18/21	By	CLS
Subject: Baseline Groundwater Model – Alluvial HSU Flow Calculation Check	Approved	2/19/21	By	ABP

RJH CONSULTANTS, INC.

Purpose:

To manually calculate the flow across alluvial hydrostratigraphic units (HSU) in the Baseline Groundwater Model for the steady-state stress period. Compare the manual calculations to the model output to verify the model output is reasonable.

Approach:

- Use Darcy's law Q = KiA to evaluate the flow. ok
- Alluvial HSUs to evaluate are: 6, 7, 8, and 9 (p. 3 ✓). HSUs are located just north of US36.

Methods:

1. Identify the horizontal hydraulic conductivity (Kh) for each HSU. Added HSUs to GIS map showing alluvial Kh zones (p. 4 ✓). Kh values for each zone are shown on p. 5 ✓.
    a. HSU 6: Kh Zone A = 1.9x10-2 cm/s = 6.2x10-4 ft/s ✓
    b. HSU 7: Kh Zones A & B, calculate weighted average:
        i. Zone A portion
            1. 963.2 ft/1303.8 ft = 0.74 (74% of HSU is Zone A) ✓
        ii. Zone B portion
            1. 340.6 ft/1303.8 ft = 0.26 (26% of HSU is Zone B) ✓
        iii. Weighted average
            1. 0.74(6.2x10-4 ft/s) + 0.26(1.1x10-5 ft/s) = 4.6x10-4 ft/s ✓
    c. HSU 8: Kh Zone B = 3.5x10-4 cm/s = 1.1x10-5 ft/s ✓
    d. HSU 9: Kh Zone C = 7.1x10-4 cm/s = 2.3x10-5 ft/s ✓

2. Identify perpendicular area for flow to cross for each HSU. CAD drawings show HSU in groundwater model in section; area of saturated alluvium calculated using Bluebeam (p. 6-9). ✓
    a. HSU 6: Area (A) = 2685.8 SF ✓
    b. HSU 7: A = 9233.5 SF ✓
    c. HSU 8: A = 9664.6 SF ✓
    d. HSU 9: A = 5902.4 SF ✓

3. Estimate the typical hydraulic gradient (i) perpendicular to each HSU, where i = ΔH/L (p. 3 ✓).

    change in head

    length

    a. HSU 6:
        i. The groundwater contours exhibit a significant change in density across HSU 6 such that two gradients were identified to act as bookends.
        ii. Lower gradient: i = (5331-5326 ft)/891.8 ft = 0.0056 ~ 0.006 ✓
        iii. Upper gradient: i = (5341-5327 ft)/892.3 ft = 0.0156 ~ 0.016 ✓
    b. HSU 7: i = (5337-5329 ft)/901.5 ft = 0.0088 ~ 0.009 ✓
    c. HSU 8: i = (5351-5343 ft)/881.9 ft = 0.00907 ~ 0.009 ✓
    d. HSU 9: i = (5355-5346 ft)/832.9 ft = 0.0108 ~ 0.011 ✓

Upper gradient is not applicable because saturated alluvium is only located in the eastern half of HSU 6 (page 6)

4. Calculate the flow across each HSU using Q = KiA.
   a. HSU 6:
      i. Lower Q = 6.2x10-4 ft/s (0.006) (2685.8 SF) = 0.00999 ~ 0.01 cfs
      ii. Higher Q = 6.2x10-4 ft/s (0.016) (2685.8 SF) = 0.0266 ~ 0.03 cfs
   b. HSU 7: Q = 4.6x10-4 ft/s (0.009) (9233.5 SF) = 0.0382 ~ 0.04 cfs
   c. HSU 8: Q = 1.1x10-5 ft/s (0.009) (9664.6 SF) = 0.000956 ~ 0.001 cfs
   d. HSU 9: 2.3x10-5 ft/s (0.011) (5902.4 SF) = 0.00149 ~ 0.001 cfs

5. Identify the flow for each HSU from the model output (p.10-13).
   a. HSU 6: 846.3 ft^3/d
   b. HSU 7: 4275.8 ft^3/d
   c. HSU 8: 197.3 ft^3/d
   d. HSU 9: 323.8 ft^3/d

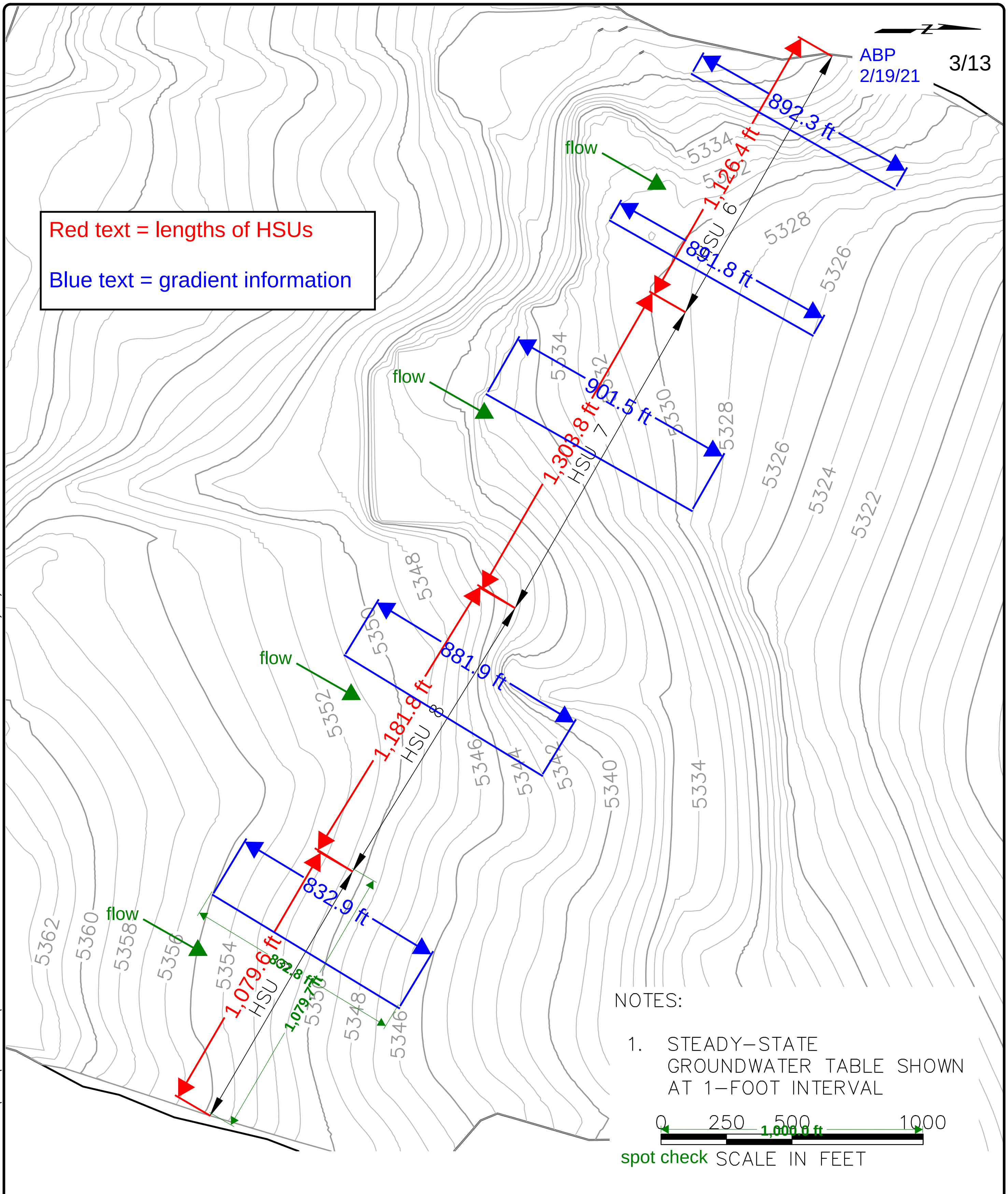
Tabulated Results:

See note on bottom of page 1.

HSU	Calculated		Model Output
	Flow (cfs)	Flow (ft^3/d)	Flow (ft^3/d)
HSU 6 (low estimate)	0.01	864	846.3
~~HSU 6 (high estimate)~~	~~0.03~~	~~2592~~	
HSU 7	0.04	3456	4275.8
HSU 8	0.001	86.4	197.3
HSU 9	0.001	86.4	323.8

- Model results are relatively similar to the manual calculations.
- Model results for HSU 6 are more similar to the low estimate manual calculation.

2/18/21 CLS



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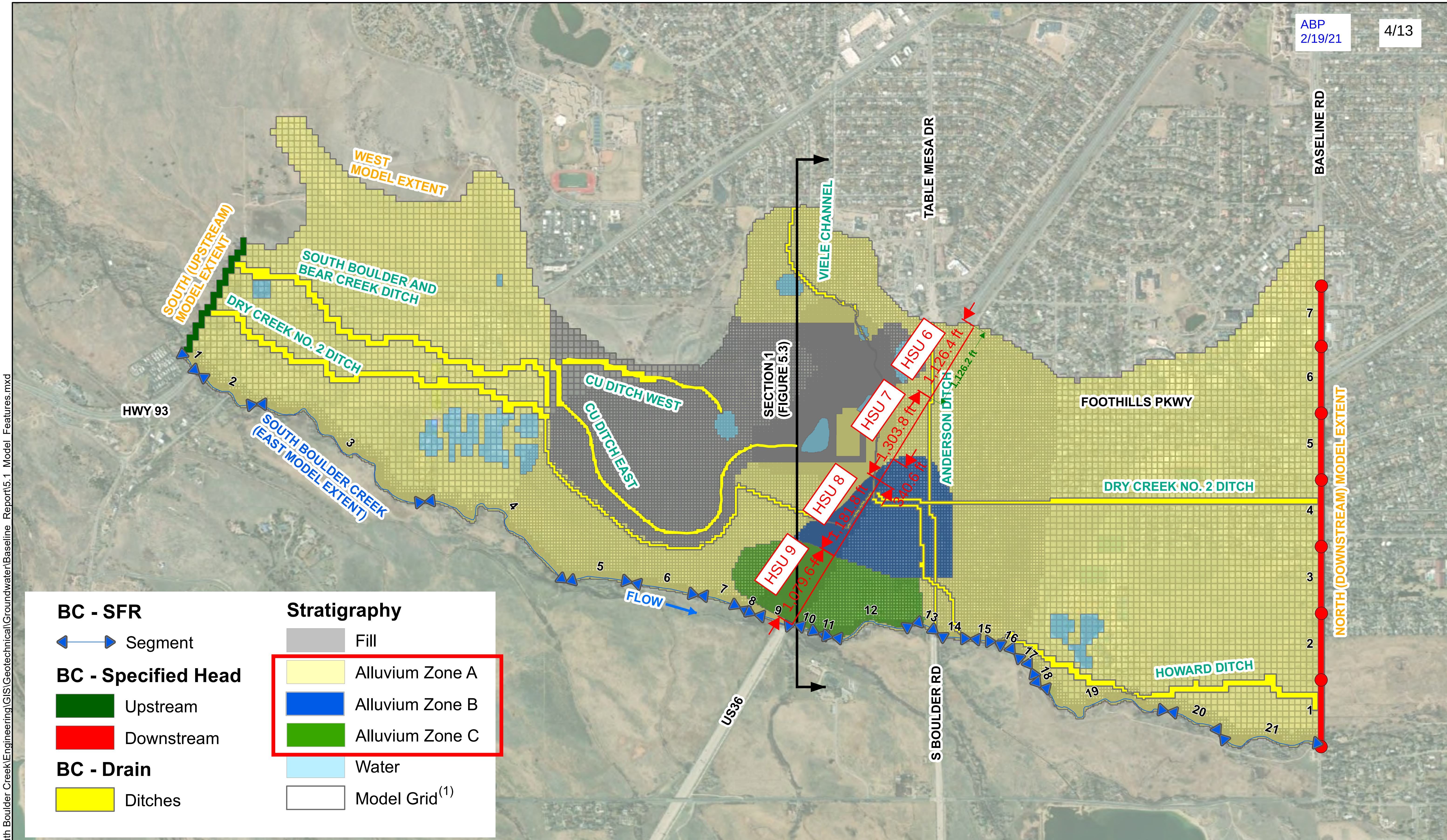
RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION PROJECT	BASELINE GROUNDWATER MODEL HSU PLAN
	PROJECT NO. 16134	February 2021 **Figure 1**



NOTE:
1. MODEL GRID CELL SIZE RANGES FROM 80X80 FT AT THE FAR-FIELD MODEL EXTENTS TO 5X5 FT NEAR THE PROPOSED PROJECT FACILITIES.
2. PROPOSED PROJECT FACILITIES ARE SHOWN ON FIGURE 1.2.

0 600 1,200 2,400 Feet

2,400.0 ft
spot check

REPRODUCE IN COLOR

N

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

MODEL FEATURES

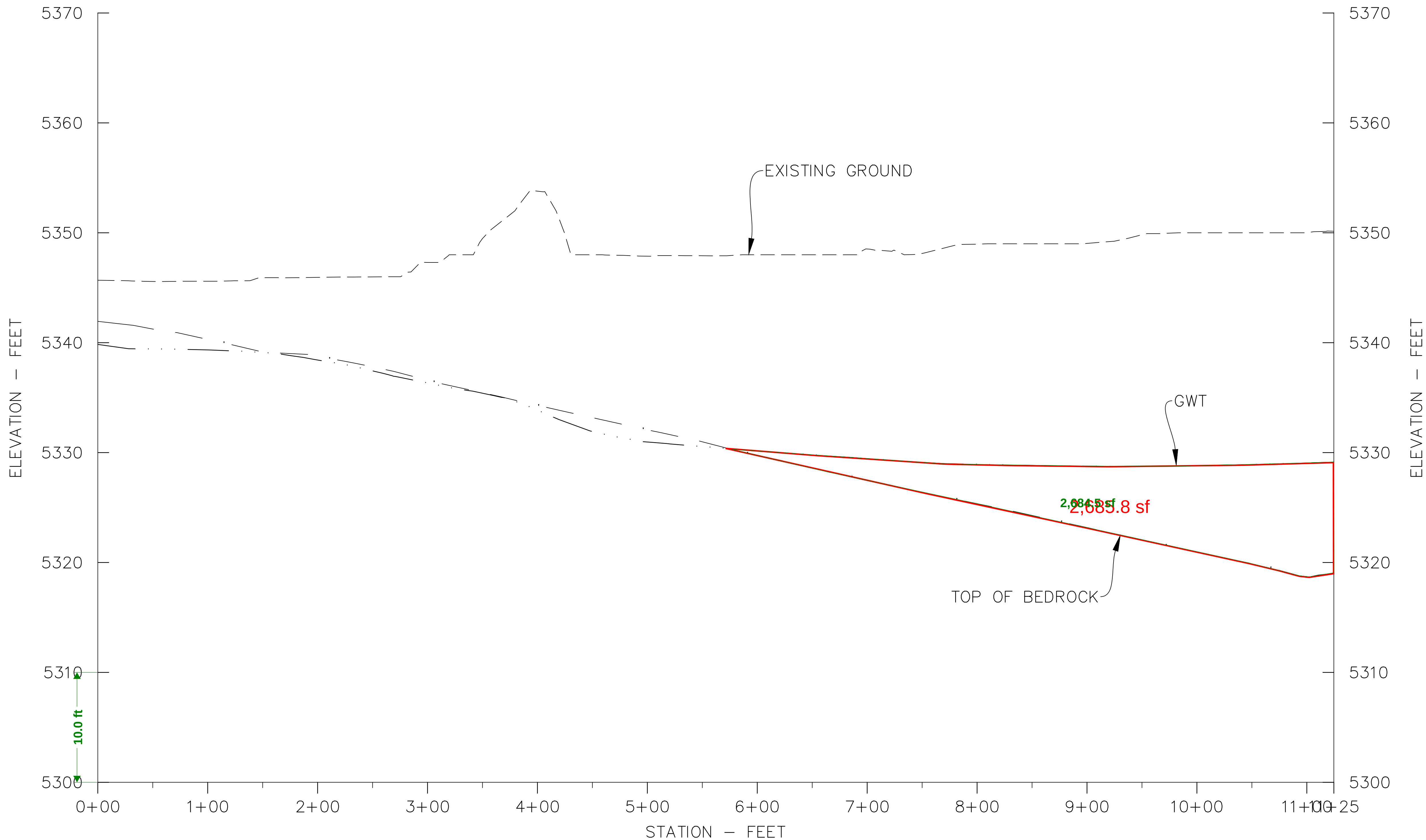
PROJECT NO. 16134 | October 2020 | **Figure 5.1**

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline Report\5.1 Model Features.mxd

TABLE 5.1
SUMMARY OF SIMULATED HORIZONTAL HYDRAULIC CONDUCTIVITY AND ANISOTROPY VALUES

Unit	Horizontal Hydraulic Conductivity (cm/s)	Anisotropy Ratio (K_h/K_v)
Fill	3.7×10^{-5}	3.7
Alluvium Zone A	1.9×10^{-2}	10.0
Alluvium Zone B	3.5×10^{-4}	10.0
Alluvium Zone C	7.1×10^{-4}	10.0
Weathered Pierre Shale	1.4×10^{-4}	10.0
Unweathered Pierre Shale	2.5×10^{-5}	10.0
Ponds	1.8×10^{-1}	1.0

ABP
2/19/21



NOTES:

1. BASELINE MODEL GROUNDWATER TABLE COMPUTED DURING THE STEADY–STATE STRESS PERIOD (STRESS PERIOD 1).

PRELIMINARY
NOT FOR CONSTRUCTION

0 50 100 200
SCALE IN FEET
200.0 ft
spot check HORIZONTAL

0 5 10 20
SCALE IN FEET
VERTICAL

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION PROJECT

PROJECT NO. 16134

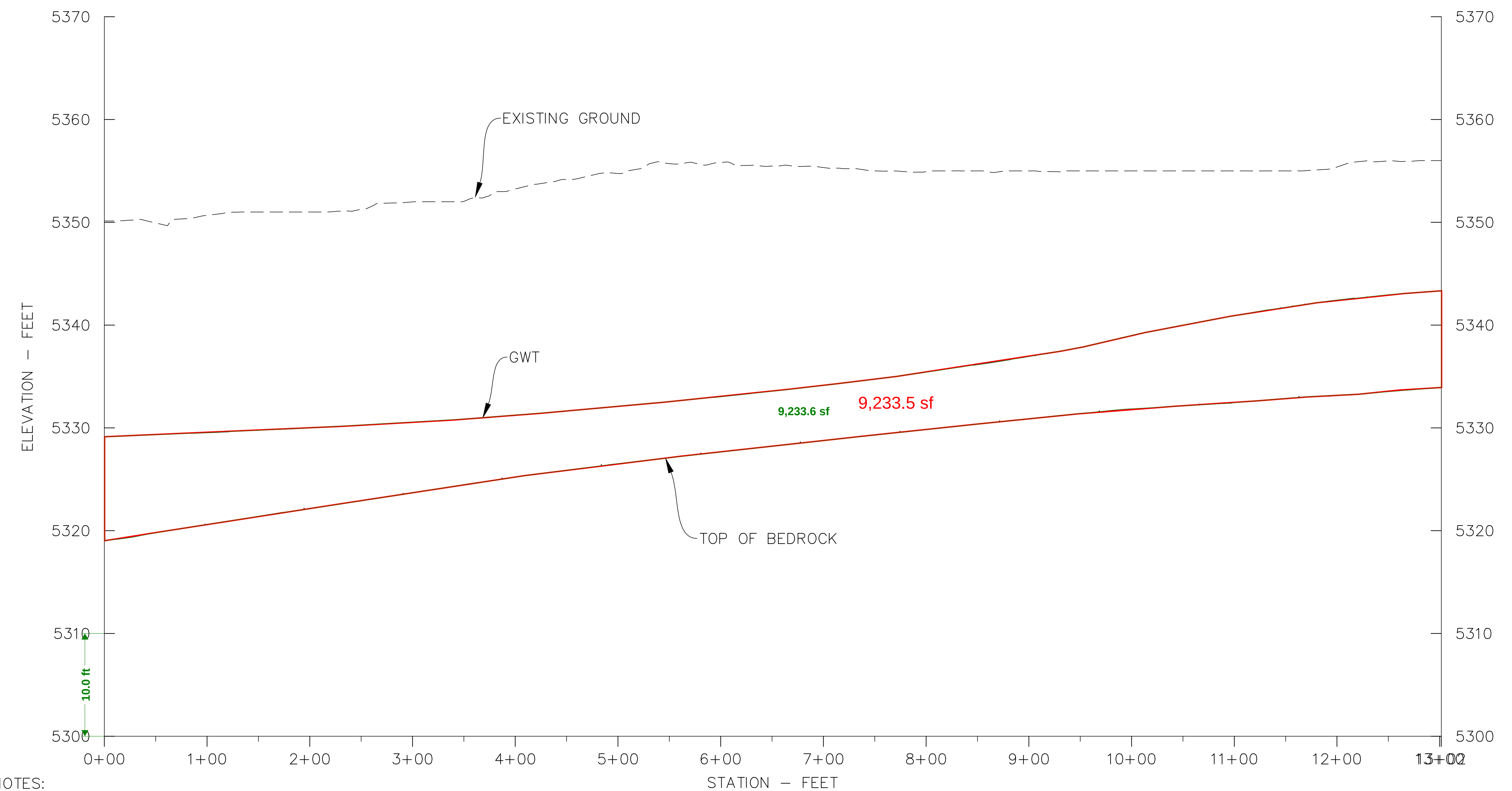
GROUNDWATER MODEL
US36 FLUX SECTIONS
HSU 6

February 2021

Figure 2

P:\16134 – SOUTH BOULDER CREEK\CAD\WORKING\16134_3004_HSU_SECTIONS_BASELINESTEADYSTATEGWT.DWG 2/16/2021 2:27 PM

ABP
2/19/21



NOTES:

