Boulder Creek Commons
Ground Water Recharge Evaluation
Boulder, Colorado

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1.0 INTRODUCTION

At the request of BCC, LLC (BCC), Telesto Solutions, Inc. (Telesto) has prepared this report to document a ground water recharge evaluation for Boulder Creek Commons (Project) located in Boulder, Colorado. The Project (approximately 19.44 acres) is located in the lowest portion of the South Boulder Creek watershed. The watershed drains an area of approximately 132 square miles from the headwaters on James Peak to its confluence with Boulder Creek northeast of Valmont and 55th Street (Figure 1). The Project and surrounding areas overlie a thin (10 to 30 feet thick) unconfined aquifer with a high water table that fluctuates seasonally in response to processes occurring throughout the entire watershed. During spring, the aquifer water table rises due to snowmelt and generally higher rainfall within the entire watershed. Locally, the high water table persists through the summer due to ditch leakage, local pond/reservoir leakage, and residential lawn watering. Prior to 2008, flood irrigation within the Project area also contributed to the high summer water table. During the high water table period (spring and summer), some houses in neighborhoods adjacent to the Project area have used sump pumps to prevent ground water seepage into basements. The water table drops during the fall and winter months and sump pumping is not generally required. This pattern of a fluctuating water table exists prior to any development activities at the Project site.

Residents in the adjacent neighborhood are concerned that development of residential housing in the Project area could cause the water table to rise higher than normal and lead to increased basement sump pumping rates. In response to this concern, Telesto was commissioned by BCC to evaluate how the ground water system will respond to the presence of new residential properties in the Project area. The Project area is a minor subset of the entire watershed (0.025% of the total watershed area), and BCC can only control changes within the Project area as a part of its development. Thus, Telesto's evaluation is based on estimates of ground water recharge conditions within the Project area before and after residential development and the potential effects on adjacent neighbor's sump pumping.

The evaluation presented herein incorporates the relevant hydrologic processes that affect the amount of water flowing to the ground water system (i.e., "recharge"). Of particular interest are the effects of: 1) the change from pre-development flood irrigation to residential lawn/shrub watering and storm water management within the Project area after development, 2) the change from the current non-irrigated condition to the developed condition, and 3) eliminating seepage from Dry Creek Ditch No. 2 across the Project area. Although flood irrigation was discontinued before the 2008 growing season, it is considered a reasonable baseline case because it represents the conditions that would be present if the property was not developed and flood irrigation was resumed. For comparative purposes, an evaluation is also presented for the current, non-irrigated case.

Figure 2 is a site map showing the Project area and the layout of adjacent residential neighborhoods. Figure 3 shows the important hydrologic features (irrigation ditches and basement sumps) immediately adjacent to the Project area. Also shown is the Area of Interest, within which some houses have had to use basement sumps when ground water levels are elevated during the spring and summer.

2.0 APPROACH

The evaluation requires a two-part approach. First, a rigorous water balance was completed to estimate the areal recharge to ground water under pre-development and post development land uses. Second, using the rise in the water levels when the ditch was first turned on in late April 2012; the leakage rate from Dry Creek Ditch No. 2 was estimated using an analytical element ground water model.

A water balance was used to estimate the areal recharge to the ground water system for pre-development flood irrigation conditions, current pre-development non-irrigated conditions, and post-development conditions. In a water balance, each component of the hydrologic process, including precipitation, irrigation, evapotranspiration, and runoff is estimated and then recharge is calculated as the difference of precipitation plus irrigation minus evapotranspiration and runoff. Brief descriptions of the calculations used to estimate evapotranspiration and runoff are presented in Appendix A. The relative

difference between the recharge estimated for each scenario provides an indication of how land use changes affect recharge to the ground water system.

If the recharge is relatively higher for a given scenario, more water will enter the ground water system. If the recharge is relatively less, not as much water will enter the ground water system. When inflows to the ground water system are higher than the outflows from the system the water level rises. When inflows to the ground water system are lower than the system outflows, the water level lowers. The magnitude of the response (i.e., water level change) is dependent on several factors including the change in recharge, the ability of the ground water system to transmit water, and the size of the Area of Interest compared to the size of the watershed and ground water system. An alternative method such as an analytical model or a numerical model is needed to estimate the magnitude of the water level change. A numerical model has been developed for the site and has been used for this purpose (Telesto, 2010a, 2010b).

The Dry Creek Ditch No. 2 summer leakage rate was estimated using an analytical element ground water model. The model is focused on the Project area and incorporates the properties of the ground water system that affect transmission of water (i.e., saturated thickness and hydraulic conductivity). The model frames the area in the local context by incorporating the relevant hydrologic components. These include the prescribed head boundaries associated with the Howard Superphostical Ditch, transient flux boundaries associated with Dry Creek Ditch No. 2 and Bodam Lateral, and pumping from nearby residential sump pumps. A detailed description of the analytical ground water model is provided in Appendix B.

3.0 THE HYDROLOGIC PROCESS

Figures 4a, 4b, 4c, and 4d present a conceptual depiction of the hydrologic process near the Project area and the Area of Interest. This process is common along the Colorado Front Range and is prevalent throughout the west. In the late fall and during the winter (Figure 4a), the ground water table has dropped because:

- South Boulder Creek has drained the area due to its low flow condition

- The amount of recharge reaching the ground water table is limited because snowmelt is not prevalent, surface ponds are not full and residential lawn watering does not exist.

The lower ground water table in the late fall, and winter, generally does not intersect basement sumps in the Area of Interest and no sump pumping is required.

In early spring (Figure 4b), flow in South Boulder Creek starts to increase due to mountain snow melt from high in the basin, surface ponds start to be filled, local snowmelt starts, and precipitation near the Project area and Area of Interest increases. These increases start to fill the aquifer and the water table begins to rise.