1. BASELINE MODEL GROUNDWATER TABLE COMPUTED DURING THE STEADY–STATE STRESS PERIOD (STRESS PERIOD 1).

0 50 100 200
SCALE IN FEET
HORIZONTAL
200.0 ft
spot check

0 5 10 20
SCALE IN FEET
VERTICAL

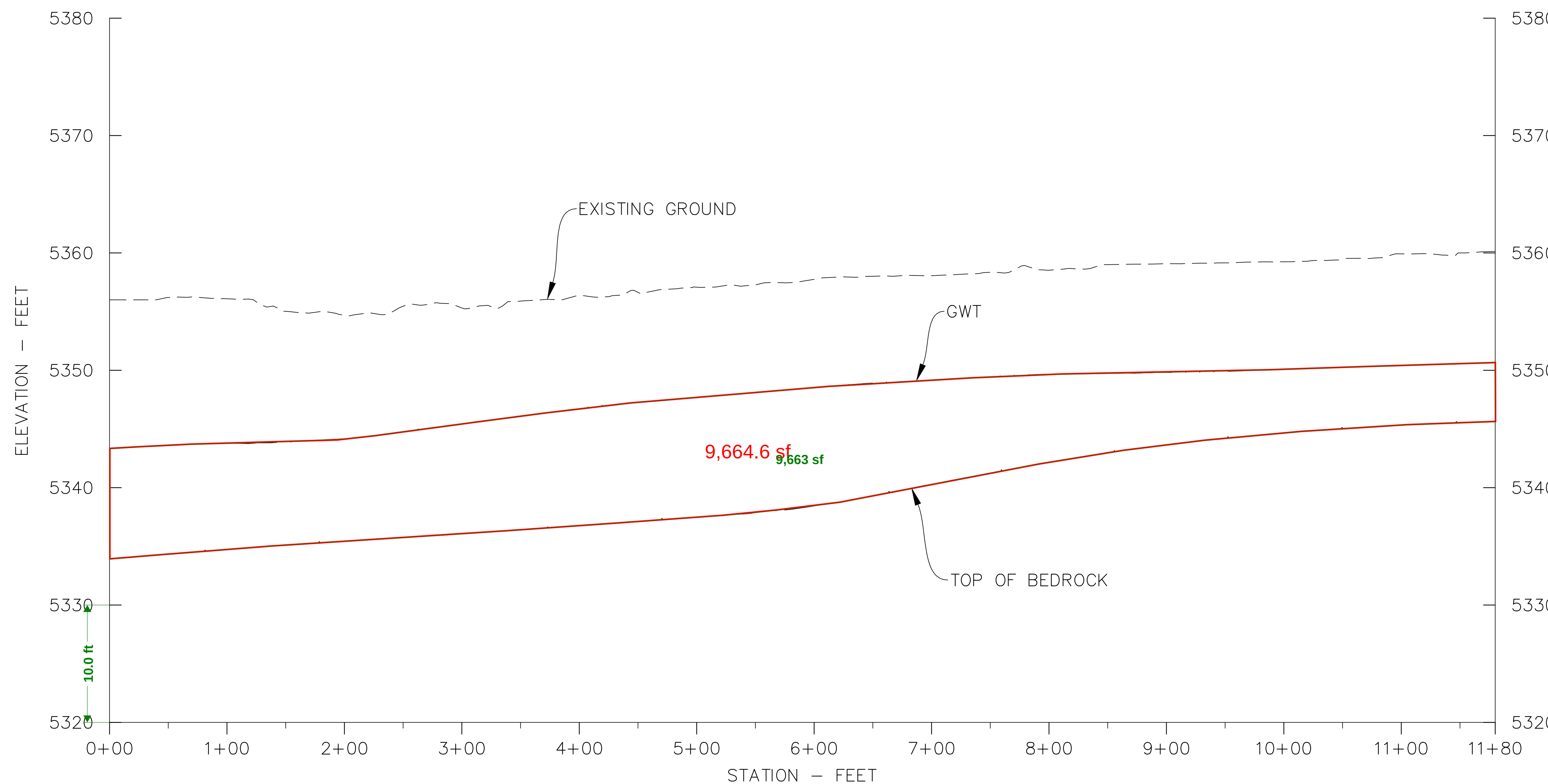
PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION PROJECT	GROUNDWATER MODEL US36 FLUX SECTIONS HSU 7	
PROJECT NO. 16134	February 2021	Figure 3

P:\16134 – SOUTH BOULDER CREEK\CAD\WORKING\16134_3004_HSU_SECTIONS_BASELINESTEADYSTATEGWT.DWG 2/16/2021 2:28 PM

ABP
2/19/21



NOTES:

1. BASELINE MODEL GROUNDWATER TABLE COMPUTED DURING THE STEADY–STATE STRESS PERIOD (STRESS PERIOD 1).

0 50 100 200
SCALE IN FEET
HORIZONTAL
200.0 ft
spot check

0 5 10 20
SCALE IN FEET
VERTICAL

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION PROJECT

PROJECT NO. 16134

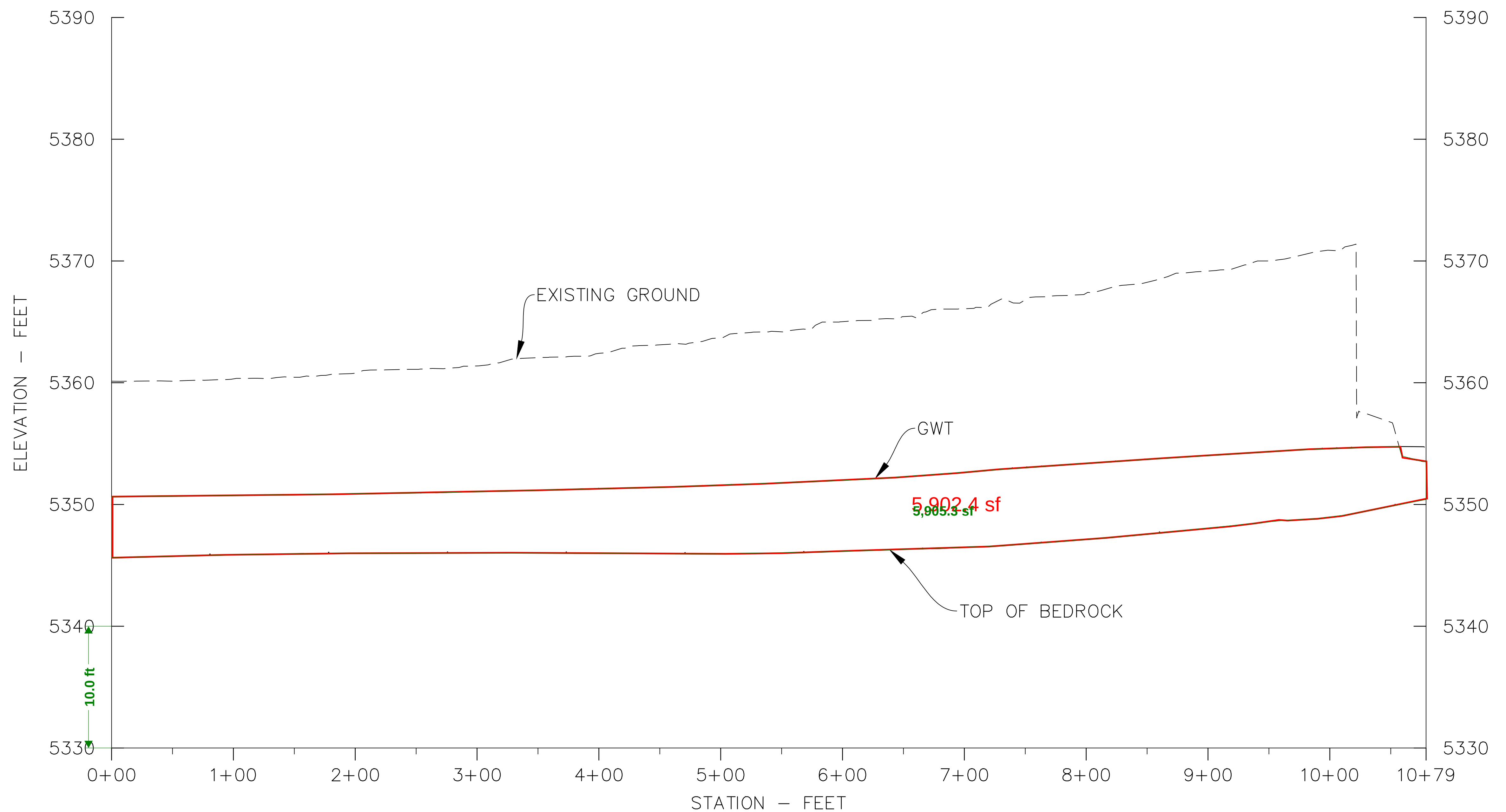
GROUNDWATER MODEL
US36 FLUX SECTIONS
HSU 8

February 2021

Figure 4

P:\16134 – SOUTH BOULDER CREEK\CAD\WORKING\16134_3004_HSU_SECTIONS_BASELINESTEADYSTATEGWT.DWG 2/16/2021 2:35 PM

ABP
2/19/21



NOTES:

1. BASELINE MODEL GROUNDWATER TABLE COMPUTED DURING THE STEADY–STATE STRESS PERIOD (STRESS PERIOD 1).

0 50 100 200
SCALE IN FEET
HORIZONTAL
200.0 ft
spot check

0 5 10 20
SCALE IN FEET
VERTICAL

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.	SOUTH BOULDER CREEK REGIONAL DETENTION PROJECT	GROUNDWATER MODEL US36 FLUX SECTIONS HSU 9	
	PROJECT NO. 16134	February 2021	Figure 5

P:\16134 – SOUTH BOULDER CREEK\CAD\WORKING\16134_3004_HSU_SECTIONS_BASELINESTEADYSTATEGWT.DWG 2/16/2021 2:42 PM

ABP
2/19/21

TYP: Time 1 = steady-state

	Baseline INFLOW		QalK1 INFLOW		QalK2 INFLOW	A IN
Time	Flux	Time	Flux	Time	Flux	Time
1	846.3071107	1	219.9204464	1	914.8695896	1
2	846.3080943	2	219.9206573	2	914.8678394	2
3	846.307767	3	219.9204515	3	914.8673899	3
4	846.3077633	4	219.9207364	4	914.8671578	4
5	846.3077291	5	219.9204514	5	914.867129	5
6	846.3077272	6	219.9207367	6	914.8669762	6
7	846.307707	7	219.9204657	7	914.8669405	7
8	846.3077076	8	219.9207394	8	914.8668366	8
9	846.3076747	9	219.9204784	9	914.8667862	9
10	846.3076726	10	219.9207414	10	914.8667127	10
11	846.3076374	11	219.9204919	11	914.8666602	11
12	846.3076353	12	219.9207334	12	914.8666003	12
13	846.3075931	13	219.9206159	13	914.8665652	13
14	846.3075827	14	219.9207316	14	914.8665111	14
15	846.3075671	15	219.9223263	15	914.8664769	15
16	846.3075654	16	219.9206875	16	914.8664504	16
17	846.3075412	17	219.920474	17	914.8663998	17
18	846.3075342	18	219.920688	18	914.8663829	18
19	846.3075232	19	219.9223357	19	914.8663503	19
20	846.3075223	20	219.9206309	20	914.8663396	20
21	846.3075029	21	219.9204093	21	914.8663086	21
22	846.3074986	22	219.9206528	22	914.8663032	22
23	846.3074717	23	219.9223699	23	914.8662737	23
24	846.3074685	24	219.920583	24	914.8662744	24
25	846.3074582	25	219.920319	25	914.8662382	25
26	846.3074557	26	219.9206113	26	914.8662443	26
27	846.3074462	27	219.9222362	27	914.8662173	27
28	846.3074411	28	219.9205386	28	914.8662528	28
29	846.3074283	29	219.9214573	29	914.8662293	29
30	846.3074356	30	219.9205651	30	914.8662605	30
31	846.3074315	31	219.9216512	31	914.8662404	31
32	817.0697528	32	201.3040765	32	883.9042207	32
33	815.1572017	33	201.1561237	33	881.0272833	33
34	813.3616565	34	200.8701695	34	878.1625499	34
35	811.5758986	35	200.5788074	35	875.2902831	35
36	809.8125672	36	200.4167929	36	872.4493334	36
37	808.0767117	37	200.2482161	37	869.6326163	37
38	806.368989	38	200.0737848	38	866.8427697	38
39	804.6877356	39	199.8944563	39	864.0821228	39
40	803.0301601	40	199.7112433	40	861.3513999	40
41	801.3937458	41	199.5251111	41	858.6513136	41

P:\16134 - South Boulder Creek\Engineering\Geotechnical\Groundwater\Groundwater_Model\3-Models\16134_Model_Calc_Packages\27-Appdx_Well_Results\Updated\US36_Flux\16134_02112021_US36_Flux_HSU

HSU 6

ABP
2/19/21

	Baseline INFLOW		QalK1 INFLOW		QalK2 INFLOW	A IN
Time	Flux	Time	Flux	Time	Flux	Time
1	4275.799579	1	508.8052678	1	4847.960946	1
2	4275.80011	2	508.8052159	2	4847.964717	2
3	4275.799428	3	508.8052513	3	4847.963456	3
4	4275.799405	4	508.80528	4	4847.962904	4
5	4275.799353	5	508.8052363	5	4847.962489	5
6	4275.799342	6	508.8052913	6	4847.962091	6
7	4275.799301	7	508.8052329	7	4847.961645	7
8	4275.799293	8	508.8052989	8	4847.961241	8
9	4275.799273	9	508.8052313	9	4847.960774	9
10	4275.799237	10	508.8053082	10	4847.960474	10
11	4275.799232	11	508.805232	11	4847.960005	11
12	4275.799195	12	508.8053141	12	4847.959726	12
13	4275.799169	13	508.8053296	13	4847.959257	13
14	4275.799157	14	508.8053196	14	4847.958992	14
15	4275.799144	15	508.8064953	15	4847.958516	15
16	4275.799116	16	508.8052927	16	4847.958278	16
17	4275.799093	17	508.805288	17	4847.957823	17
18	4275.799074	18	508.8052998	18	4847.957599	18
19	4275.799107	19	508.8065329	19	4847.957165	19
20	4275.799103	20	508.8052654	20	4847.957037	20
21	4275.799119	21	508.8053018	21	4847.956652	21
22	4275.799109	22	508.8052818	22	4847.956532	22
23	4275.799168	23	508.8065766	23	4847.956229	23
24	4275.799201	24	508.8052428	24	4847.956122	24
25	4275.799247	25	508.8053056	25	4847.955964	25
26	4275.79925	26	508.8052619	26	4847.9559	26
27	4275.799372	27	508.806496	27	4847.955812	27
28	4275.799377	28	508.8052209	28	4847.955816	28
29	4275.79949	29	508.8061012	29	4847.955702	29
30	4275.799565	30	508.8052408	30	4847.95576	30
31	4275.799684	31	508.8061211	31	4847.95581	31
32	4251.900241	32	497.0905805	32	4820.732154	32
33	4248.533231	33	497.0497552	33	4816.062905	33
34	4244.718612	34	497.0060237	34	4810.940022	34
35	4241.052798	35	496.9492593	35	4805.530591	35
36	4237.33052	36	496.8749418	36	4799.95047	36
37	4233.580885	37	496.7751123	37	4794.242733	37
38	4229.810403	38	496.5563761	38	4788.470646	38
39	4226.032461	39	496.4209247	39	4782.652146	39
40	4222.256805	40	496.2701118	40	4776.765291	40
41	4218.49122	41	496.1052194	41	4770.88392	41

	Baseline		QalK1		QalK2		Ar
	INFLOW		INFLOW		INFLOW		IN
Time	Flux	Time	Flux	Time	Flux	Time	
1	197.2671887	1	60.42186472	1	1108.301466	1	
2	197.2671918	2	60.42187085	2	1108.302391	2	
3	197.2671915	3	60.42186689	3	1108.302183	3	
4	197.2671913	4	60.42187202	4	1108.302017	4	
5	197.2671909	5	60.42186734	5	1108.301957	5	
6	197.2671909	6	60.42187225	6	1108.301799	6	
7	197.2671906	7	60.42186763	7	1108.301716	7	
8	197.2671906	8	60.4218725	8	1108.301568	8	
9	197.2671906	9	60.42186798	9	1108.301465	9	
10	197.2671905	10	60.42187256	10	1108.301325	10	
11	197.2671905	11	60.42186932	11	1108.301216	11	
12	197.2671904	12	60.42187278	12	1108.301086	12	
13	197.2671902	13	60.42187126	13	1108.300963	13	
14	197.2671901	14	60.42187278	14	1108.300848	14	
15	197.2671899	15	60.42186832	15	1108.300716	15	
16	197.2671899	16	60.42187398	16	1108.300606	16	
17	197.2671897	17	60.42187178	17	1108.300464	17	
18	197.2671897	18	60.42187333	18	1108.300369	18	
19	197.2671895	19	60.42186785	19	1108.300216	19	
20	197.2671895	20	60.42187421	20	1108.30013	20	
21	197.2671895	21	60.42187221	21	1108.299973	21	
22	197.2671895	22	60.42187373	22	1108.29989	22	
23	197.2671893	23	60.42186781	23	1108.29974	23	
24	197.2671892	24	60.4218745	24	1108.299661	24	
25	197.2671891	25	60.42187268	25	1108.299505	25	
26	197.2671891	26	60.42187397	26	1108.299423	26	
27	197.2671891	27	60.42186757	27	1108.299281	27	
28	197.2671888	28	60.421875	28	1108.299192	28	
29	197.2671886	29	60.42187036	29	1108.299057	29	
30	197.2671886	30	60.42187455	30	1108.298969	30	
31	197.2671884	31	60.42186709	31	1108.298835	31	
32	193.9050758	32	58.73670314	32	1104.913926	32	
33	194.0380643	33	58.70463078	33	1105.211666	33	
34	194.1432429	34	58.6663618	34	1105.20175	34	
35	194.2247376	35	58.68344034	35	1104.987568	35	
36	194.2850535	36	58.69821825	36	1104.607745	36	
37	194.3303816	37	58.71069383	37	1104.080746	37	
38	194.3589006	38	58.72060224	38	1103.462683	38	
39	194.368277	39	58.72875772	39	1102.793837	39	
40	194.3614408	40	58.74189683	40	1102.042344	40	
41	194.3436893	41	58.75447678	41	1101.234565	41	

ABP
2/19/21

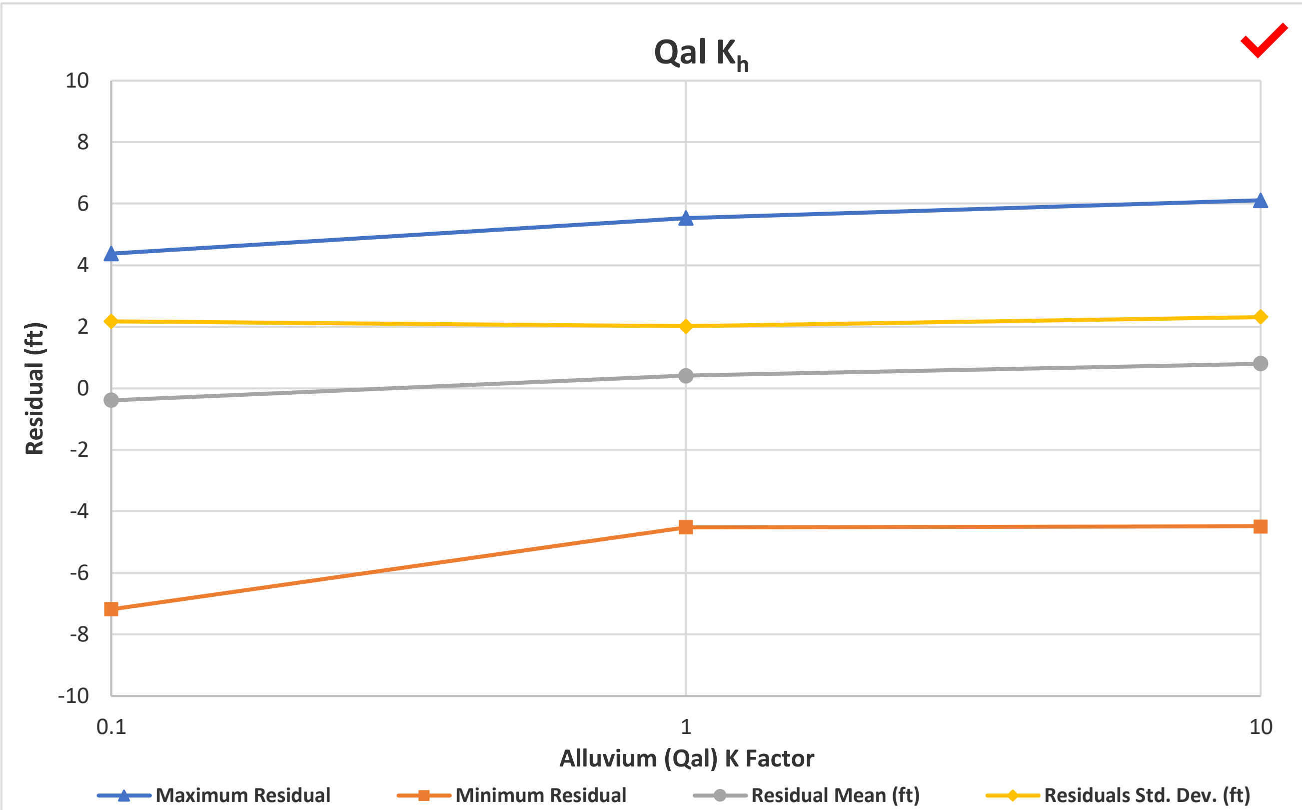
	Baseline		QalK1		QalK2	A
	INFLOW		INFLOW		INFLOW	IN
Time	Flux	Time	Flux	Time	Flux	Time
1	323.8151495	1	46.66992036	1	1500.427453	1
2	323.8150318	2	46.66990905	2	1500.438404	2
3	323.8153662	3	46.6699157	3	1500.434203	3
4	323.8157035	4	46.66990748	4	1500.43066	4
5	323.8158259	5	46.66991377	5	1500.429466	5
6	323.8159535	6	46.669908	6	1500.427663	6
7	323.8158118	7	46.66991587	7	1500.426222	7
8	323.8158044	8	46.66990935	8	1500.425245	8
9	323.8156425	9	46.66991572	9	1500.42392	9
10	323.8156168	10	46.66991021	10	1500.423396	10
11	323.8154716	11	46.66991603	11	1500.422264	11
12	323.815439	12	46.66991128	12	1500.421989	12
13	323.8153604	13	46.66991661	13	1500.420983	13
14	323.8153422	14	46.66991199	14	1500.420855	14
15	323.8152764	15	46.66991617	15	1500.419988	15
16	323.8152601	16	46.66991401	16	1500.419926	16
17	323.8152312	17	46.66991738	17	1500.419127	17
18	323.8152071	18	46.66991366	18	1500.419093	18
19	323.815182	19	46.66991745	19	1500.418416	19
20	323.8151815	20	46.66991391	20	1500.418348	20
21	323.8151667	21	46.66991854	21	1500.417792	21
22	323.8151615	22	46.66991525	22	1500.417725	22
23	323.8151498	23	46.6699205	23	1500.417262	23
24	323.8151403	24	46.66991582	24	1500.417123	24
25	323.815127	25	46.66992203	25	1500.416763	25
26	323.8151214	26	46.66991592	26	1500.41658	26
27	323.815115	27	46.66991995	27	1500.416325	27
28	323.8151092	28	46.66991602	28	1500.416098	28
29	323.8151037	29	46.66991985	29	1500.415914	29
30	323.8151023	30	46.66991857	30	1500.415676	30
31	323.8150991	31	46.66992061	31	1500.415533	31
32	320.0885664	32	43.36509729	32	1497.47244	32
33	318.5771005	33	42.96698199	33	1495.525576	33
34	318.2116343	34	42.59911083	34	1494.441597	34
35	319.5785751	35	42.56637373	35	1495.302742	35
36	320.4532834	36	42.61670308	36	1495.756233	36
37	320.8853805	37	42.67489108	37	1495.667989	37
38	321.1000393	38	42.72926981	38	1495.298071	38
39	321.2075825	39	42.77845267	39	1494.802085	39
40	321.2560463	40	42.82179928	40	1494.26709	40
41	321.2719293	41	42.86037779	41	1493.712277	41

APPENDIX K.5

SENSITIVITY RESULTS

APPENDIX K.5.1

OVERALL MODEL SENSITIVITY AND TRANSIENT SENSITIVITY OF HEADS



Qal K Factor	Unweighted Maximum Residual (ft)	Unweighted Minimum Residual (ft)	Unweighted Residual Mean (ft)	Unweighted Residuals Std. Dev. (ft)	Unweighted Scaled RMS	Weighted Scaled RMS
0.1[1]	4.38	-7.18	-0.39	2.17	0.012	0.007
1.0	5.53	-4.52	0.41	2.01	0.011	0.007
10[2]	6.11	-4.49	0.8	2.32	0.013	0.009

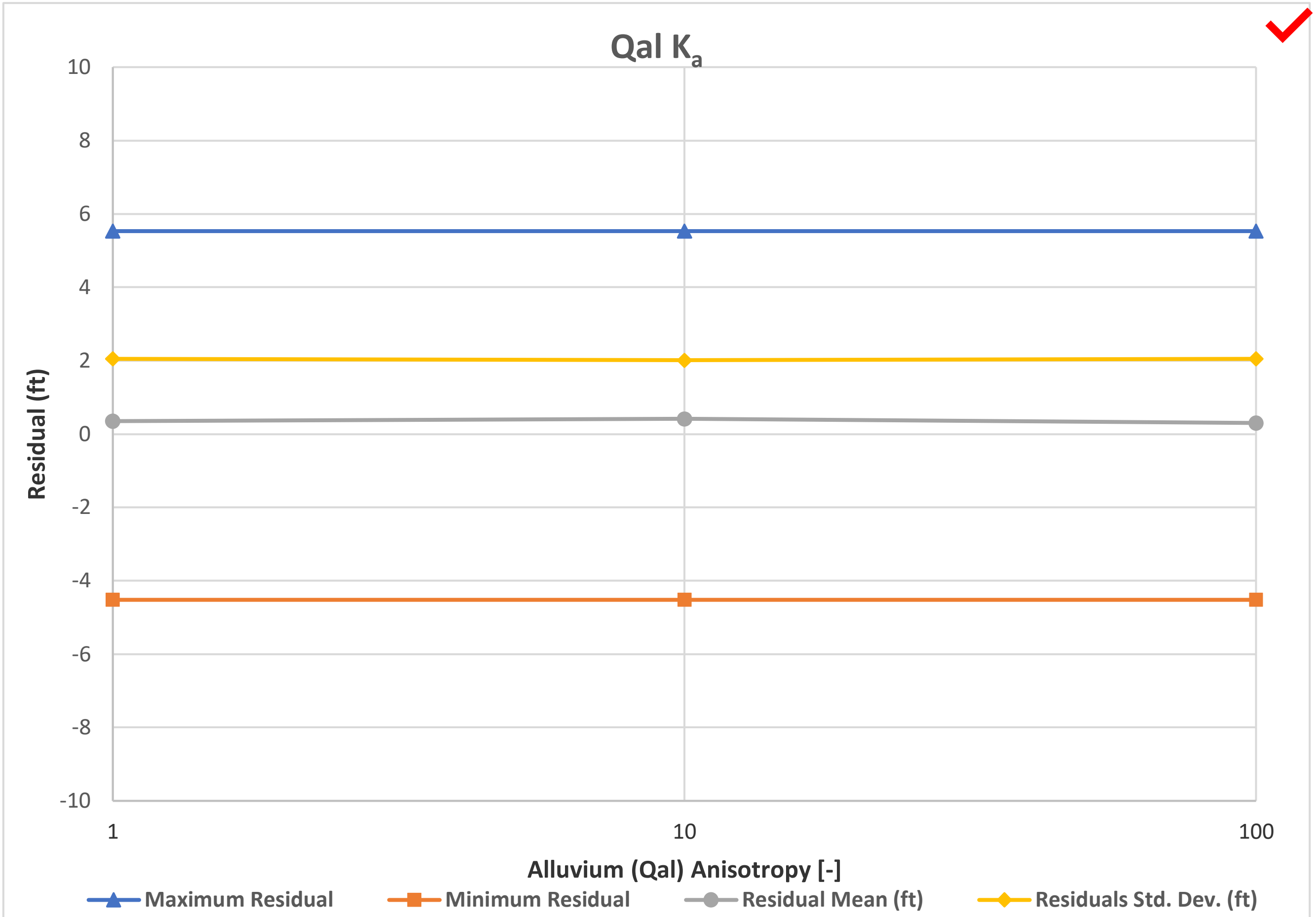
Notes:

1. The lower bound of the Qal K sensitivity range is either 1 order of magnitude lower than the Baseline model value or the lowest value of Qal K estimated from field data, whichever is greater.

2. The upper bound of the Qal K sensitivity range is either 1 order of magnitude greater than the Baseline model value or the high value of Qal K from field data, whichever is less.

3. The residual mean and standard deviation are based on 389 observations.

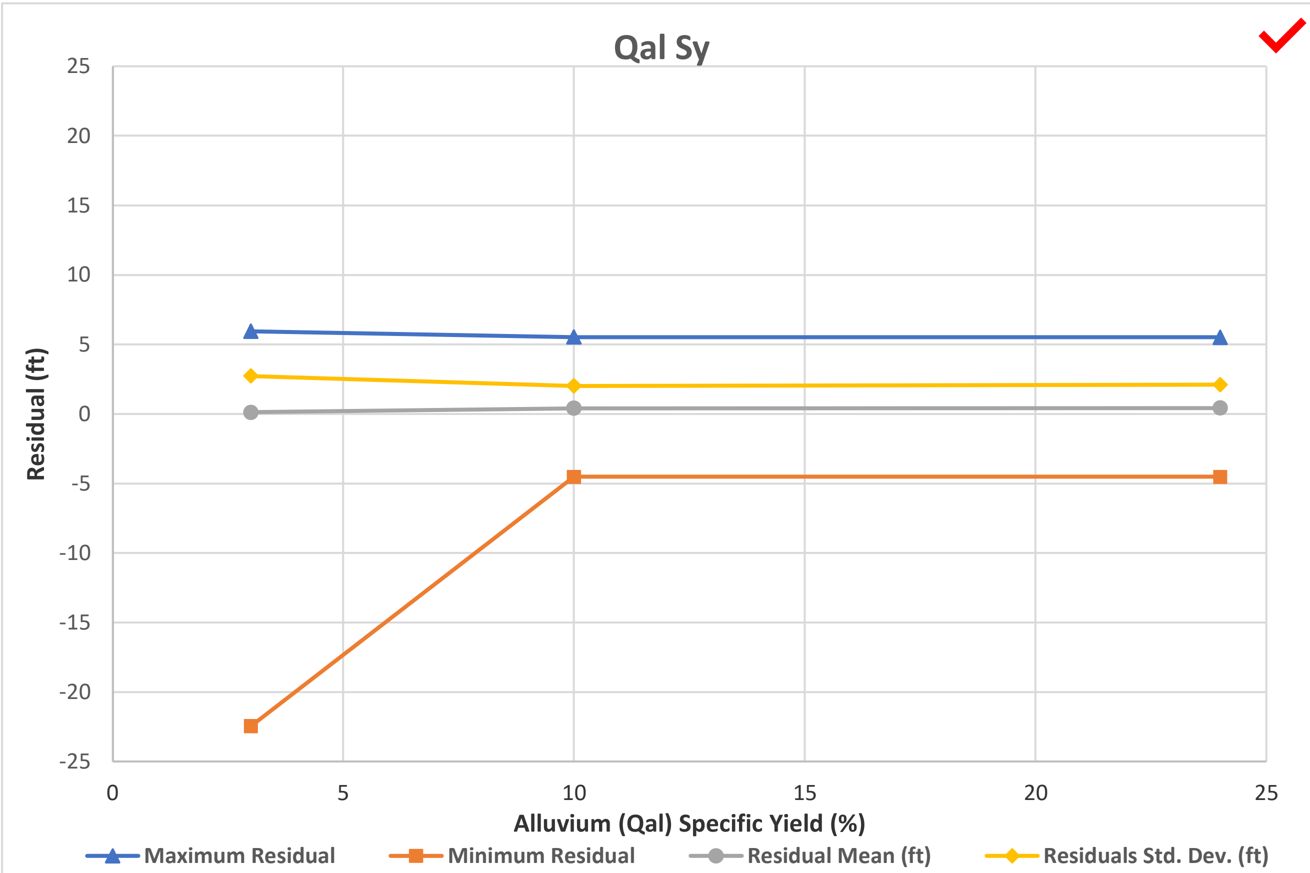
REPRODUCE IN COLOR



Qal Anisotropy (K_h/K_v) [-]	Unweighted Maximum Residual (ft)	Unweighted Minimum Residual (ft)	Unweighted Residual Mean (ft)	Unweighted Residuals Std. Dev. (ft)	Unweighted Scaled RMS	Weighted Scaled RMS
1	5.53	-4.52	0.35	2.05	0.011	0.007
10	5.53	-4.52	0.41	2.01	0.011	0.007
100	5.53	-4.52	0.30	2.05	0.011	0.006

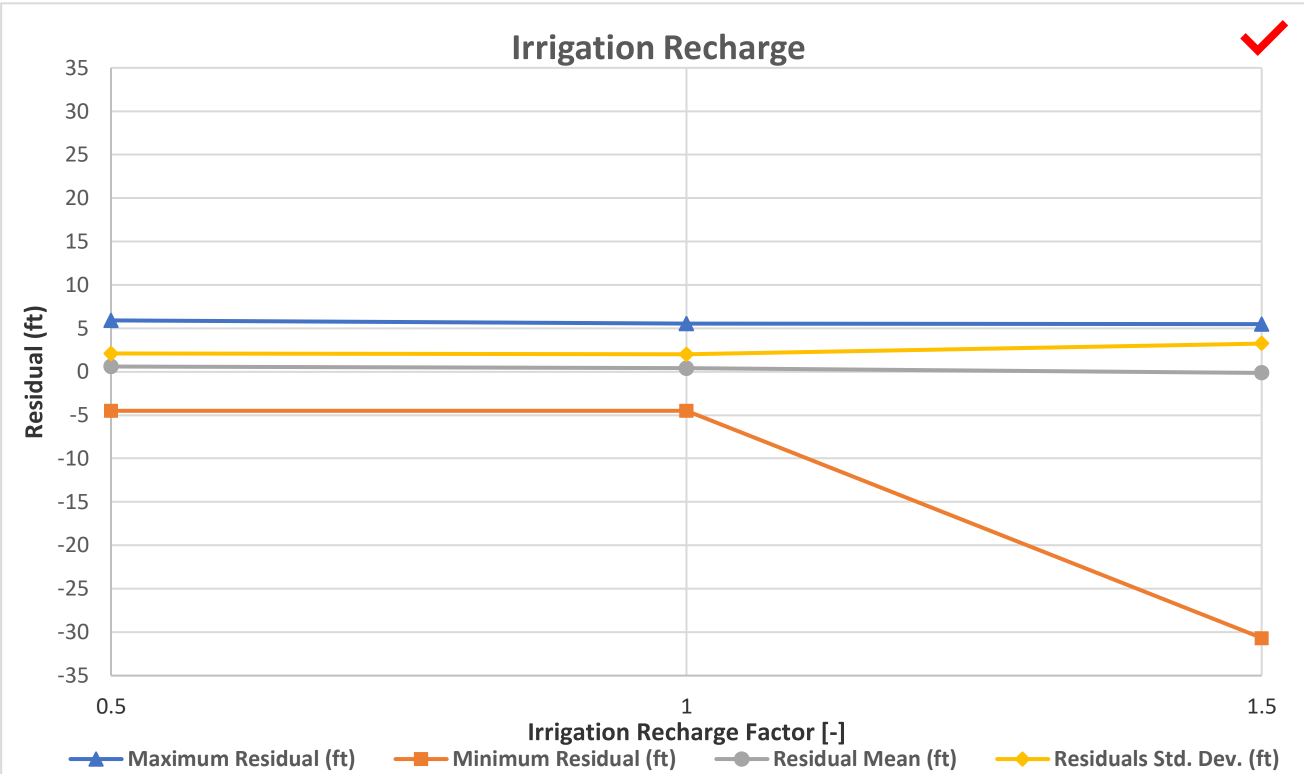
Note: The residual mean and standard deviation are based on 389 observations.

REPRODUCE IN COLOR



Qal Sy (%)	Unweighted Maximum Residual (ft)	Unweighted Minimum Residual (ft)	Unweighted Residual Mean (ft)	Unweighted Residuals Std. Dev. (ft)	Unweighted Scaled RMS	Weighted Scaled RMS
3	5.94	-22.43	0.12	2.73	0.015	0.011
10	5.53	-4.52	0.41	2.01	0.011	0.007
24	5.52	-4.52	0.43	2.11	0.011	0.007

Note: The residual mean and standard deviation are based on 389 observations.



Irrigation Recharge Factor [-]	Unweighted Maximum Residual (ft)	Unweighted Minimum Residual (ft)	Unweighted Residual Mean (ft)	Unweighted Residuals Std. Dev. (ft)	Unweighted Scaled RMS	Weighted Scaled RMS
0.5[1]	5.91	-4.52	0.60	2.10	0.012	0.007
1.0	5.53	-4.52	0.41	2.01	0.011	0.007
1.5[2]	5.49	-30.70	-0.14	3.26	0.017	0.015

Notes:

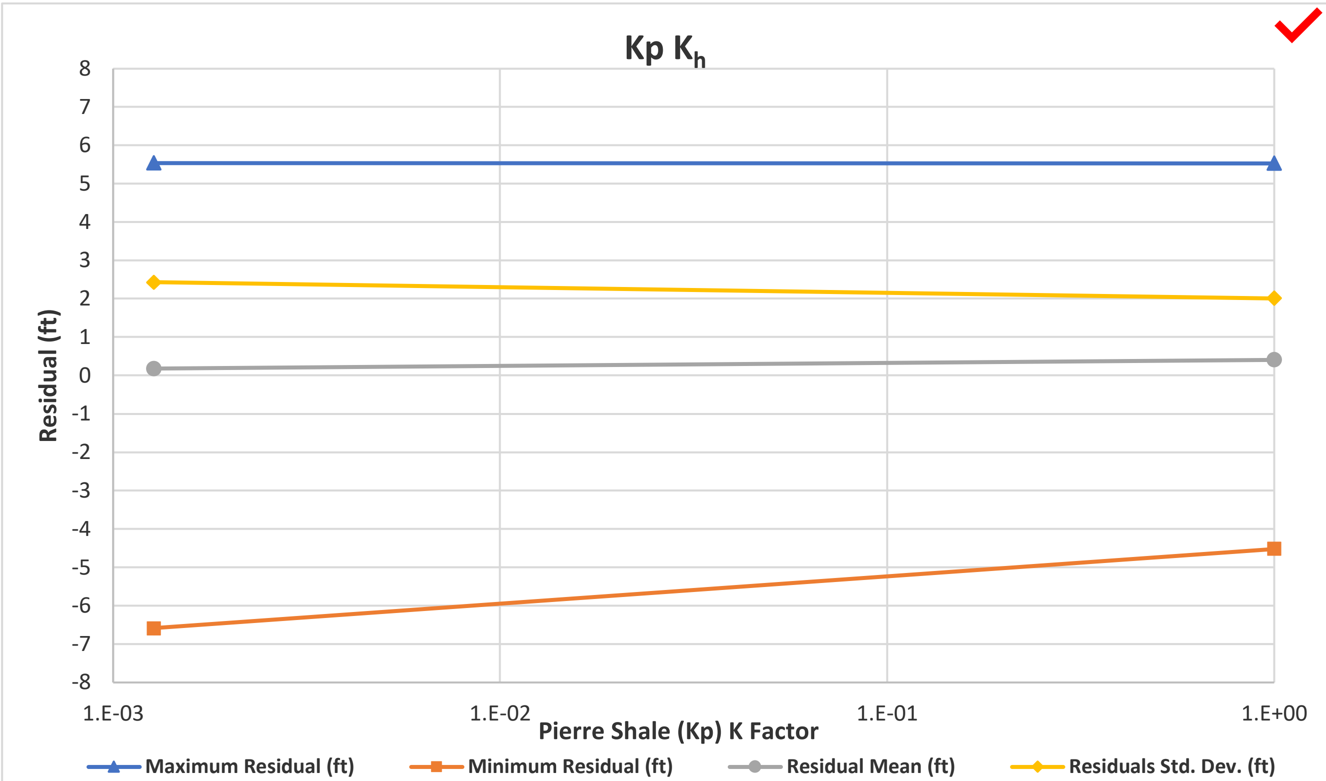
1. The lower bound of the irrigation recharge sensitivity range is 50% lower than the Baseline model value.