By late spring and early summer (Figure 4c), the aquifer has been filled by inflows from South Boulder Creek, leaking ponds and irrigation ditches, natural precipitation recharge, and recharge from residential lawn watering. The ground water table is now high enough that it intersects basement sumps in the Area of Interest, which then must be pumped. The amount of water recharging the aquifer required to cause this rise in the water table is on the order of 10,000 gallons per minute (Telesto, 2010a, 2010b).

As summer progresses, South Boulder Creek no longer carries snowmelt from high in the basin. Ground water flow is now sustained by the water stored in the aquifer, and South Boulder Creek begins to drain the aquifer (Figure 4d). Locally, the water table remains elevated in comparison to winter conditions due to recharge from residential lawn watering, recirculation from neighborhood sumps, pasture flood irrigation, leakage of surface ponds and reservoirs, and ditch leakage. As these mechanisms cease in early fall, the water table experiences a more rapid decline back to winter conditions (Figure 4a).

Of the hydrologic processes described, recharge from precipitation, ditch leakage and pasture flood irrigation occurring within the Project area are the only hydrologic variables on site that may be manipulated in order to affect <u>minimal</u> changes in the natural hydrologic process. As depicted in Figures 4a-d, the Project is a small component of the overall hydrologic process.

The analyses provided herein are based on two different time periods (Winter Period – Figure 4a, and Summer Period – Figure 4d) because these periods represent the times where significant differences to basement sump pumping occur.

4.0 LOCAL MECHANISMS AFFECTING THE GROUND WATER SYSTEM

4.1 Area of Interest

The Project area and the Area of Interest lie on either side of Dry Creek Ditch No. 2, which typically flows from March through August. Because Dry Creek Ditch No. 2 is unlined, water seeps from the channel into the underlying ground water system thereby having a localized impact on the ground water table. In addition, flood irrigation has been historically practiced within the Project area and intense sprinkler irrigation is currently performed on a 7-acre single-residence property directly south of the Project area. Ditch leakage, reservoir and pond leakage, flood irrigation, and summer lawn watering in the residential areas south and west of the Area of Interest are the most probable causes of the sustained high water table in the Area of Interest during the spring and summer (Figure 4d). These mechanisms are currently leading to basement sump pumping at some houses in the adjacent neighborhoods; that is, prior to any residential development within the Project area.

During August 2005, Telesto sent questionnaires to residents in the surrounding neighborhoods. Consistent with the hydrologic process described in Section 3, respondents indicated that little or no basement sump pumping is required during the fall and winter, but pumping needs is required at some residences during the spring and summer. From May 5, 2011 to October 25, 2011, Telesto periodically measured the sumping rate at a residence adjacent to the west property line (260 Cimmaron Way). During this time, the sump-pumping rate ranged from a minimum of 0.5 gpm to a maximum of 8.1 gpm (Appendix A).

4.2 Recharge Calculation

Recharge to ground water can be estimated by performing a water balance for the Project area. A steady-state water balance is an accounting of all the water flowing into or out of a system. For the Project area, the following equation describes the various components of the soil water balance present at the site:

$$R = L + P + I - ET - RO$$

Where:

R = Recharge to ground water

L = Ditch leakage

P = Precipitation

I = Irrigation water

ET = Evapotranspiration

RO = Runoff

With the exception of recharge, which is calculated based on the other components, each water balance component can be estimated. The various components of the water balance are illustrated in Figure 5, which shows the general hydrologic processes for the Project area under pre-development flood irrigation conditions.

The analysis presented herein is focused on quantifying the pre- and post-development changes to recharge. The Dry Creek Ditch No. 2 pre-development leakage rate was estimated because piping of the ditch across the Project area will eliminate this source of recharge to ground water. However, Howard Superphostical Ditch and the unnamed ditch (located along the east parcel south property line) leakage rates are expected to be similar pre- and post-development and were not quantified in the analysis.

As mentioned in Section 2.0, an analytical element ground water model was used to estimate the Dry Creek Ditch No. 2 leakage rate. A detailed description of the model can be found in Appendix B.

A stochastic weather generator (Cligen, USDA) was used to produce a long term daily synthetic precipitation data set that was scaled to equal the Boulder average annual precipitation. Cligen was used because there is missing data in the daily measured precipitation record and because Cligen also provides estimates of the daily temperature, dewpoint, wind, and solar radiation data needed for estimating evapotranspiration. Although the synthetic data set summer (13.1 in) and winter period (7.8 in) averages are slightly different than the measured data (13.5 inches and 7.4 inches, respectively), the data set is considered valid because local precipitation will always vary slightly from the values measured at the weather station. Runoff in response to precipitation was estimated using the SCS curve number method (USDA, 1986). For the winter frost period (December through February), the ground is normally frozen so precipitation occurring during this period becomes runoff, evaporates or sublimes.

Irrigation rates used in the estimate are based on the data sources presented Appendix A. Appendix A also provides a brief description of the Penman-Monteith method and crop specific values used to estimate vegetation evapotranspiration rates.

4.3 Pre-Development Flood Irrigation Recharge

Figure 5 shows the general hydrologic processes associated with the Project area under pre-development flood irrigation conditions.

Historically, the Project area was covered with flood-irrigated pasture grass. The amount of net irrigation water (irrigation plus precipitation) is typically 3 feet (36 inches, Appendix A) per irrigation season. During the summer, recharge from precipitation and flood irrigation is offset by evapotranspiration, which removes approximately one-half of the inflow. A small portion of the precipitation becomes storm water runoff when large storms are prevalent or snowmelt is rapid. As shown in Table 2, leakage from Dry Creek Ditch No. 2 comprises the majority of the pre-development summer recharge.