2. The upper bound of the irrigation recharge sensitivity range is either 50% higher than the Baseline model value or the maximum available water from the irrigation source ditch, whichever is less.

3. Multipliers are applied to each recharge zone individually; accounting of available and applied irrigation water was completed independently of this appendix.

4. The residual mean and standard deviation are based on 389 observations.

REPRODUCE IN COLOR

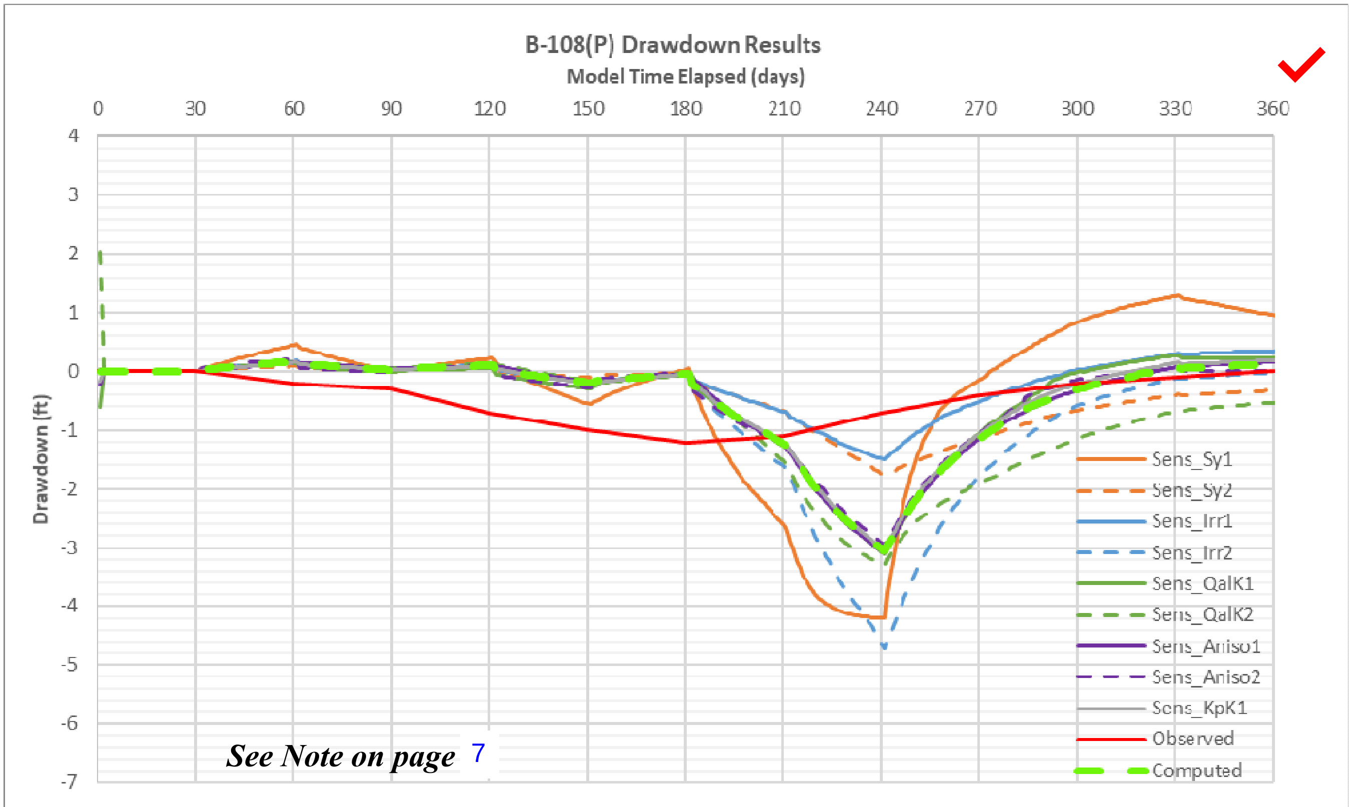


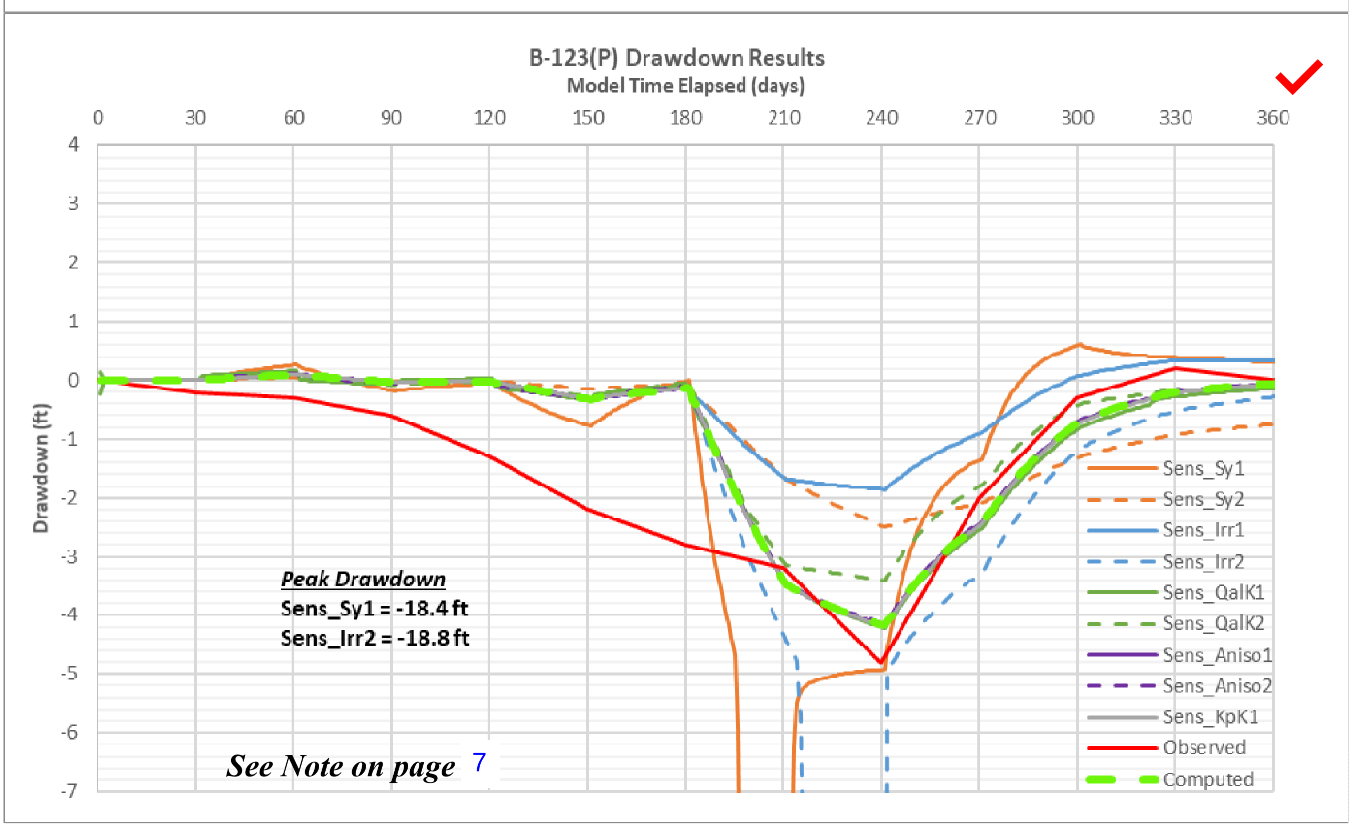
Kp K Factor	Unweighted Maximum Residual (ft)	Unweighted Minimum Residual (ft)	Unweighted Residual Mean (ft)	Unweighted Residual Std. Dev. (ft)	Unweighted Scaled RMS	Weighted Scaled RMS
0.0013	5.54	-6.59	0.18	2.43	0.013	0.007
1	5.53	-4.52	0.41	2.01	0.011	0.007

Notes:

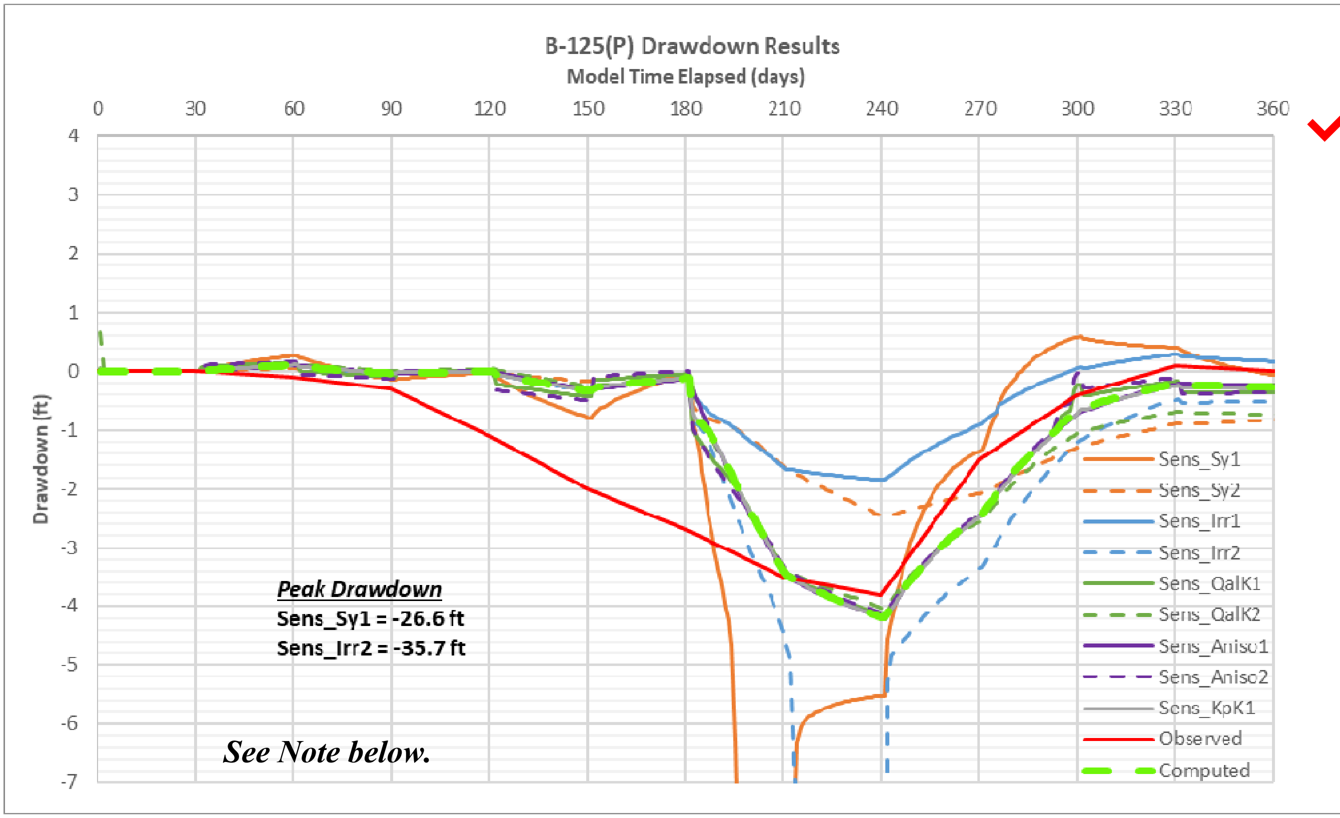
1. The lower bound of the Kp K sensitivity range was set to a value representative of an aquitard. (1.8 E-7 cm/s)
2. Permeability values for both weathered and unweathered bedrock were set equal to the lower value. (1.8 E-7 cm/s)
3. No models were executed with bedrock permeability values higher than the Baseline model.
4. The residual mean and standard deviation are based on 389 observations.

REPRODUCE IN COLOR





REPRODUCE IN COLOR



Note:
The graphs on pages 6 and 7 are drawdown curves for three selected wells on OSMP fields. These graphs illustrate the sensitivity to the High and Low values of evaluated parameters during a one-year transient simulation. Well locations are shown on Figure 6.1.

On each graph, the red line is the observed drawdown in the well and the dashed green line is the drawdown predicted by the Baseline Model. The table below defines the rest of the data series (see also Table 7.1 in the Report text):

Definition of Series Names for Sensitivity Drawdown Plots:

Sensitivity Parameter	Low Values Series Name	High Values Series Name
Alluvium Hydraulic Conductivity	Sens_QalK1	Sens_QalK2
Alluvium Anisotropy Ratio	Sens_Aniso1	Sens_Aniso2
Alluvium Specific Yield	Sens_Sy1	Sens_Sy2
Irrigation Recharge	Sens_Irr1	Sens_Irr2
Bedrock Hydraulic Conductivity	Sens_KpK1	

REPRODUCE IN COLOR

APPENDIX K.5.2

LOCAL SENSITIVITY OF HEADS

	Project	16134	Page	1/17
	Date	~~2/29~~ 3/1/2021	By	ATMerook
Client: City of Boulder	Checked	3/1/21	By	JNH
Subject: Normalized Residual Ranges	Approved	3/5/21	By	ABP

Purpose:

Normalize the computed range of Head residuals at each well for each parameter evaluated during the sensitivity analysis.

Plot the normalized range of Head residuals to provide spatial context for model sensitivity to the evaluated parameters.

Approach:

- A maximum and minimum Head residual are computed at each well for the Baseline model and each sensitivity model. The difference in these maximum and minimum values yields the range of over- and underpredictions computed across the entire model period for each well.
- Model responses to different sensitivity parameters are spatially varied.
- The range of residuals for each well in each sensitivity model are normalized by subtracting the Baseline model residuals range at the corresponding well to support the following conventions:
  - Positive normalized ranges mean the sensitivity value yields a larger range of residuals than the Baseline model at a particular well (weaker fit).
  - Negative normalized ranges mean that the sensitivity value yields a smaller range of residuals than the Baseline model at a particular well (stronger fit).
  - Zero-value normalized ranges mean the sensitivity value produced a similar range of residuals as the Baseline model at a particular well (equivalent fit).
- The normalized residual ranges are grouped by parameter and are shown in plan to illustrate the spatial distribution of parameter sensitivity relative to the Baseline model.

Assumptions/Limitations:

- Unweighted residuals were used for this analysis.
- Wells B-102(P) and B-106(P) occupy cells controlled by boundary conditions at the upstream and downstream edges of the model domain. Heads computed at these wells are not influenced by the parameters changed during sensitivity analysis. These wells are omitted from the attached figures.
- Well B-105(P) is approximately one mile downstream of the proposed Project facilities. Sensitivities in computed Heads at this well will have limited impact on model fit near the proposed Project facilities. This well is omitted from the attached figures.

See Note on page 2.

Results:

- Calculated residual ranges for the Baseline model are presented on p. 8 .
-
- Normalized residual ranges for each well are grouped by model and are tabulated on p. 9-17 .
- Plan maps of normalized residual ranges grouped by sensitivity parameter are presented on p. 3-7 .

	Project	16134	Page	2/17
	Date	~~2/29~~ 3/1/2021	By	ATMerook
Client: City of Boulder	Checked	3/1/21	By	JNH
Subject: Normalized Residual Ranges	Approved	3/5/21	By	ABP

Analysis:
Example Calculation (QalK1 and QalK2 - Well B-101(P)):

Note: Residuals are displayed to the nearest 0.01 foot for presentation purposes. Rounding errors caused by hidden decimals may exist.

Baseline Max. Residual = 2.57 ft (p. 8)
Baseline Min. Residual = -1.41 ft (p. 8)
Baseline Residual Range = |Max. Residual – Min. Residual| = |2.57 ft- (-1.41 ft)| = 3.98 ft (p. 8)

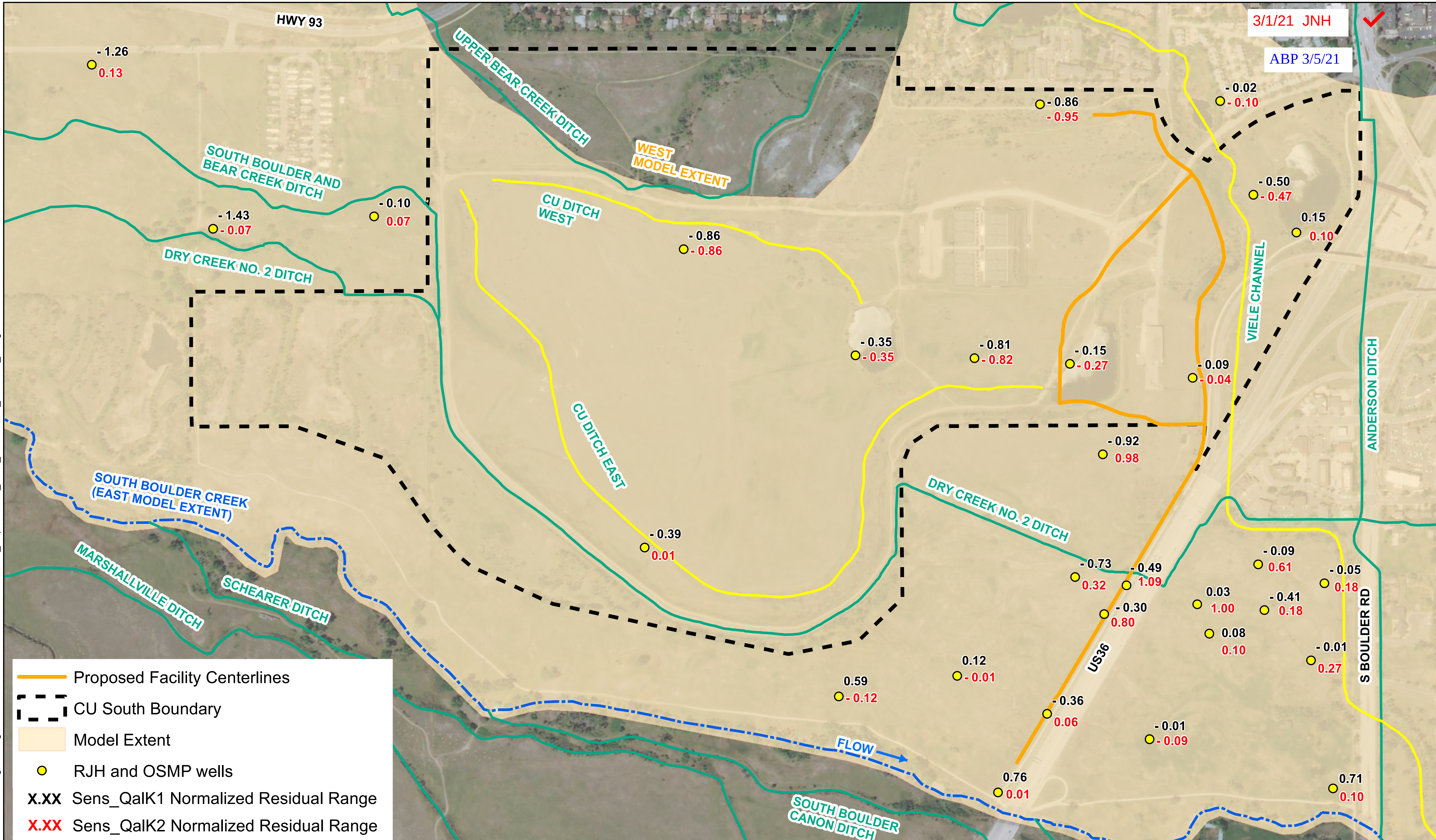
QalK1 Max. Residual = 1.09 ft (p. 9)
QalK1 Min. Residual = -1.63 ft (p. 9)
QalK1 Residual Range = |1.09 ft – (-1.63 ft)| = 2.72 ft (p. 9)
QalK1 Normalized Residual Range = QalK1 Res. Range – Baseline Res. Range = -1.26 ft (p. 8-9)
2.72 ft - 3.98 ft

QalK2 Max. Residual = 2.74 ft (p. 10)
QalK2 Min. Residual = -1.38 ft (p. 10)
QalK2 Residual Range = |2.74 ft - (-1.38 ft)| = 4.11 ft (p. 10)
QalK2 Normalized Residual Range = QalK2 Res. Range – Baseline Res. Range = 0.13 ft (p. 8,10)
4.11 ft - 3.98 ft

The normalized residual ranges for QalK1 and QalK2 are plotted as a group on p. 3 . Well B-101(P) is located in the ~~northwestern~~ upper left (southwest) corner of the map. Well locations are labeled on figures 6.1 in the report.

- The plan maps of normalized residual ranges grouped by sensitivity parameter are shown on p. 3-7 . Normalized residual ranges from sensitivity models using parameter values lower than the Baseline model (e.g., QalK1) are shown in black. Normalized residual ranges from sensitivity models using parameter values larger than the Baseline model (e.g., QalK2) are shown in red.

Note: Normalized residual ranges may not necessarily correlate to overall model calibration because they do not account for how residuals from each stress period vary between the max. and min. observed values.



NOTE:
1. THE MODELED AREA EXTENDS BEYOND THE LIMITS OF THIS FIGURE AND 3 WELLS ARE NOT SHOWN.

0 250 500 1,000 Feet

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REPRODUCE IN COLOR

CITY OF BOULDER

RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

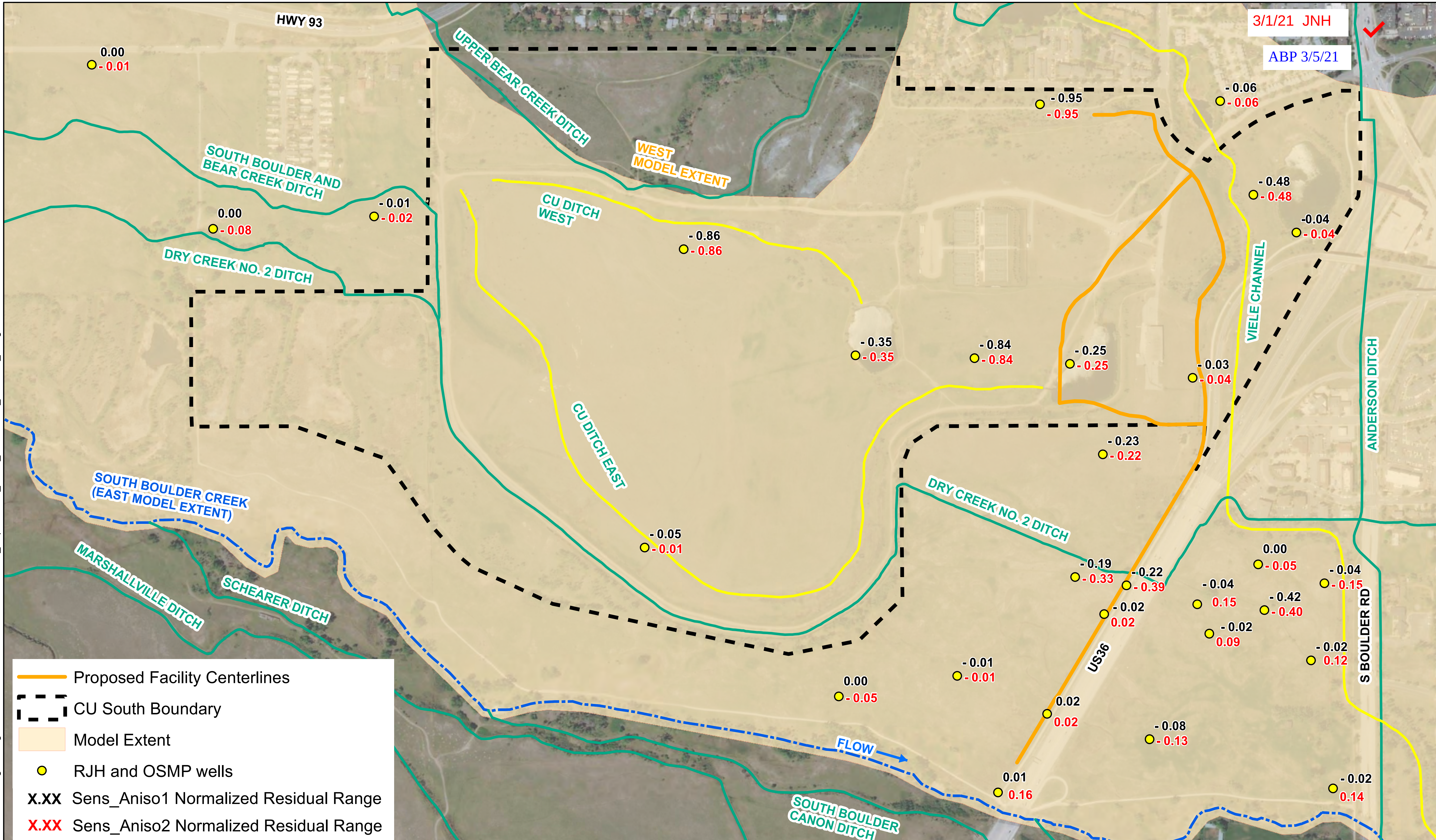
PROJECT NO. 16134

NORMALIZED RESIDUAL RANGES - QAL HORIZONTAL HYDRAULIC CONDUCTIVITY

April 2021

Figure K.5.1

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline_Report\K.5.1_QalK_Normalized_Residual_Ranges.mxd



NOTE:
1. THE MODELED AREA EXTENDS BEYOND THE LIMITS OF THIS FIGURE AND 3 WELLS ARE NOT SHOWN.

0 250 500 1,000 Feet

N

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RJH CONSULTANTS, INC.

SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

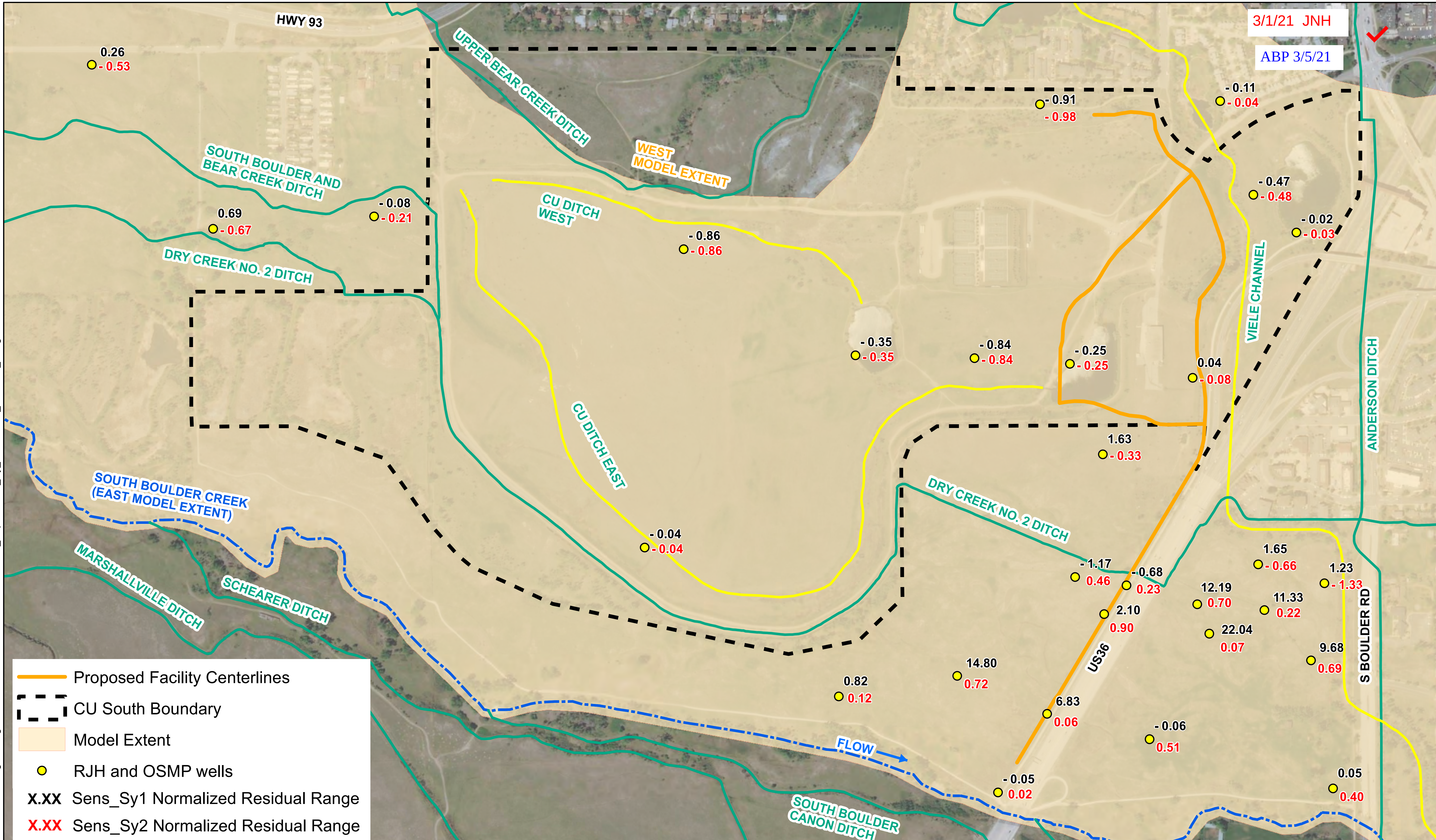
PROJECT NO. 16134

NORMALIZED RESIDUAL RANGES - QAL ANIOSTROPY

April 2021

Figure K.5.2

P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline_Report\K.5.2_Aniso_Normalized_Residual_Ranges.mxd



NOTE:
1. THE MODELED AREA EXTENDS BEYOND THE LIMITS OF THIS FIGURE AND 3 WELLS ARE NOT SHOWN.

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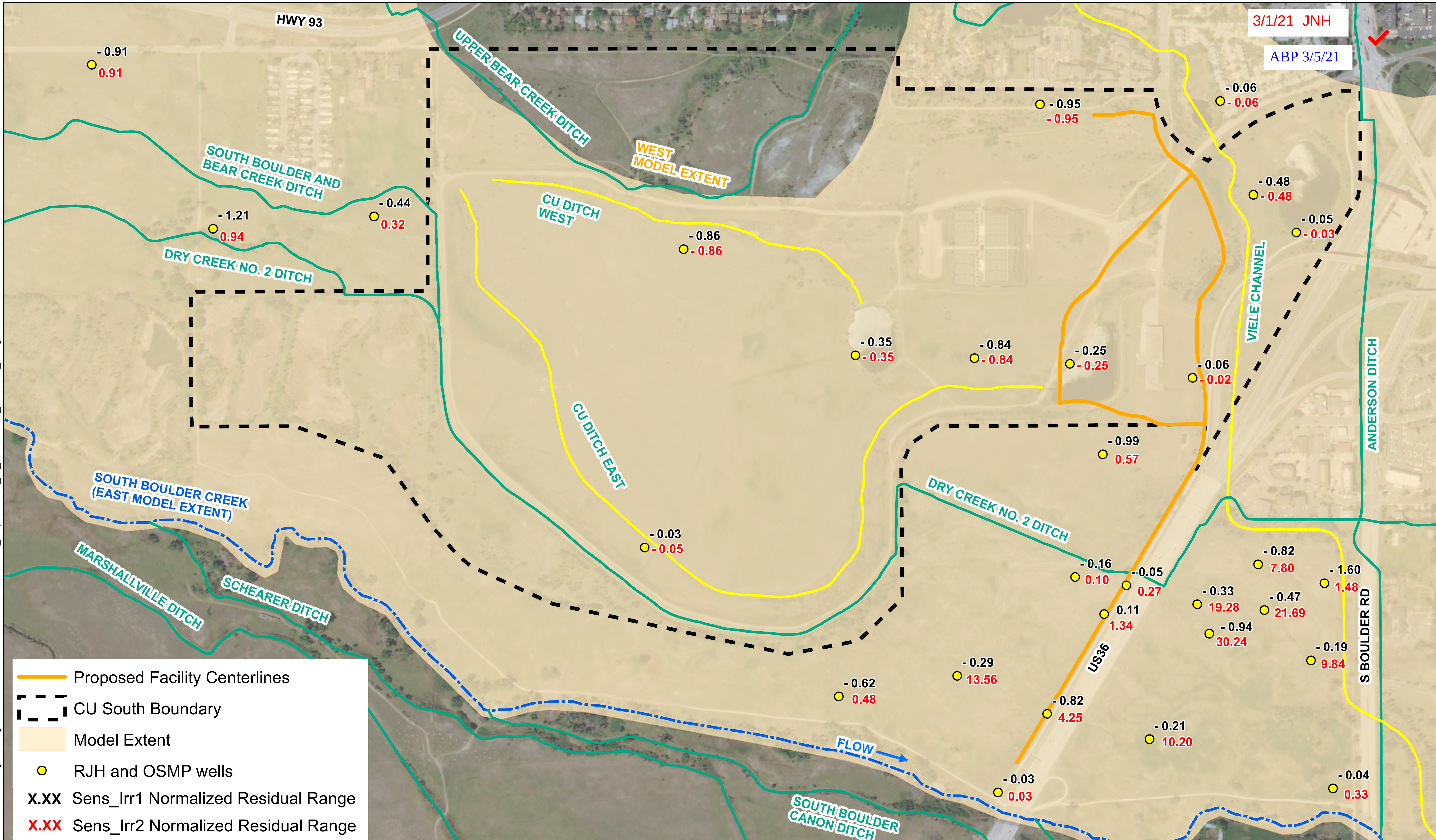
NORMALIZED RESIDUAL RANGES - QAL SPECIFIC YIELD

April 2021

Figure K.5.3



P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline_Report\K.5.4_Irr_Normalized_Residual_Ranges.mxd

NOTE:
1. THE MODELED AREA EXTENDS BEYOND THE LIMITS OF THIS FIGURE AND 3 WELLS ARE NOT SHOWN.

0 250 500 1,000 Feet

N

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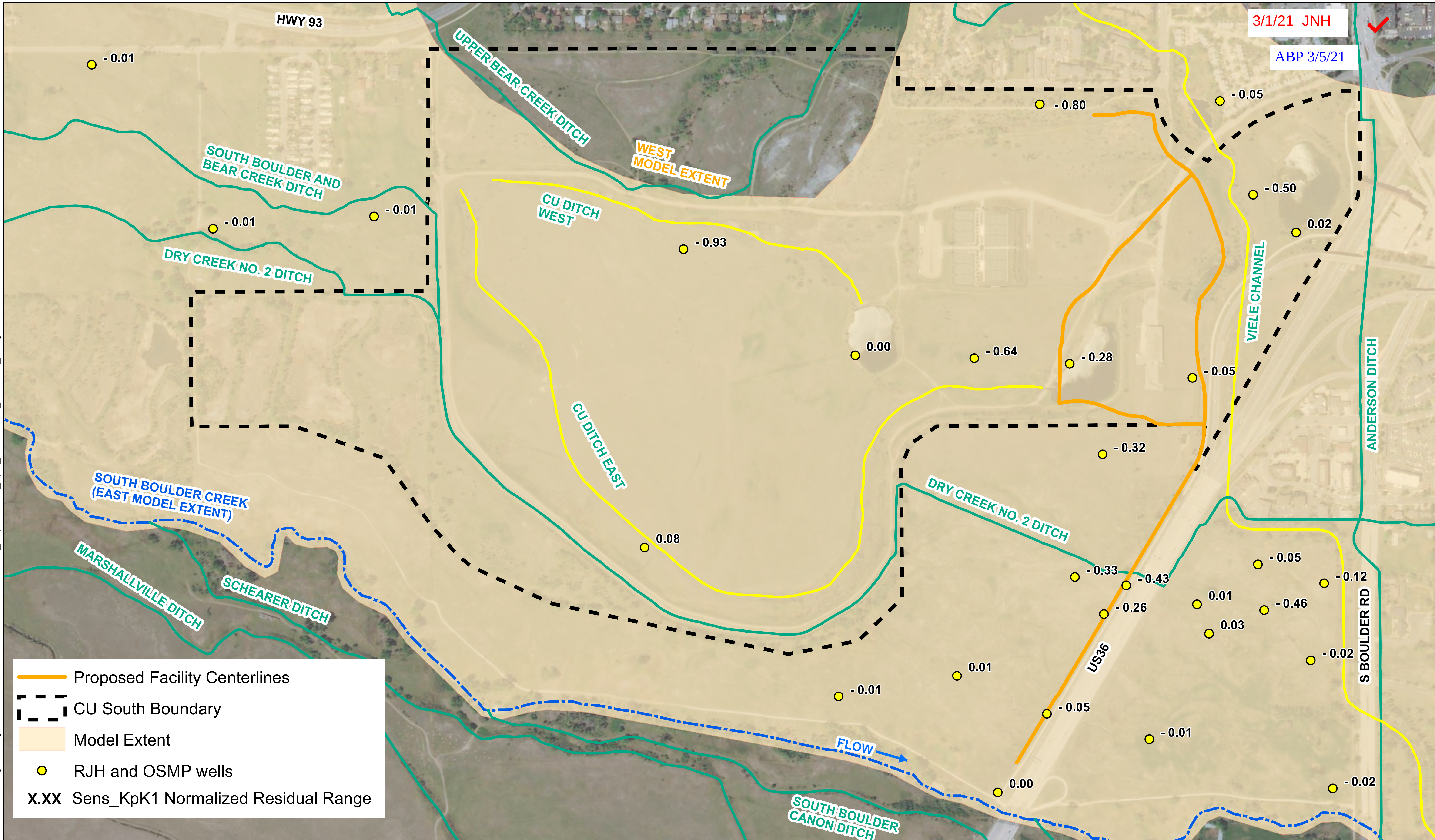
PROJECT NO. 16134

NORMALIZED RESIDUAL RANGES - IRRIGATION RECHARGE

April 2021

Figure K.5.4



P:\16134 - South Boulder Creek\Engineering\GIS\Geotechnical\Groundwater\Baseline_Report\K.5.5_KpK_Normalized_Residual_Ranges.mxd

NOTE:
1. THE MODELED AREA EXTENDS BEYOND THE LIMITS OF THIS FIGURE AND 3 WELLS ARE NOT SHOWN.

0 250 500 1,000 Feet

N

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SOUTH BOULDER CREEK REGIONAL DETENTION - BASELINE GROUNDWATER MODEL REPORT

PROJECT NO. 16134

NORMALIZED RESIDUAL RANGES - KP HYDRAULIC CONDUCTIVITY

April 2021

Figure K.5.5

ABP 3/5/21

Baseline Model			
Well	**Max. Residual (ft)**	**Min. Residual (ft)**	**Baseline Range (ft)**
B-101(P)	2.57	-1.41	3.98
B-102(P)	0.30	-0.40	0.70
B-103(P)	5.53	3.17	2.36
B-105(P)	1.89	-1.50	3.39
B-106(P)	0.40	-0.90	1.30
B-107(P)	1.08	-1.26	2.34
B-108(P)	1.54	-1.99	3.53
B-109(P)	0.53	-0.79	1.32
B-110(P)	2.91	-1.52	4.43
B-111(P)	3.55	2.44	1.11
B-112(P)	-2.44	-4.08	1.63
B-113(P)	0.64	-2.79	3.43
B-114(P)	-0.81	-4.33	3.52
B-115(P)	1.21	-4.52	5.73
B-116(P)	2.66	-0.06	2.72
B-117(P)	0.60	-2.48	3.08
B-118(P)	5.25	0.72	4.53
B-119(P)	2.97	-0.35	3.32
B-121(P)	-0.05	-2.51	2.46
B-122(P)	3.26	-1.81	5.08
B-123(P)	1.98	-1.15	3.13
B-124(P)	2.68	-0.46	3.14
B-125(P)	3.07	-0.45	3.52
B-126(P)	1.07	-2.70	3.77
OSMP_1S	2.57	-0.73	3.30
OSMP_2N	3.95	0.34	3.61
OSMP_2S	2.72	-0.03	2.75
OSMP_4	3.55	-1.35	4.89
OSMP_6	3.30	-0.73	4.03
SW-101	3.64	0.88	2.76
SW-102	1.08	0.41	0.67
SW-103	4.78	3.91	0.87

Note:
1. ' 'Baseline Range' = |'Max Residual' - 'Min. Residual'|.