Under pre-development flood irrigation conditions the total winter recharge is estimated to be 10.2 gpm and the total summer recharge is estimated to be 116.0 gpm (Table 2).

Total annual recharge under flood irrigation pre-development conditions, including recharge from Dry Creek Ditch No. 2, is estimated to be 126.2 gpm.

4.4 Pre-Development Non-Irrigation Recharge

Figure 6 shows the general hydrologic processes associated with the Project area under pre-development non-irrigated conditions. Flood irrigation was discontinued before the 2008 growing season; therefore, the irrigation rate under current conditions is zero. As shown in Table 3, evapotranspiration exceeds precipitation and leakage from Dry Creek Ditch No. 2 comprises 100% of the pre-development summer recharge. Also, a small portion of the precipitation becomes storm water runoff when large storms are prevalent or snowmelt is rapid.

Under pre-development, non-irrigated conditions, the total winter recharge is estimated to be 10.2 gpm and the total summer recharge is estimated to be 64.7 gpm. Total annual recharge under current pre-development conditions, including recharge from Dry Creek Ditch No. 2, is 74.9 gpm (Table 3).

4.5 Post-Development Recharge

Figure 7 shows the anticipated hydrologic components following development when several large changes will occur:

- Storm water runoff within the Project area will drain to a series of stormwater swales
- Flood irrigation will not be reinitiated and would be replaced by efficient lawn watering and low water demand landscaping
- impermeable surfaces (e.g., houses, driveways, sidewalks) will be added
- Dry Creek Ditch No. 2 will be piped across the Project area.

Following development there will be four primary land use types within the Project area:

- Irrigated lawn (turf) and shrubs (~5.82 acres)
- Irrigated low use water plants (~4.26 acres)
- Non-irrigation open space areas (~0.39 acres)
- Impervious areas (~8.97 acres)
- Stormwater swale (assumed to be zero acres).

Approximately 30% of the developed Project area will be sprinkler-irrigated lawn (turf) and shrubs areas. Approximately 22% of the area will consist of irrigated, low water-use plants. A summary of the recharge estimate for all post-development irrigated areas is provided in Table 4a. For purposes of this evaluation, it was assumed that the required lawn, shrub, and low use water plant irrigation rates are the same. This assumption is conservative (i.e., predicts more recharge) because it results in a slightly higher recharge estimate for the area landscaped with low use water plants.

Approximately 2% of the Project area will consist of non-irrigated open space areas. A summary of the recharge estimate for all post-development non-irrigated areas is presented in Table 4b.

Approximately 46% of the developed area will consist of impermeable features such as roads, driveways, and roofing that will eliminate some of the infiltration that is now occurring over the entire Project area. No direct recharge to ground water takes place beneath impermeable areas. However, these features will increase storm water runoff and snowmelt which will be routed to the storm water swales. A summary of the recharge estimate for all post-development impervious areas is provided in Table 4c.

The stormwater swales are designed to contain all storm runoff within the Project area and prevent surface water flows to adjacent properties except during extreme rainfall events. Therefore, for purposes of this evaluation it was assumed that 100% of the storm water runoff entering the stormwater swales from irrigated, non-irrigated, and impervious areas will percolate downward and provide seepage recharge to ground water. This assumption is conservative (i.e., predicts more recharge) because a portion of the swale influent water flowing will evaporate or be evapotranspired by plants growing in the swales. A summary of the storm water swale recharge estimate is provided in Table 4d.

Following development the total winter recharge is estimated to be 12.5 gpm and the total summer recharge is estimated to be 13.7 gpm (Table 4e). Total annual recharge under post-development conditions is 26.2 gpm. Following development, recharge within the

Project area is reduced dramatically during the summer months due to piping of Dry Creek Ditch No. 2.

5.0 DISCUSSION

Residential sump pumping occurs when the ground water table rises to the level of the sump system installed just below the adjacent neighbor's basement slabs. The amount of recharge occurring within the South Boulder Creek watershed is on the order of 10,000 gpm (Telesto, 2010a, 2010b). As shown in Figure 4c, the primary factors supplying this water, are recharge from South Boulder Creek, seepage from unlined irrigation ditches, pasture flood irrigation and residential lawn watering. Until the sum of these mechanisms provide a significant amount of water to the ground water, the water table does not rise sufficiently to invoke basement sump pumping in the Area of Interest.

The winter recharge rates under pre- and post-development conditions are summarized in Table 5. For the winter period, there is no ditch seepage, and recharge conditions inside the Project area are nearly the same pre- and post-development. The only change is a nominal increase in winter recharge within the Project area. However, the magnitude of the pre-development to post-development winter recharge increase is not enough to raise the ground water levels to those needed to affect basement sump pumping. Thus, during the winter, the improved storm water management system (stormwater swales) has a positive impact by diminishing surface water flows to neighboring areas while causing no measureable change to the ground water system.

For the summer period (Table 5), the primary change from pre- to post-development is the piping of Dry Creek Ditch No. 2 along the Project area western boundary. This will totally eliminate the ditch leakage that now occurs along this portion of the ditch, which currently causes localized increases in the ground water table. Compared to current non-irrigated conditions summer recharge to ground water will decrease by approximately 51 gpm.

When comparing the conversion from historic flood irrigation to sprinkler irrigation and the management of storm water using swales and a detention pond, summer recharge is reduced by 102.3 gpm (Table 5). This reduction in recharge to the ground water system will tend to reduce localized increases of the water table elevation in the Area of Interest. Because recharge within the Project area, and in particular, along the western property boundary, is reduced, the only logical conclusion is that development in the Project area will lead to a potential reduction in basement sump pumping within the Area of Interest. There are simply no mechanisms associated with the development that could cause the summer pumping rates to increase.

6.0 CONCLUSIONS

The conclusions of this evaluation are as follows:

- Compared to current winter conditions, the development of the Project area will cause a nominal increase in total winter recharge within the Project area. However, there are large benefits of improved storm water management that outweigh the increase in winter recharge. Also, the amount of recharge increase is insignificant in comparison to the amount or recharge required to raise the water table to sump pumping elevations and thus, will not be noticed.
- Compared to flood irrigation and current non-irrigated summer conditions, the development will reduce the total summer recharge to ground water. This reduction is caused in a large part by the piping of Dry Creek Ditch No. 2 which will eliminate ditch seepage along the Project area western boundary. Cessation of historic flood irrigation will also decrease areal recharge within the Project area. Thus, the only logical conclusion is that the development will lead to a reduction in ground water recharge and potentially to reduced residential sump pumping by the adjacent residents.

Based on this evaluation, the proposed housing development will not adversely affect the basement sump pumping currently being performed by the adjacent residents and, in fact, may lead to a reduction in the total sump pumping rate. This conclusion is contingent on the assumptions that: 1) turf and shrub irrigation rates are not higher than standard residential values associated with use of sprinklers, and 2) there is no change in the current operation of irrigation ditches, with the exception that Dry Creek Ditch No. 2 will be piped along the western boundary of the Project area.

The most important conclusion of this study is that the proposed housing development can only result in a decrease in ground water recharge and may lead to a decrease in sump pumping in nearby residences.

7.0 REFERENCES

CLIGEN USDA Water Erosion Prediction Project (WEPP) Climate Input Data Generator Version 5.22564.

Telesto (Telesto Solutions, Inc.). 2010a. Ground Water Evaluation for the Hogan-Pancost Development Boulder, Colorado. May 2010.

Telesto (Telesto Solutions, Inc.). 2010b. Ground Water Evaluation for the Hogan-Pancost Property Boulder, Colorado Revision 3. June 2010.

USDA. 1986. Urban Hydrology for Small Watersheds. Technical Release 55. June 1986.

TABLES

Table 1 Boulder Area Measured Rainfall

Year	Winter (inches)						Summer (inches)					
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1990	0.96	1.6	0.75	1.04	1.32	4.55	2.16	1.73	0.39	4.23	1.13	1.84
1991	0.93	3.3	0.01	1.05	0.15	0.43	2.41	2.9	3.59	3.11	2.08	1.21
1992	0.79	2.56	0.84	0.67	0	5.17	0.46	1.7	0.96	1.13	3.08	0.02
1993	2.42	2.17	0.55	0.25	0.9	2.15	2.56	1.73	3.38	1.4	1.04	3.32
1994	1.02	2.25	0.49	0.86	1.37	1.61	3.46	1.35	0.93	0.35	2.56	0.54
1995	0.59	1.51	0.25	0.64	1.53	1.21	5.45	9.59	4.03	0.72	1.45	2.96
1996	0.28	1.43	0.37	1.89	0.29	2.16	1.49	4.63	2.77	1.96	0.63	3.48
1997	2.7	1.52	0.68	0.87	1.83	0.91	5.77	2.19	3.69	1.14	5.27	1.92
1998	1.12	1.53	1.05	1.07	0.23	3.41	4.56	1.82	1.85	4.02	0.97	0.66
1999	1.33	0.81	1.01	0.65	0.08	1.09	7.55	1.84	0.82	2.54	5.54	2.62
2000	1.28	0.89	0.44	0.29	0.55	2.56	1.5	1.6	1.53	2.09	0.72	2.51
2001	0.4	1.02	0.36	0.73	0.86	2.01	3.02	3.62	1.09	1.76	1.64	1.77
2002	2.44	0.78	0.02	1.07	0.44	1.5	0.2	3.2	1.18	0.09	1.44	1.52
2003	0.45	0.8	0.84	0.09	1.52	5.44	2.99	2.62	2.69	0.71	3.52	0.35
2004	2.32	1.99	0.35	0.82	1.31	1.09	5.66	1.28	3.96	3.44	2.88	2.07
2005	2.8	0.34	0.43	1.4	0.31	1.22	3.86	1.91	2.68	0.42	1.63	0.52
2006	3.71	0.74	3.05	0.44	0.68	2.08	1.04	1.14	1.32	2.63	1.23	1.25
2007	1.38	0.47	2.1	1.68	0.86	1.69	2.24	1.79	0.38	0.8	1.82	1.92
2008	1.18	0.13	1.33	0.46	0.63	1.47	1.13	4.21	1.58	0.09	2.97	1.84
2009	3.26	0.93	1.39	0.62	0.27	1.89	5.88	3.08	2.7	1.42	0.33	0.42
2010	0.95	0.61	0.48	0.28	1.37	3.3	3.63	2.71	3.36	2.31	1.07	0.25
2011	1.65	0.98	1.92	0.96	1.02	0.33	2.41	5.16	1.35	2.87	1.08	2.56
Totals	7.4						13.5					
	20.9											

Table 2 Pre-Development Recharge (Flood Irrigation)

Hydrologic Process	Depth (in)	Area (acre)	Rate (gpm)
Dry Creek Ditch No. 2 Leakage	-	-	
Summer	-	-	64.7
Winter			0
Precipitation			
Annual	20.9	19.44	-
Summer	13.1	19.44	26.3
Winter	7.8	19.44	15.7
Irrigation			
Summer	36.0	19.44	72.3
Winter	0.0	-	0
Evapotranspiration **Table 3 Pre-Development Recharge (Non-Irrigated)**			
Summer (Pasture Grasses)	23.5	19.44	47.1
Winter	0	19.44	0.0
Runoff (CN = 61)			
Summer	0.12	19.44	0.2
Winter	0.01	19.44	0.0
Winter Frost Period	2.7	19.44	5.4
Areal Recharge			
Summer (182.5 days)	25.5	19.44	51.3
Winter (182.5 days)	5.1	19.44	10.2
		Total	61.5
Total Recharge			
Summer			116.0
Winter			10.2