QalK1				
Well	**Max. Residual (ft)**	**Min. Residual (ft)**	**Range (ft)**	**Normalized Range (ft)**
B-101(P)	1.09	-1.63	2.72	-1.26
B-102(P)	0.30	-0.40	0.70	0.00
B-103(P)	3.87	2.95	0.93	-1.43
B-105(P)	1.60	-4.28	5.87	2.49
B-106(P)	0.40	-0.90	1.30	0.00
B-107(P)	0.81	-2.25	3.06	0.71
B-108(P)	0.82	-2.65	3.47	-0.05
B-109(P)	1.39	-0.69	2.08	0.76
B-110(P)	1.83	-2.11	3.94	-0.49
B-111(P)	-2.65	-3.67	1.02	-0.09
B-112(P)	-3.51	-4.65	1.13	-0.50
B-113(P)	-0.07	-3.48	3.41	-0.02
B-114(P)	-4.53	-7.18	2.66	-0.86
B-115(P)	0.31	-4.61	4.92	-0.81
B-116(P)	3.05	-0.26	3.31	0.59
B-117(P)	0.69	-2.00	2.69	-0.39
B-118(P)	4.38	0.72	3.66	-0.86
B-119(P)	2.65	-0.57	3.22	-0.10
B-121(P)	-2.69	-4.23	1.54	-0.92
B-122(P)	1.94	-2.40	4.34	-0.73
B-123(P)	2.16	-1.09	3.26	0.12
B-124(P)	2.46	-0.60	3.06	-0.09
B-125(P)	3.25	-0.34	3.60	0.08
B-126(P)	1.21	-2.55	3.76	-0.01
OSMP_1S	2.41	-0.59	3.00	-0.30
OSMP_2N	3.72	0.12	3.60	-0.01
OSMP_2S	2.79	0.41	2.39	-0.36
OSMP_4	2.77	-1.71	4.48	-0.41
OSMP_6	3.11	-0.96	4.06	0.03
SW-101	3.29	0.88	2.41	-0.35
SW-102	0.74	0.22	0.52	-0.15
SW-103	1.52	0.51	1.01	0.15

Notes:
1. 'Range' = |'Max. Residual' - 'Min. Residual'|.
2. 'Normalized Range' = 'Range' - 'Baseline Range'

3/1/21 JNH

ABP 3/5/21

QalK2				
Well	**Max. Residual (ft)**	**Min. Residual (ft)**	**Range (ft)**	**Normalized Range (ft)**
B-101(P)	2.74	-1.38	4.11	0.13
B-102(P)	0.30	-0.40	0.70	0.00
B-103(P)	5.26	2.98	2.28	-0.07
B-105(P)	1.90	-1.17	3.07	-0.32
B-106(P)	0.40	-0.90	1.30	0.00
B-107(P)	0.30	-2.14	2.44	0.10
B-108(P)	3.50	-0.20	3.70	0.18
B-109(P)	0.54	-0.80	1.33	0.01
B-110(P)	5.36	-0.16	5.53	1.09
B-111(P)	4.76	3.68	1.07	-0.04
B-112(P)	-2.86	-4.03	1.16	-0.47
B-113(P)	0.62	-2.71	3.33	-0.10
B-114(P)	-1.31	-3.88	2.57	-0.95
B-115(P)	0.42	-4.49	4.91	-0.82
B-116(P)	2.80	0.20	2.60	-0.12
B-117(P)	0.54	-2.55	3.09	0.01
B-118(P)	4.38	0.72	3.66	-0.86
B-119(P)	2.63	-0.76	3.39	0.07
B-121(P)	2.26	-1.18	3.44	0.98
B-122(P)	5.13	-0.27	5.40	0.32
B-123(P)	1.84	-1.28	3.12	-0.01
B-124(P)	4.62	0.86	3.76	0.61
B-125(P)	3.67	0.05	3.62	0.10
B-126(P)	0.34	-3.33	3.68	-0.09
OSMP_1S	4.06	-0.05	4.11	0.80
OSMP_2N	4.91	1.03	3.88	0.27
OSMP_2S	2.43	-0.39	2.81	0.06
OSMP_4	6.11	1.03	5.08	0.18
OSMP_6	4.90	-0.13	5.03	1.00
SW-101	3.29	0.88	2.41	-0.35
SW-102	0.85	0.45	0.40	-0.27
SW-103	5.66	4.69	0.96	0.10

Notes:

1. 'Range' = |'Max. Residual' - 'Min. Residual'|.
2. 'Normalized Range' = 'Range' - 'Baseline Range'

3/1/21 JNH

ABP 3/5/21

		Aniso1		
Well	**Max. Residual (ft)**	**Min. Residual (ft)**	**Range (ft)**	**Normalized Range (ft)**
B-101(P)	2.58	-1.41	3.99	0.00
B-102(P)	0.30	-0.40	0.70	0.00
B-103(P)	5.53	3.18	2.35	0.00
B-105(P)	1.86	-1.51	3.36	-0.02
B-106(P)	0.40	-0.90	1.30	0.00
B-107(P)	1.04	-1.29	2.32	-0.02
B-108(P)	1.50	-1.98	3.48	-0.04
B-109(P)	0.56	-0.77	1.33	0.01
B-110(P)	2.98	-1.23	4.21	-0.22
B-111(P)	3.54	2.46	1.08	-0.03
B-112(P)	-2.92	-4.08	1.16	-0.48
B-113(P)	0.59	-2.79	3.37	-0.06
B-114(P)	-1.76	-4.33	2.57	-0.95
B-115(P)	0.37	-4.52	4.89	-0.84
B-116(P)	2.67	-0.06	2.72	0.00
B-117(P)	0.56	-2.47	3.03	-0.05
B-118(P)	4.38	0.72	3.66	-0.86
B-119(P)	2.97	-0.34	3.31	-0.01
B-121(P)	-0.03	-2.26	2.23	-0.23
B-122(P)	3.31	-1.58	4.89	-0.19
B-123(P)	1.98	-1.14	3.12	-0.01
B-124(P)	2.68	-0.46	3.14	0.00
B-125(P)	3.05	-0.46	3.50	-0.02
B-126(P)	0.98	-2.71	3.69	-0.08
OSMP_1S	2.54	-0.74	3.28	-0.02
OSMP_2N	3.94	0.35	3.59	-0.02
OSMP_2S	2.72	-0.05	2.77	0.02
OSMP_4	3.57	-0.91	4.48	-0.42
OSMP_6	3.30	-0.69	3.99	-0.04
SW-101	3.29	0.88	2.41	-0.35
SW-102	0.83	0.41	0.42	-0.25
SW-103	4.74	3.92	0.83	-0.04

Notes:
1. 'Range' = |'Max. Residual' - 'Min. Residual'|.
2. 'Normalized Range' = 'Range' - 'Baseline Range'

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3/1/21 JNH

ABP 3/5/21

Aniso2				
Well	Max. Residual (ft)	Min. Residual (ft)	Range (ft)	Normalized Range (ft)
B-101(P)	2.57	-1.41	3.98	-0.01
B-102(P)	0.30	-0.40	0.70	0.00
B-103(P)	5.53	3.26	2.28	-0.08
B-105(P)	1.91	-1.52	3.43	0.04
B-106(P)	0.40	-0.89	1.29	-0.01
B-107(P)	1.17	-1.32	2.48	0.14
B-108(P)	1.24	-2.13	3.37	-0.15
B-109(P)	0.75	-0.73	1.48	0.16
B-110(P)	2.38	-1.67	4.05	-0.39
B-111(P)	3.50	2.43	1.07	-0.04
B-112(P)	-2.92	-4.08	1.16	-0.48
B-113(P)	0.57	-2.80	3.37	-0.06
B-114(P)	-1.77	-4.34	2.57	-0.95
B-115(P)	0.37	-4.52	4.89	-0.84
B-116(P)	2.59	-0.08	2.67	-0.05
B-117(P)	0.55	-2.51	3.07	-0.01
B-118(P)	4.38	0.72	3.66	-0.86
B-119(P)	2.99	-0.31	3.30	-0.02
B-121(P)	-0.11	-2.35	2.24	-0.22
B-122(P)	2.93	-1.82	4.75	-0.33
B-123(P)	2.00	-1.12	3.13	-0.01
B-124(P)	2.70	-0.39	3.09	-0.05
B-125(P)	3.23	-0.38	3.61	0.09
B-126(P)	1.03	-2.61	3.64	-0.13
OSMP_1S	2.75	-0.57	3.32	0.02
OSMP_2N	4.01	0.28	3.73	0.12
OSMP_2S	2.79	0.02	2.77	0.02
OSMP_4	3.30	-1.19	4.49	-0.40
OSMP_6	3.33	-0.84	4.18	0.15
SW-101	3.29	0.88	2.41	-0.35
SW-102	0.83	0.41	0.42	-0.25
SW-103	4.74	3.91	0.83	-0.04

Notes:
1. 'Range' = |'Max. Residual' - 'Min. Residual'|.
2. 'Normalized Range' = 'Range' - 'Baseline Range'

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3/1/21 JNH

ABP 3/5/21

		Sy1		
Well	**Max. Residual (ft)**	**Min. Residual (ft)**	**Range (ft)**	**Normalized Range (ft)**
B-101(P)	2.69	-1.56	4.25	0.26
B-102(P)	0.30	-0.40	0.70	0.00
B-103(P)	5.94	2.89	3.05	0.69
B-105(P)	1.98	-1.58	3.56	0.17
B-106(P)	0.40	-0.90	1.30	0.00
B-107(P)	1.15	-1.23	2.39	0.05
B-108(P)	1.59	-3.16	4.76	1.23
B-109(P)	0.54	-0.74	1.27	-0.05
B-110(P)	2.82	-0.93	3.75	-0.68
B-111(P)	3.54	2.38	1.15	0.04
B-112(P)	-2.92	-4.08	1.16	-0.47
B-113(P)	0.54	-2.78	3.32	-0.11
B-114(P)	-1.77	-4.38	2.61	-0.91
B-115(P)	0.37	-4.52	4.89	-0.84
B-116(P)	2.76	-0.78	3.54	0.82
B-117(P)	0.56	-2.48	3.04	-0.04
B-118(P)	4.38	0.72	3.66	-0.86
B-119(P)	2.70	-0.54	3.24	-0.08
B-121(P)	-0.30	-4.40	4.10	1.63
B-122(P)	3.10	-0.81	3.90	-1.17
B-123(P)	2.10	-15.83	17.94	14.80
B-124(P)	2.74	-2.06	4.79	1.65
B-125(P)	3.13	-22.43	25.56	22.04
B-126(P)	1.11	-2.60	3.71	-0.06
OSMP_1S	2.49	-2.91	5.40	2.10
OSMP_2N	4.01	-9.27	13.29	9.68
OSMP_2S	2.70	-6.88	9.58	6.83
OSMP_4	3.49	-12.73	16.22	11.33
OSMP_6	3.36	-12.86	16.22	12.19
SW-101	3.29	0.88	2.41	-0.35
SW-102	0.83	0.41	0.42	-0.25
SW-103	4.72	3.87	0.85	-0.02

Notes:

1. 'Range' = |'Max. Residual' - 'Min. Residual'|.
2. 'Normalized Range' = 'Range' - 'Baseline Range'

3/1/21 JNH

ABP 3/5/21

Sy2				
Well	Max. Residual (ft)	Min. Residual (ft)	Range (ft)	Normalized Range (ft)
B-101(P)	2.62	-0.83	3.45	-0.53
B-102(P)	0.30	-0.40	0.70	0.00
B-103(P)	5.52	3.84	1.68	-0.67
B-105(P)	1.76	-1.37	3.14	-0.25
B-106(P)	0.40	-0.90	1.30	0.00
B-107(P)	1.05	-1.69	2.74	0.40
B-108(P)	1.48	-0.72	2.19	-1.33
B-109(P)	0.52	-0.82	1.34	0.02
B-110(P)	3.24	-1.42	4.66	0.23
B-111(P)	3.53	2.50	1.04	-0.08
B-112(P)	-2.92	-4.08	1.16	-0.48
B-113(P)	0.59	-2.80	3.39	-0.04
B-114(P)	-1.77	-4.31	2.54	-0.98
B-115(P)	0.37	-4.52	4.89	-0.84
B-116(P)	2.61	-0.23	2.84	0.12
B-117(P)	0.56	-2.48	3.04	-0.04
B-118(P)	4.38	0.72	3.66	-0.86
B-119(P)	2.92	-0.19	3.11	-0.21
B-121(P)	0.43	-1.70	2.13	-0.33
B-122(P)	3.71	-1.83	5.53	0.46
B-123(P)	2.04	-1.81	3.85	0.72
B-124(P)	2.72	0.23	2.49	-0.66
B-125(P)	3.12	-0.47	3.59	0.07
B-126(P)	1.04	-3.24	4.28	0.51
OSMP_1S	3.30	-0.91	4.20	0.90
OSMP_2N	3.99	-0.31	4.30	0.69
OSMP_2S	2.79	-0.02	2.81	0.06
OSMP_4	3.61	-1.51	5.12	0.22
OSMP_6	3.35	-1.39	4.74	0.70
SW-101	3.29	0.88	2.41	-0.35
SW-102	0.83	0.41	0.42	-0.25
SW-103	4.76	3.92	0.84	-0.03

Notes:

1. 'Range' = |'Max. Residual' - 'Min. Residual'|.
2. 'Normalized Range' = 'Range' - 'Baseline Range'

		Irr1		
Well	**Max. Residual (ft)**	**Min. Residual (ft)**	**Range (ft)**	**Normalized Range (ft)**
B-101(P)	2.57	-0.50	3.08	-0.91
B-102(P)	0.30	-0.40	0.70	0.00
B-103(P)	5.91	4.76	1.15	-1.21
B-105(P)	1.90	-1.33	3.22	-0.17
B-106(P)	0.40	-0.90	1.30	0.00
B-107(P)	1.07	-1.23	2.31	-0.04
B-108(P)	1.46	-0.47	1.92	-1.60
B-109(P)	0.52	-0.77	1.29	-0.03
B-110(P)	3.38	-1.00	4.38	-0.05
B-111(P)	3.54	2.48	1.05	-0.06
B-112(P)	-2.92	-4.08	1.16	-0.48
B-113(P)	0.58	-2.79	3.37	-0.06
B-114(P)	-1.76	-4.33	2.57	-0.95
B-115(P)	0.37	-4.52	4.89	-0.84
B-116(P)	2.66	0.56	2.10	-0.62
B-117(P)	0.58	-2.48	3.05	-0.03
B-118(P)	4.38	0.72	3.66	-0.86
B-119(P)	3.55	0.67	2.88	-0.44
B-121(P)	0.18	-1.30	1.48	-0.99
B-122(P)	3.83	-1.09	4.91	-0.16
B-123(P)	2.16	-0.69	2.85	-0.29
B-124(P)	2.68	0.36	2.32	-0.82
B-125(P)	3.07	0.49	2.58	-0.94
B-126(P)	0.98	-2.58	3.56	-0.21
OSMP_1S	3.33	-0.08	3.41	0.11
OSMP_2N	3.95	0.53	3.42	-0.19
OSMP_2S	2.72	0.80	1.93	-0.82
OSMP_4	3.55	-0.88	4.42	-0.47
OSMP_6	3.30	-0.40	3.70	-0.33
SW-101	3.29	0.88	2.41	-0.35
SW-102	0.83	0.41	0.42	-0.25
SW-103	4.74	3.93	0.82	-0.05

Notes:

1. 'Range' = |'Max. Residual' - 'Min. Residual'|.
2. 'Normalized Range' = 'Range' - 'Baseline Range'

3/1/21 JNH

ABP 3/5/21

		Irr2		
Well	Max. Residual (ft)	Min. Residual (ft)	Range (ft)	Normalized Range (ft)
B-101(P)	2.57	-2.32	4.90	0.91
B-102(P)	0.30	-0.40	0.70	0.00
B-103(P)	5.49	2.20	3.29	0.94
B-105(P)	1.85	-2.26	4.11	0.73
B-106(P)	0.40	-0.90	1.30	0.00
B-107(P)	1.07	-1.60	2.67	0.33
B-108(P)	1.46	-3.55	5.01	1.48
B-109(P)	0.52	-0.82	1.34	0.03
B-110(P)	2.91	-1.79	4.70	0.27
B-111(P)	3.54	2.44	1.10	-0.02
B-112(P)	-2.92	-4.08	1.16	-0.48
B-113(P)	0.58	-2.79	3.37	-0.06
B-114(P)	-1.76	-4.33	2.57	-0.95
B-115(P)	0.37	-4.52	4.89	-0.84
B-116(P)	2.66	-0.54	3.20	0.48
B-117(P)	0.55	-2.48	3.03	-0.05
B-118(P)	4.38	0.72	3.66	-0.86
B-119(P)	2.55	-1.10	3.64	0.32
B-121(P)	-0.05	-3.08	3.03	0.57
B-122(P)	3.26	-1.91	5.18	0.10
B-123(P)	1.98	-14.71	16.69	13.56
B-124(P)	2.68	-8.27	10.95	7.80
B-125(P)	3.07	-30.70	33.76	30.24
B-126(P)	0.98	-12.99	13.97	10.20
OSMP_1S	2.57	-2.07	4.64	1.34
OSMP_2N	3.95	-9.50	13.45	9.84
OSMP_2S	2.72	-4.27	7.00	4.25
OSMP_4	3.55	-23.04	26.58	21.69
OSMP_6	3.30	-20.02	23.31	19.28
SW-101	3.29	0.88	2.41	-0.35
SW-102	0.83	0.41	0.42	-0.25
SW-103	4.74	3.91	0.84	-0.03

Notes:

1. 'Range' = |'Max. Residual' - 'Min. Residual'|.
2. 'Normalized Range' = 'Range' - 'Baseline Range'

		KpK1		
Well	**Max. Residual (ft)**	**Min. Residual (ft)**	**Range (ft)**	**Normalized Range (ft)**
B-101(P)	2.55	-1.43	3.98	-0.01
B-102(P)	0.30	-0.40	0.70	0.00
B-103(P)	5.54	3.19	2.35	-0.01
B-105(P)	1.86	-1.54	3.40	0.01
B-106(P)	0.40	-0.90	1.30	0.00
B-107(P)	1.10	-1.23	2.33	-0.02
B-108(P)	1.29	-2.12	3.41	-0.12
B-109(P)	0.52	-0.80	1.32	0.00
B-110(P)	2.51	-1.49	4.00	-0.43
B-111(P)	4.06	3.00	1.06	-0.05
B-112(P)	-5.46	-6.59	1.13	-0.50
B-113(P)	0.50	-2.88	3.38	-0.05
B-114(P)	-3.73	-6.45	2.72	-0.80
B-115(P)	-0.11	-5.20	5.09	-0.64
B-116(P)	2.62	-0.09	2.71	-0.01
B-117(P)	0.97	-2.19	3.16	0.08
B-118(P)	4.59	0.99	3.60	-0.93
B-119(P)	2.95	-0.36	3.31	-0.01
B-121(P)	-0.28	-2.43	2.15	-0.32
B-122(P)	3.00	-1.74	4.74	-0.33
B-123(P)	1.98	-1.16	3.14	0.01
B-124(P)	2.58	-0.52	3.10	-0.05
B-125(P)	3.12	-0.43	3.55	0.03
B-126(P)	1.08	-2.68	3.76	-0.01
OSMP_1S	2.26	-0.78	3.04	-0.26
OSMP_2N	3.85	0.26	3.59	-0.02
OSMP_2S	2.73	0.03	2.70	-0.05
OSMP_4	3.35	-1.09	4.44	-0.46
OSMP_6	3.29	-0.75	4.04	0.01
SW-101	3.67	0.92	2.76	0.00
SW-102	0.79	0.41	0.39	-0.28
SW-103	4.94	4.05	0.89	0.02

Notes:
1. 'Range' = |'Max. Residual' - 'Min. Residual'|.
2. 'Normalized Range' = 'Range' - 'Baseline Range'