Table 3 Pre-Development Recharge (Non-Irrigated)

Hydrologic Process	Depth (in)	Area (acre)	Rate (gpm)
Dry Creek Ditch No. 2 Leakage	-	-	
Summer	-	-	64.7
Winter			0
Precipitation			
Annual	20.9	19.44	-
Summer	13.1	19.44	26.3
Winter	7.8	19.44	15.7
Irrigation			
Summer	0.0	-	0.0
Winter	0.0	-	0
Evapotranspiration			
Summer (Pasture Grasses)	23.5	19.44	47.1
Winter	0	19.44	0.0
Runoff (CN = 61)			
Summer	0.12	19.44	0.2
Winter	0.01	19.44	0.0
Winter Frost Period	2.7	19.44	5.4
Areal Recharge			
Summer (182.5 days)	25.5	19.44	-21.1[(1)]
Winter (182.5 days)	5.1	19.44	10.2
		Total	61.5
Total Recharge			
Summer			64.7
Winter			10.2

[(1)] Summer evapotranspiration exceeds precipitation; therefore, net summer areal recharge is zero.

Table 4a Post-Development Recharge – Irrigated Lawn (Turf) and Shrubs; Irrigated Low Use Water Plants

Hydrologic Process	Depth (in)	Area (acre)	Rate (gpm)
Precipitation			
Annual	20.9	10.08	-
Summer	13.1	10.08	13.6
Winter	7.8	10.08	8.1
Irrigation [(2)]			
Irrigation Delivery Efficiency	77.5%		
Summer	11.9 [(1)]	10.08	12.4
Winter	0.0	-	0.0
Evapotranspiration			
Summer (KY Bluegrass)	19.3	5.82	11.6
Summer (Low water use plants)	9.8	4.26	4.31
Winter	0	10.08	0.0
Runoff (CN = 61)			
Summer	0.12	10.08	0.1
Winter	0.01	10.08	0.0
Winter Frost Period	2.7	10.08	2.8
Areal Recharge			
Summer (182.5 days)	9.6	10.08	10.0
Winter (182.5 days)	5.1	10.08	5.3
		Total	15.3

[(1)] Assuming 77.5% irrigation delivery efficiency (fixed solid). Summer precipitation (minus runoff) will provide a portion of the water needed, the remainder is provided by irrigation.

[(2)] Lawn (turf), shrubs, and low use water plants are assumed to have the same irrigation requirements.

Table 4b Post-Development Recharge – Non-irrigated Open Space Areas

Hydrologic Process	Depth (in)	Area (acre)	Rate (gpm)
Precipitation			
Annual	20.9	0.39	-
Summer	13.1	0.39	0.5
Winter	7.8	0.39	0.3
Irrigation			
Summer (Low water use plants)	0.0	0.39	0.0
Winter	0.0	0.39	0.0
Evapotranspiration			
Summer (Low water use plants)	9.8	0.39	0.4
Winter	0	0.39	0.0
Runoff (CN = 61)			
Summer	0.12	0.39	0.0
Winter	0.01	0.39	0.0
Winter Frost Period	2.7	0.39	0.1
Areal Recharge			
Summer (182.5 days)	3.2	0.39	0.1
Winter (182.5 days)	5.1	0.39	0.2
		Total	0.3

Table 4c Post-Development Recharge – Impervious Areas

Hydrologic Process	Depth (in)	Area (acre)	Rate (gpm)
Precipitation			
Annual	20.9	8.97	-
Summer	13.1	8.97	12.1
Winter	7.8	8.97	7.2
Irrigation			
Summer	0	8.97	0
Winter	0	8.97	0
Evapotranspiration			
Summer	0	8.97	0
Winter	0	8.97	0
Runoff (CN = 61)			
Summer	8.18	8.97	7.6
Winter	4.36	8.97	4.0
Areal Recharge			
Summer (182.5 days)	0	8.97	0
Winter (182.5 days)	0	8.97	0
		Total	0

Table 4d Post-Development Recharge – Stormwater Swales

Run-on from Other Areas	Rate (gpm)
Summer	
Impervious Areas	7.6
Landscaped Areas w/ Irrigation	0.13
Landscaped Areas w/o Irrigation	0
Winter	
Impervious Areas	4.0
Landscaped Areas w/ Irrigation	0.0
Landscaped Areas w/ Irrigation (frost period)	2.8
Landscaped Areas w/o Irrigation	0.0
Landscaped Areas w/o Irrigation (frost period)	0.1
Areal Recharge	
Summer (182.5 days)	7.7
Winter (182.5 days)	7.0
Total	14.7

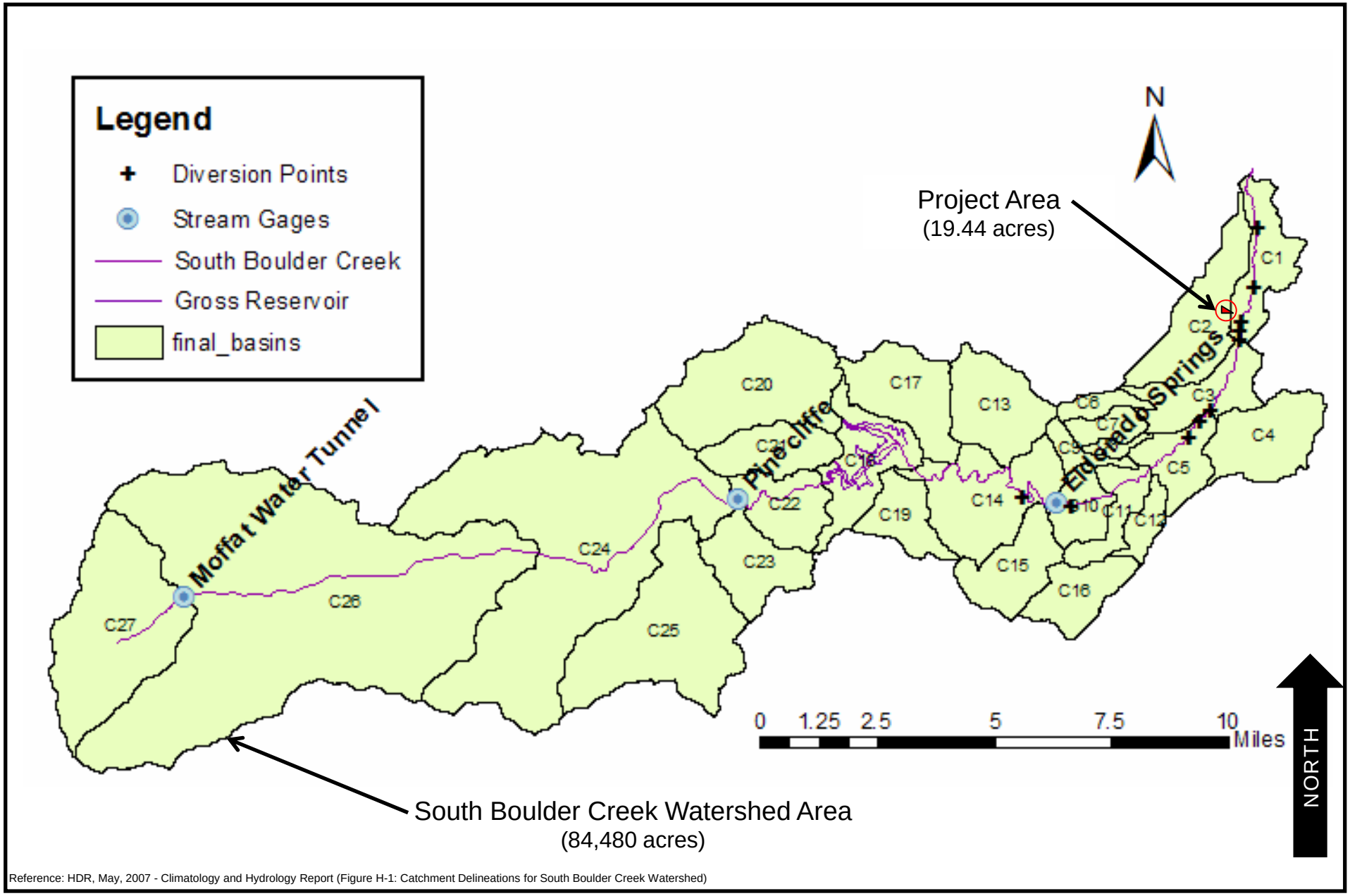
Table 4e Post-Development Recharge Summary

Hydrologic Process	Rate (gpm)
Summer	
Irrigated lawn, shrubs, and low water use plants.	10.0
Non-irrigated low use water plants	0.1
Impervious Areas	0.0
Swale	7.7
Total	17.8
Winter	
Irrigated lawn, shrubs and low water use plants	5.3
Non-irrigated low use water plants	0.2
Impervious Areas	0.0
Swale	7.0
Total	12.5

Table 5 Recharge Summary

	Developed (gpm)	Current Non-irrigated (gpm)	Flood Irrigation (gpm)
Summer			
Areal Recharge	17.8	0	51.3
Dry Creek Ditch No. 2 Leakage	0	64.7	64.7
Summer Total	17.8	64.7	116.0
Post- minus pre-development	-	-51.0	-102.3
Winter			
Areal Recharge	12.5	10.2	10.2
Dry Creek Ditch No. 2 Leakage	0	0	0
Winter Total	12.5	10.2	10.2
Post- minus pre-development	-	+2.3	+2.3
Annual Total	30.3	74.9	126.2
Post- minus pre-development	-	-48.7	-51.3

FIGURES



Reference: HDR, May, 2007 - Climatology and Hydrology Report (Figure H-1: Catchment Delineations for South Boulder Creek Watershed)