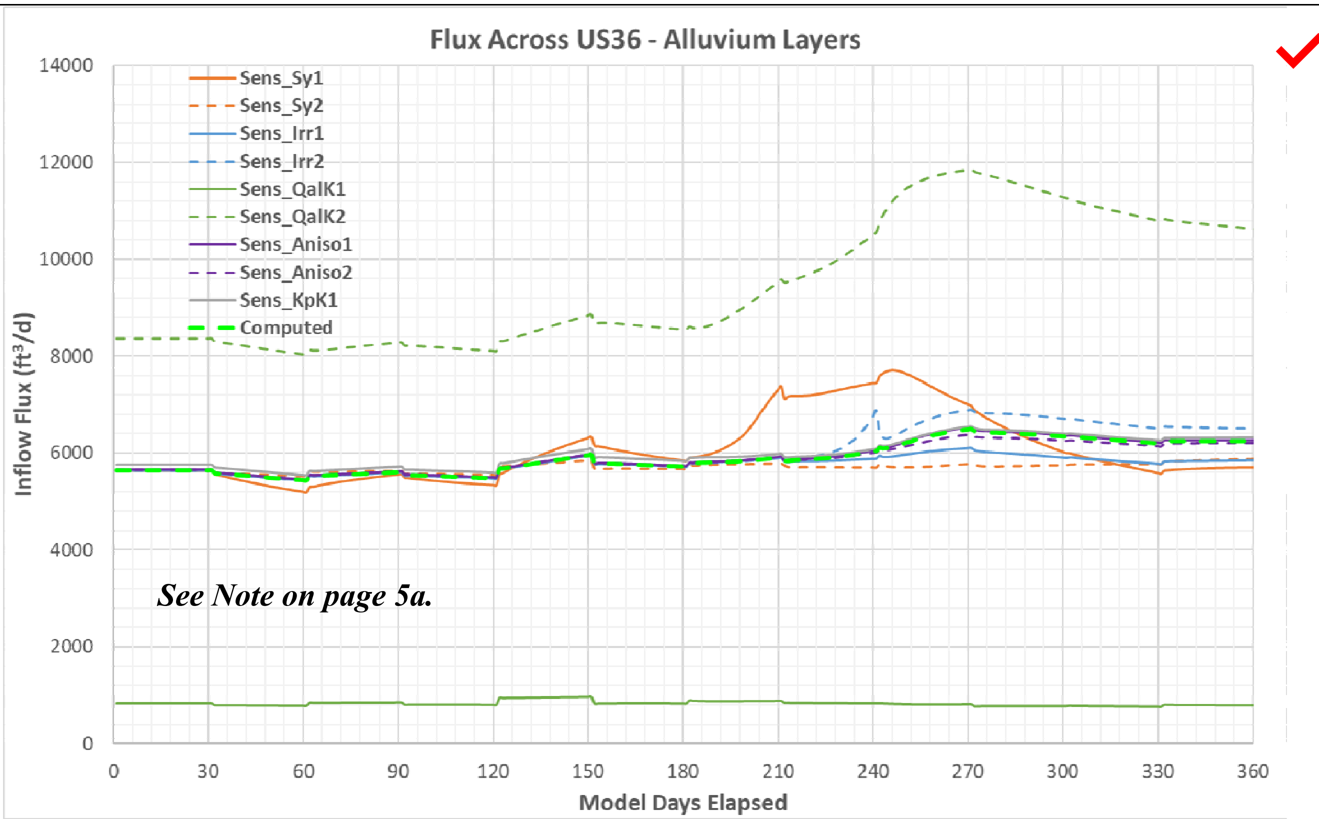
APPENDIX K.5.3

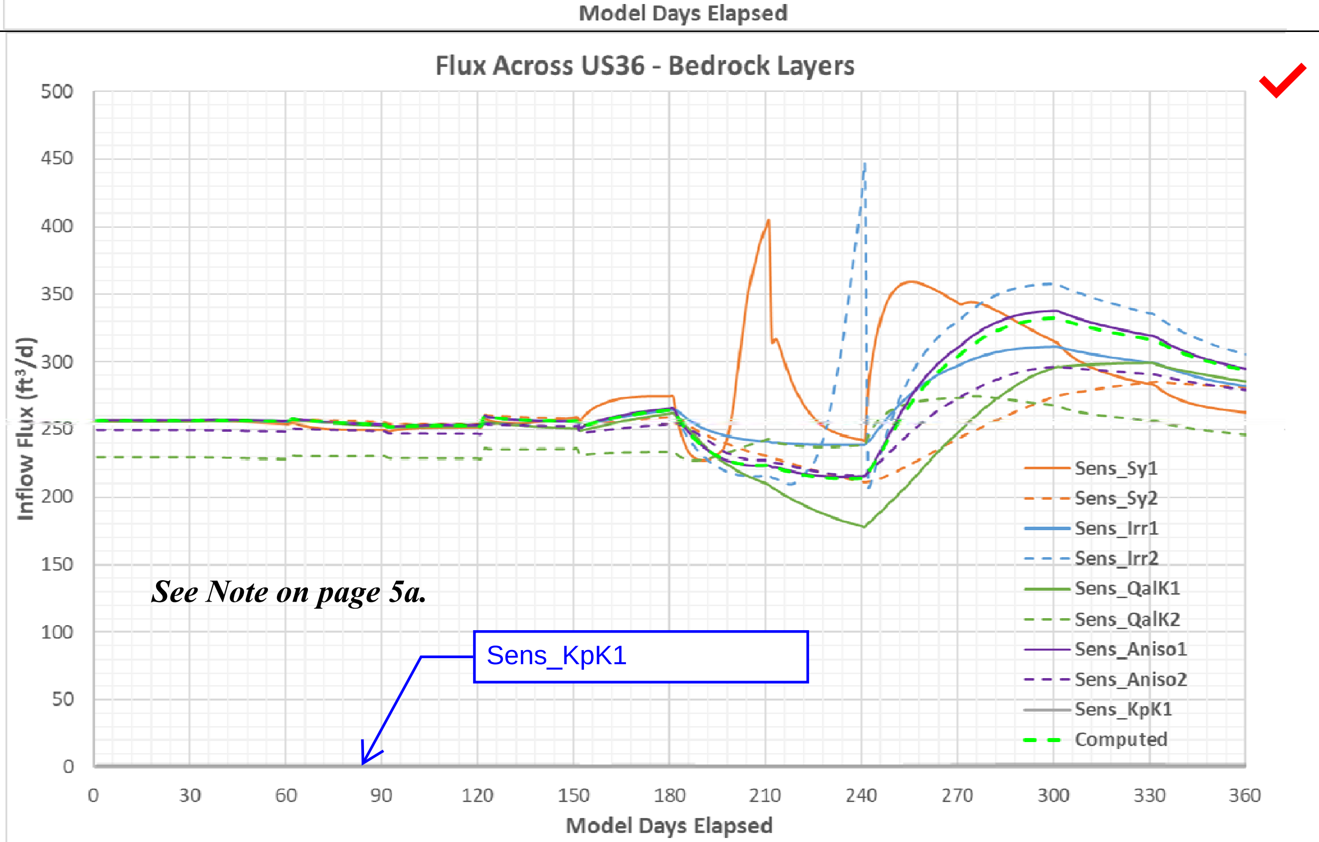
SENSITIVITY OF FLOWS

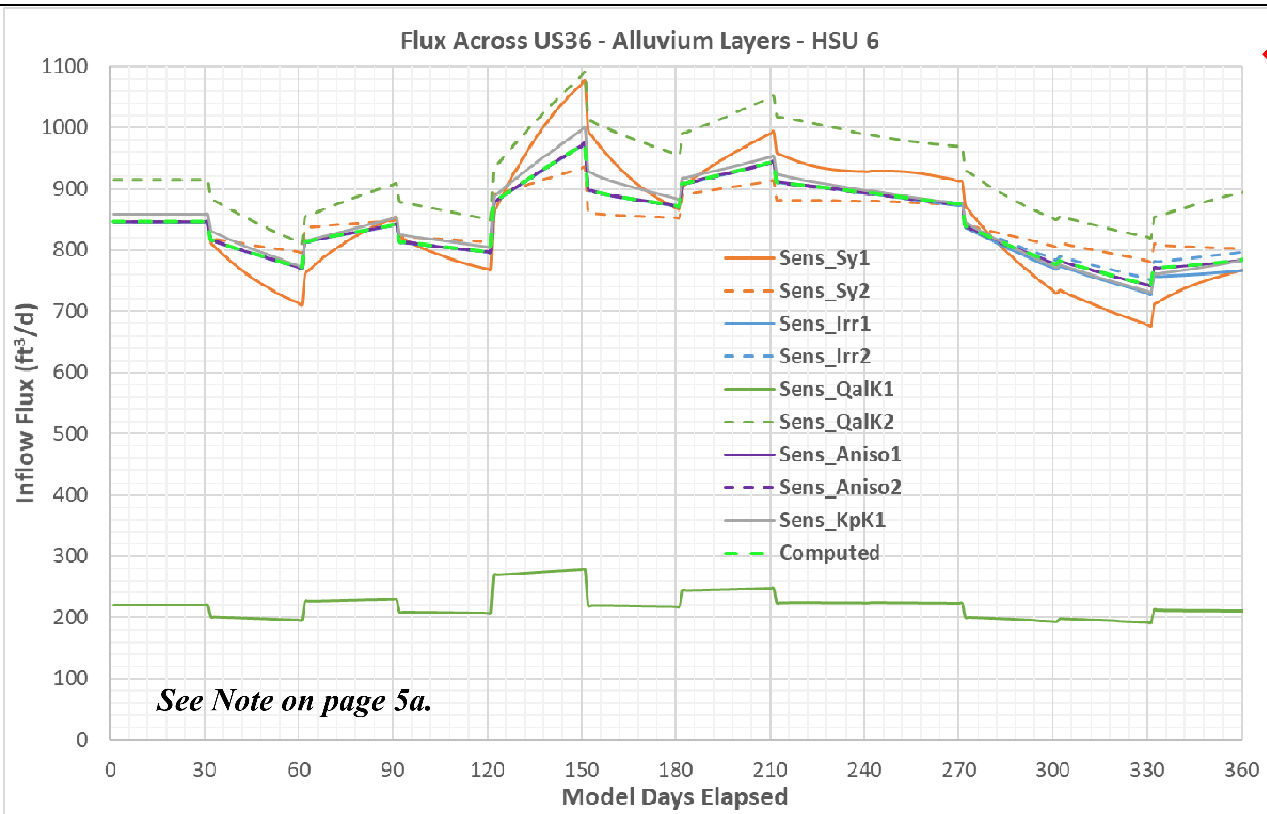
Project	16134	Page	1/5
Date	2/18/2021	By	ATMerook
Checked	3/1/21	By	JNH
Approved	3/5/21	By	ABP

Client: City of Boulder

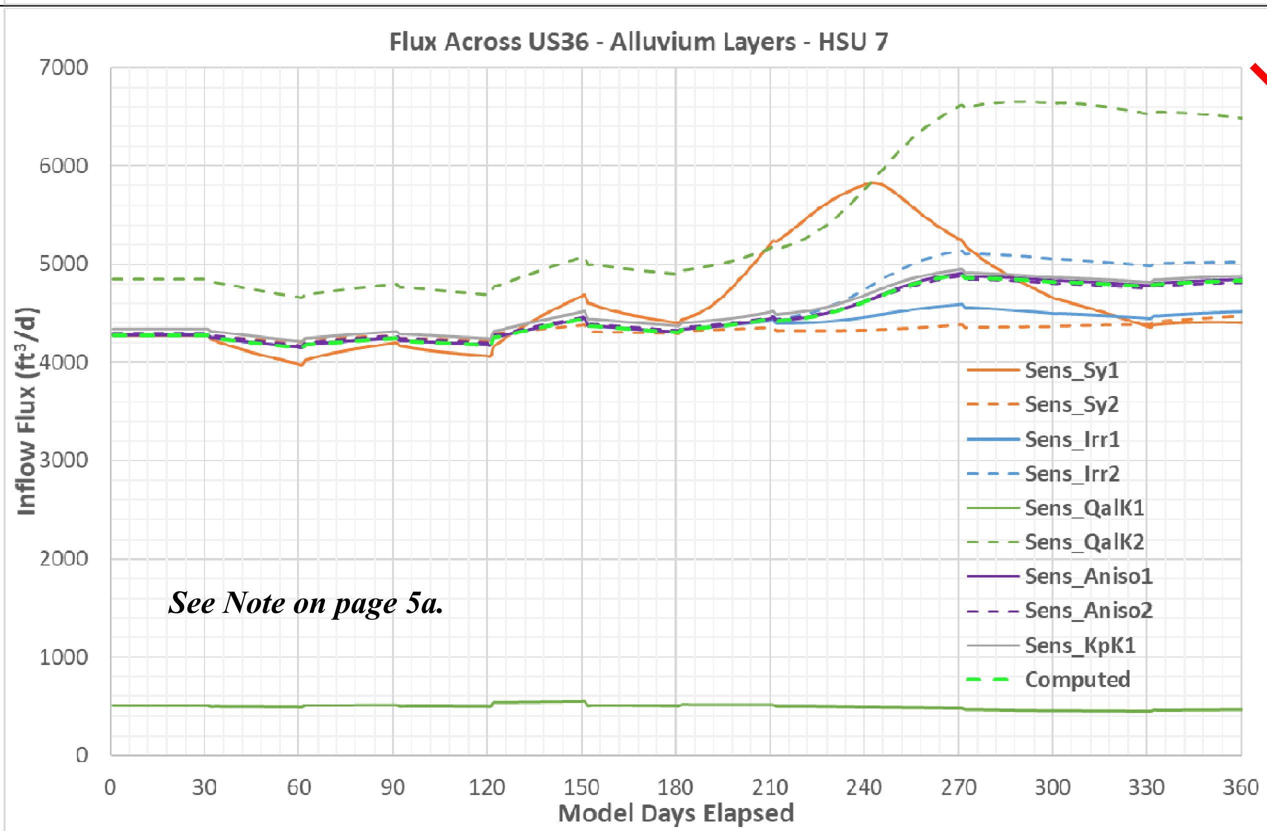
Subject: Flux Across US36





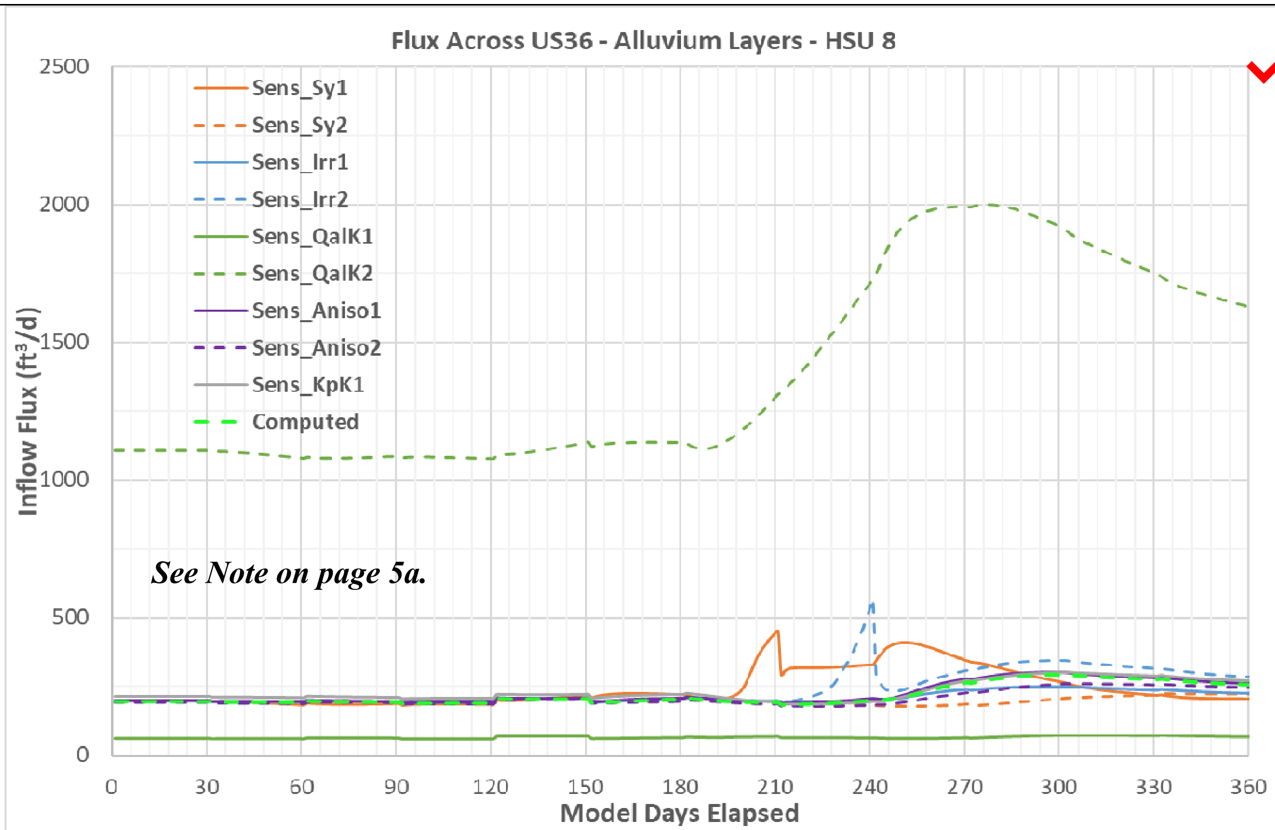


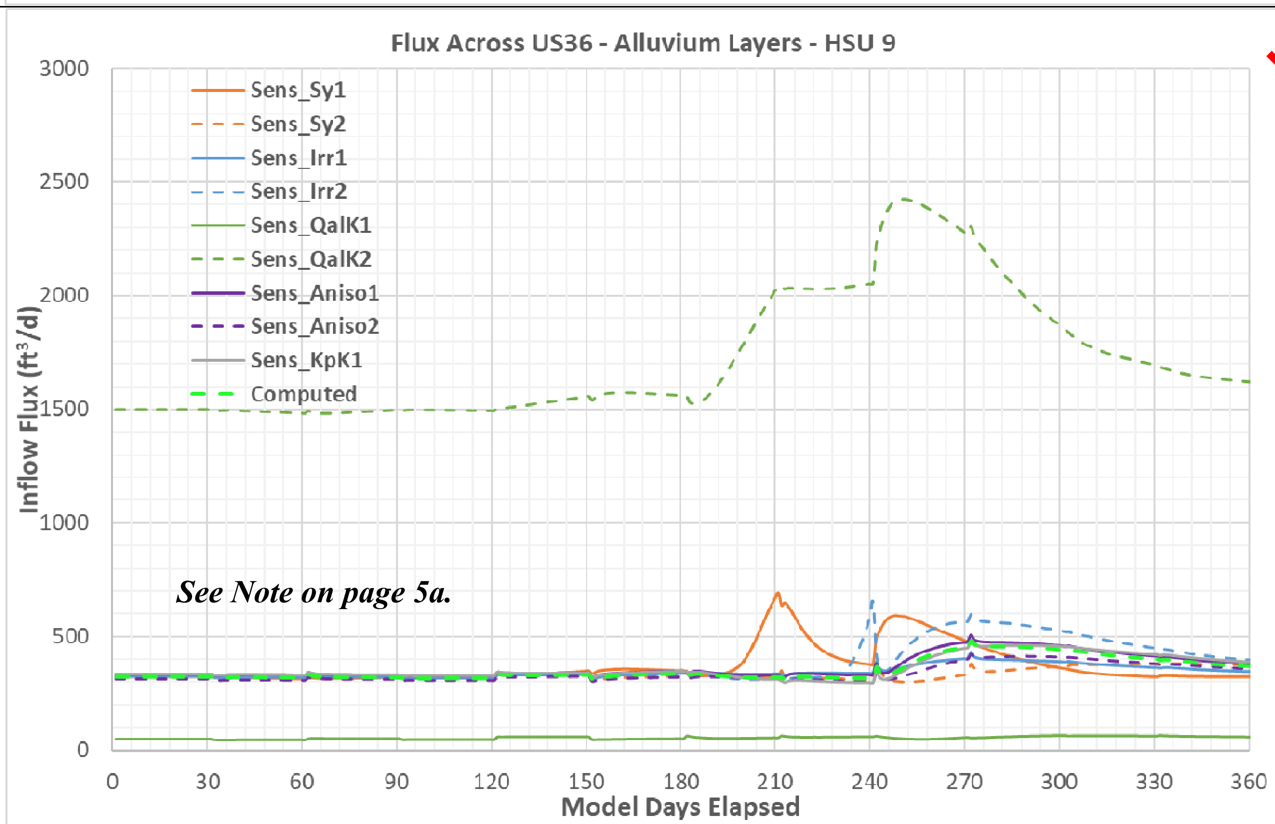
See Note on page 5a.