PROJECT: 320-100	TASK 1
PREPARED BY: TELESTO SOLUTIONS INCORPORATED	

FIGURE 1
SOUTH BOULDER CREEK WATERSHED

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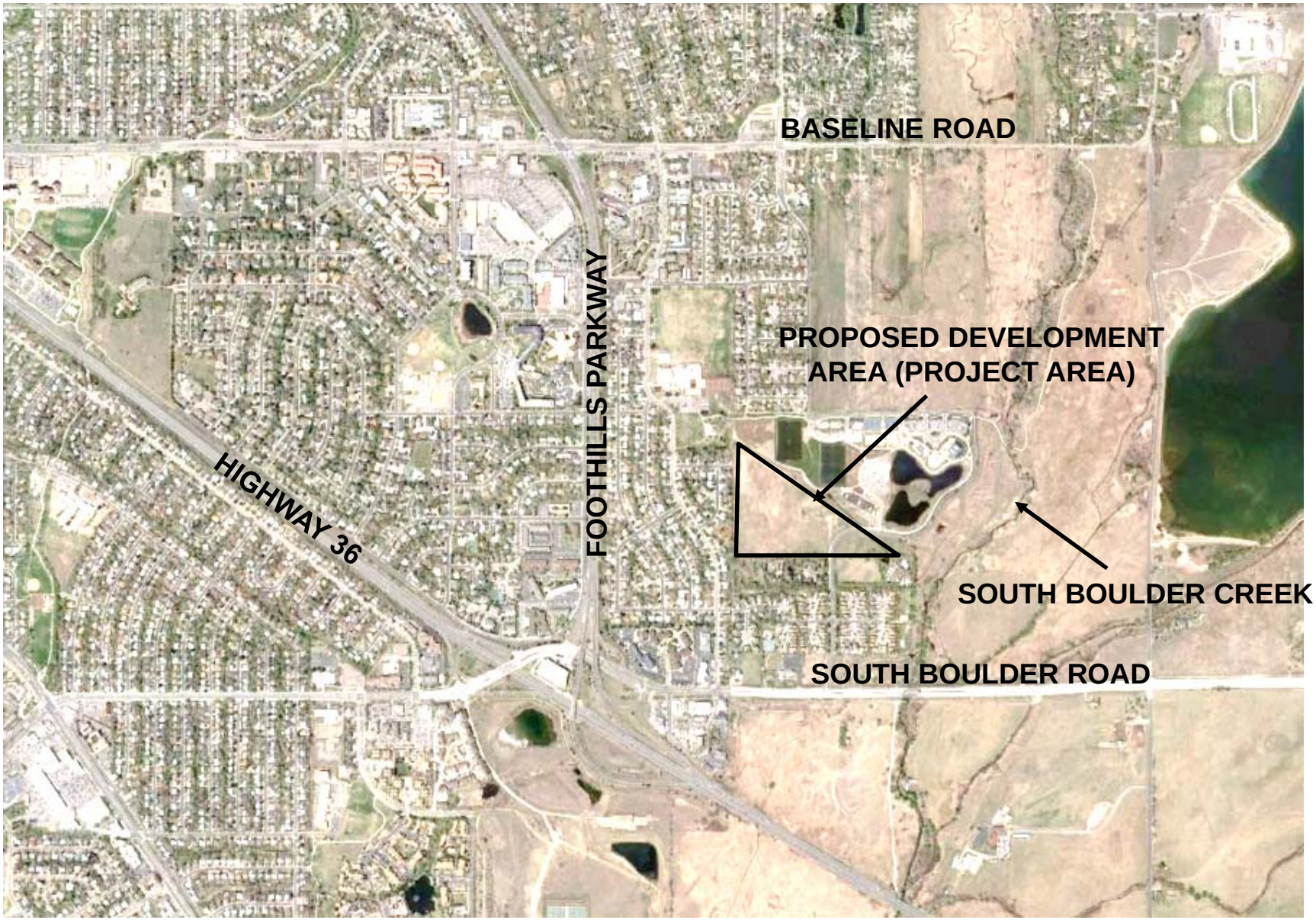
BOULDER CREEK COMMONS, LLC.