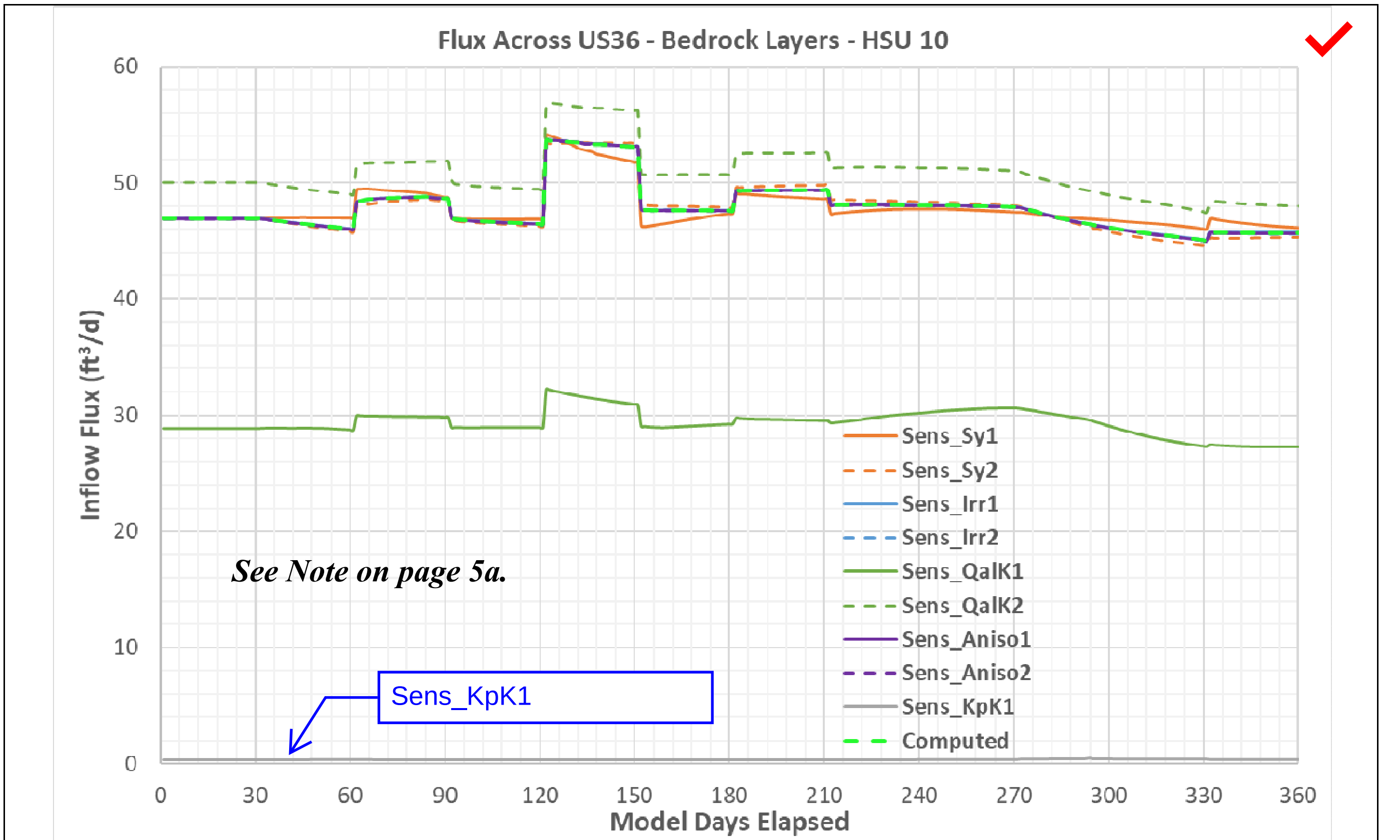
See Note on page 5a.

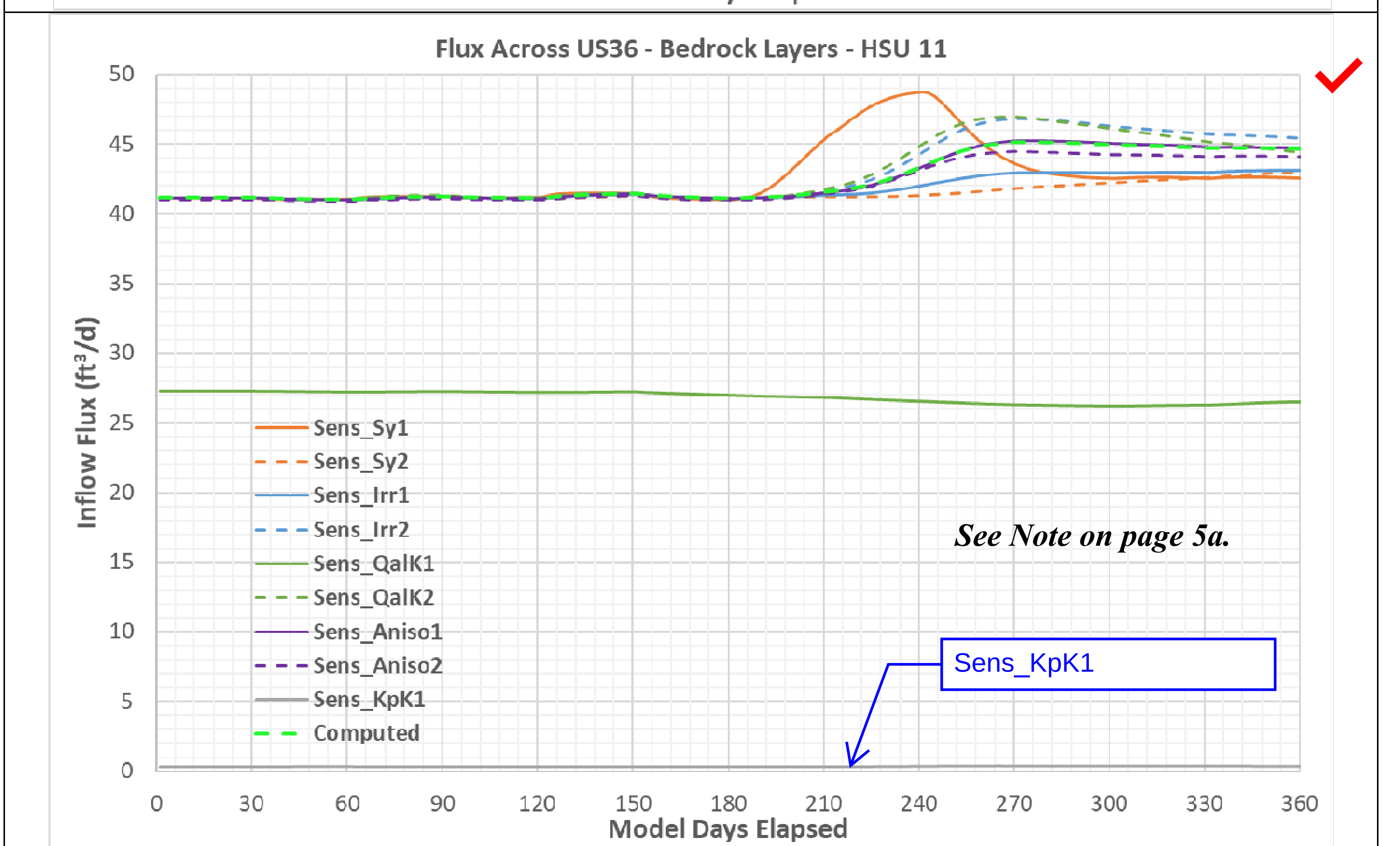
		Project	16134	Page	3/5
		Date	2/18/2021	By	ATMerook
Client	City of Boulder	Checked	3/1/21	By	JNH
Subject	Flux Across US36	Approved	3/5/21	By	ABP



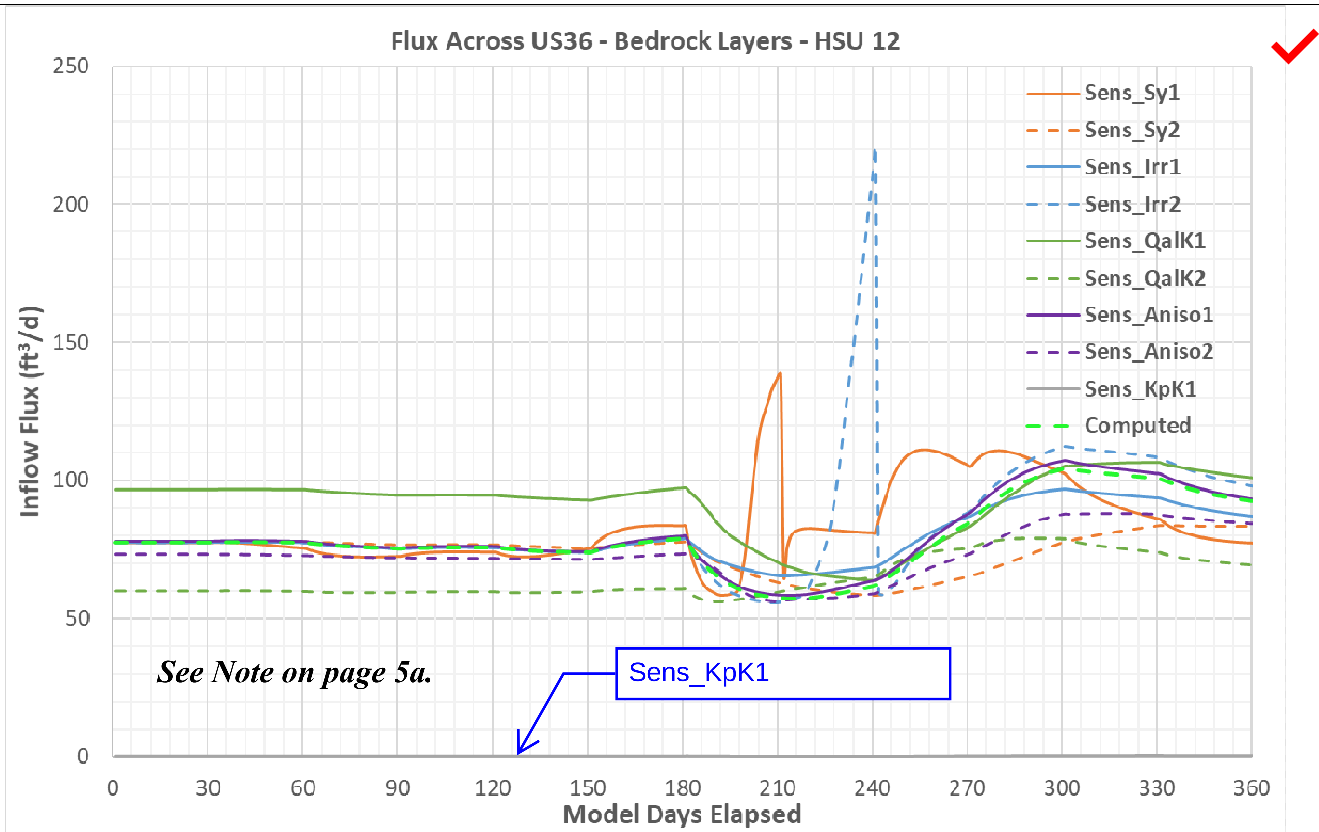


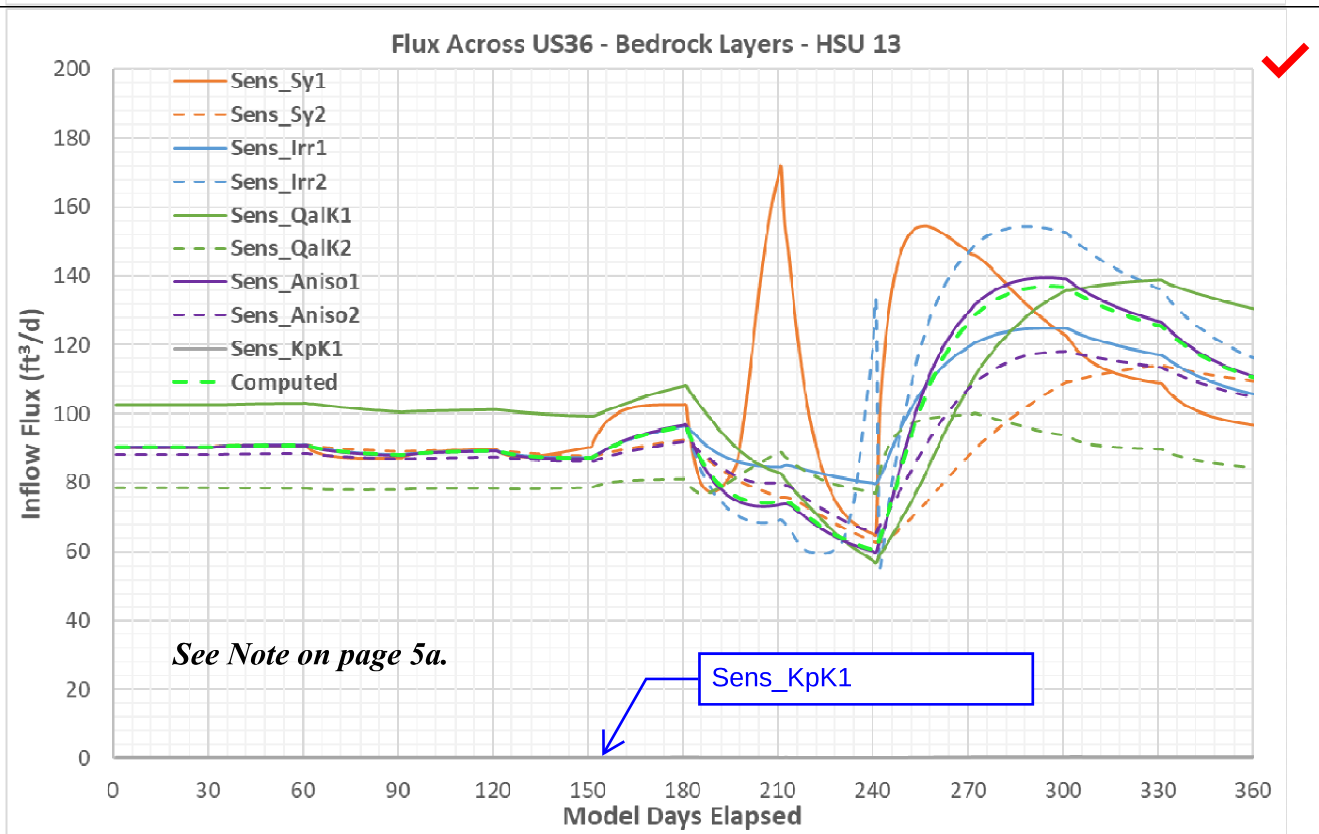
		Project	16134	Page	4/5
		Date	2/18/2021	By	ATMerook
Client	City of Boulder	Checked	3/1/21	By	JNH
Subject	Flux Across US36	Approved	3/5/21	By	ABP





		Project	16134	Page	5/5
		Date	2/18/2021	By	ATMerook
Client	City of Boulder	Checked	3/1/21	By	JNH
Subject	Flux Across US36	Approved	3/5/21	By	ABP





On each graph, the dashed green line is the inflow flux across US36 predicted by the Baseline Model. The table below defines the rest of the data series (see also Table 7.1 in the Report text):

Definition of Series Names for Sensitivity Flux Plots:

Sensitivity Parameter	Low Values Series Name	High Values Series Name
Alluvium Hydraulic Conductivity	Sens_QalK1	Sens_QalK2
Alluvium Anisotropy Ratio	Sens_Aniso1	Sens_Aniso2
Alluvium Specific Yield	Sens_Sy1	Sens_Sy2
Irrigation Recharge	Sens_Irr1	Sens_Irr2
Bedrock Hydraulic Conductivity	Sens_KpK1	

APPENDIX L

INDEPENDENT TECHNICAL REVIEW COMMENTS

Mary C. Hill and Associates, LLC

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Louisville, Colorado 80027
MCHill.LLC@gmail.com
July 2, 2021

Dr. Adam Prochaska, Ph.D., P.E.*, P.G.^
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Englewood, CO 80112
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* CO, NE, and WI
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www.rjh-consultants.com aprochaska@rjh-consultants.com

Dear Dr. Prochaska:

I appreciate the opportunity to review this report. You and your group have accomplished a great deal and deserve great praise.

I was tasked with addressing six questions related to the groundwater model being developed by RJH Consultants in relation to the South Boulder Creek Regional Detention Project. To conduct this assessment, I reviewed the report provided as file

> 16134_21-06-17_SBC_Baseline_Groundwater_Model_Report.pdf,

with the title

> Draft Baseline Groundwater Model Report, South Boulder Creek Regional Detention Project, Boulder County, Colorado,

to be Submitted to

> City of Boulder, 1777 Broadway, Boulder, CO 80301

by

> RJH Consultants, Inc., 9800 Mt. Pyramid Court, Suite 330, Englewood, Colorado 80112, 303-225-4611, www.rjh-consultants.com.

The report was dated July 2021.

I had also provided comment during model development since April 2019, including an internal review of an earlier draft of this report in August 2020 and more final versions of the report in November 2020 and April 2021.

I come to this review as a professor of Geology at the University of Kansas, where I have been since 2014. Before that, I spent 33 years at the U.S. Geological Survey (USGS) and, from about 1987 to 2010, was a major developer of previous versions of the USGS MODLOW groundwater flow model used by RJH staff. I also worked extensively on model and data integration, including data needs assessment, sensitivity analysis, and uncertainty evaluation. I am a Professional Engineer in the state of Colorado.

For my review submitted November 2020 and this current review, the six questions the charge letter asked me to address are as follows.

1. Does the conceptualization of the hydrogeologic system appear reasonable based on the currently available data?
2. Are the numerical modeling techniques appropriate for simulating the conceptualized hydrogeologic system? For example, are the aquifer properties, boundary conditions, etc. modeled using appropriate techniques and with reasonable numerical input values?
3. Do the numerical model results provide a reasonable approximation of the groundwater system in the Project vicinity?
4. Is the model suitable for evaluating impacts that Project components could have on the hydrogeologic system, and supporting design of features to mitigate groundwater impacts?
5. Are the report narrative, tables, and figures presented clearly and with an appropriate level of technical detail?
6. Are there any additional numerical techniques that should be considered during design of Project facilities to effectively simulate and evaluate the interaction between the hydrogeologic system and proposed facilities?

I was asked to construct my replies as follows in a March 31, 2021 email from Dr. Prochaska "Your responses to the questions should be concise (where possible answer yes or no) and then add your basis for your opinion. Please limit your review to the current version of the Final Draft Report, and do not reference previous report revisions in your responses."

The charge questions are addressed in the remainder of this letter. My yes/no assessment is followed by supporting comments as requested.

With kind regards,

Mary C Hill

Question 1: Does the conceptualization of the hydrogeologic system appear reasonable based on the currently available data?

Yes. The model is conceptualized to represent the system in a way that will allow the simulated system characteristics to be estimated based on available data for a clearly stated model purpose. The text does a good job of explaining the available data and how it relates to the system conceptualization.

Question 2: Are the numerical modeling techniques appropriate for simulating the conceptualized hydrogeologic system? For example, are the aquifer properties, boundary conditions, etc. modeled using appropriate techniques and with reasonable numerical input values?

Yes. The model techniques are well suited to simulating this system and are used well in model construction. The aquifer properties, boundary conditions, geometry, and stresses are well designed and informed by available data.

Question 3: Do the numerical model results provide a reasonable approximation of the groundwater system in the Project vicinity?

Yes. The model fit to data is well characterized and discrepancies clearly explained.

Question 4: Is the model suitable for evaluating impacts that Project components could have on the hydrogeologic system, and supporting design of features to mitigate groundwater impacts?

Yes. The stresses of concern are well defined and the relation of model design to these stresses are clearly explained.

Question 5: Are the report narrative, tables, and figures presented clearly and with an appropriate level of technical detail?

Yes. The narrative, tables, and figures are very well done.

Question 6: Are there any additional numerical techniques that should be considered during design of Project facilities to effectively simulate and evaluate the interaction between the hydrogeologic system and proposed facilities?

No additional numerical methods need to be considered. The methods applied are suitable for simulating and evaluating the interaction between the hydrogeologic system and the proposed facilities.