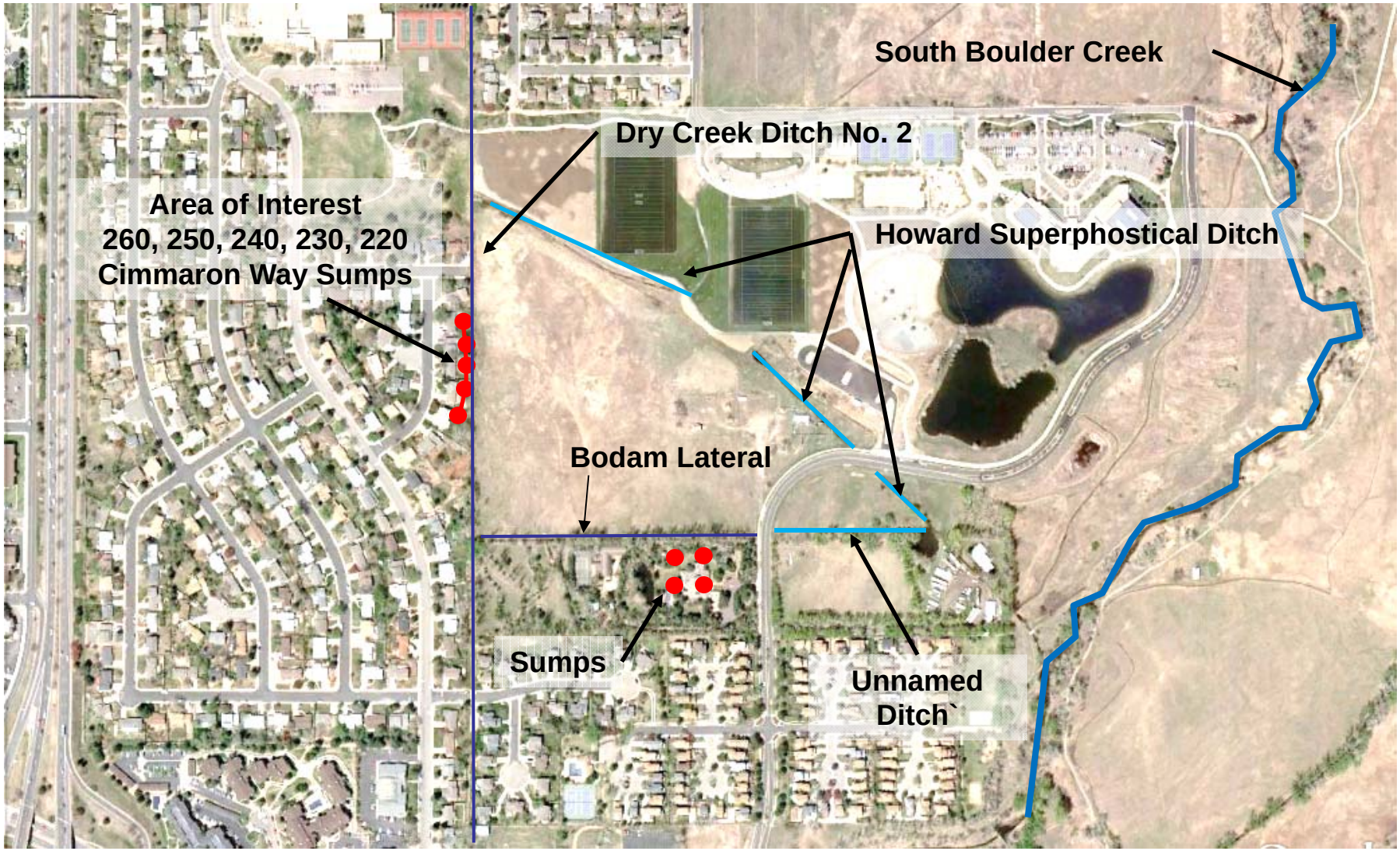


PROJECT:	TASK
320-100	1

PREPARED BY:
TELESTO SOLUTIONS INCORPORATED

FIGURE 2
SITE MAP

PREPARED FOR:
BOULDER CREEK COMMONS, LLC.

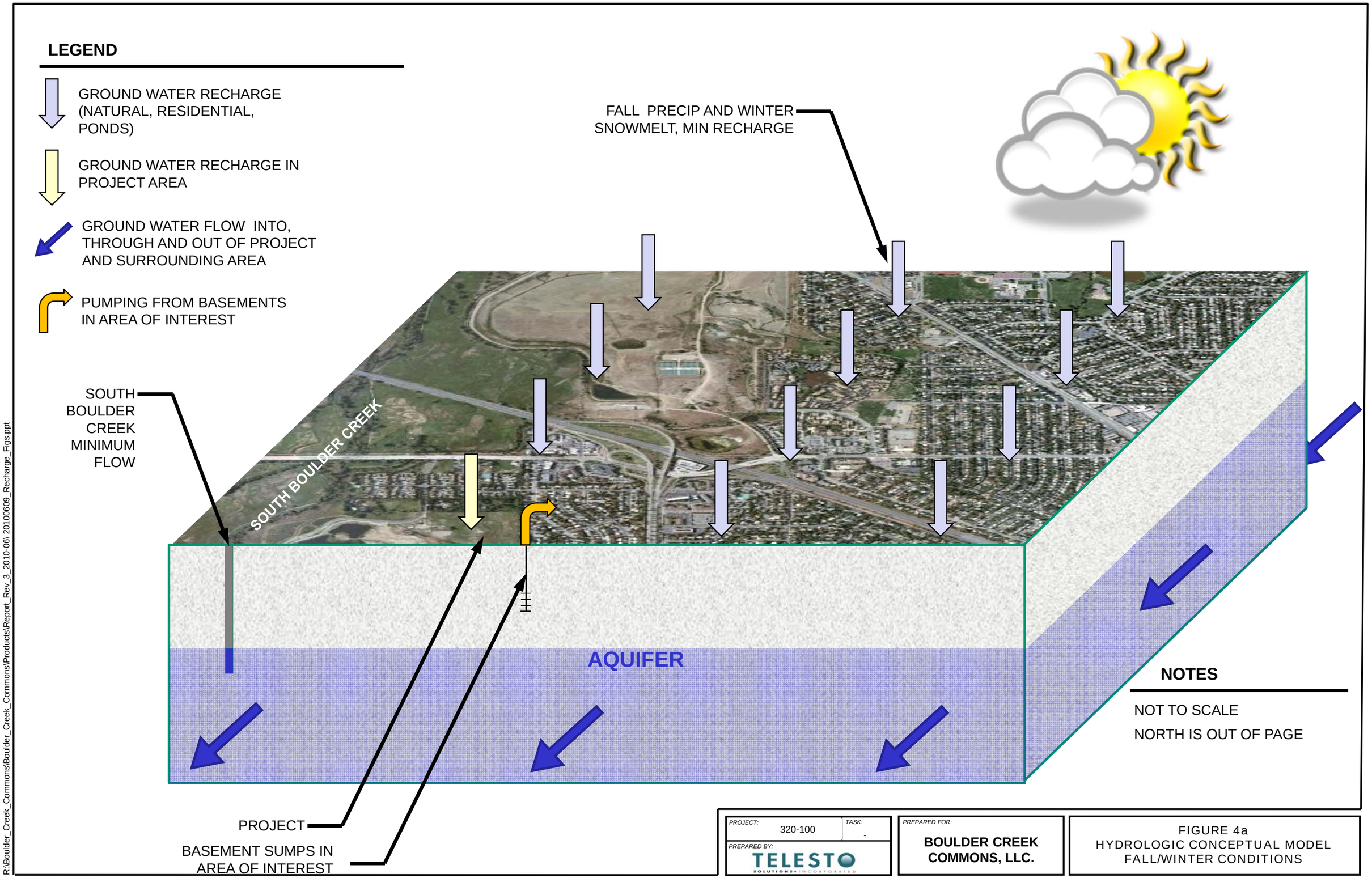


PROJECT:	TASK
320-100	1

PREPARED BY:
TELESTO SOLUTIONS INCORPORATED

FIGURE 3
STUDY AREA HYDROLOGIC FEATURES

PREPARED FOR:
BOULDER CREEK COMMONS, LLC.


LEGEND
GROUND WATER RECHARGE (NATURAL, RESIDENTIAL, PONDS)
GROUND WATER RECHARGE IN PROJECT AREA
GROUND WATER FLOW INTO, THROUGH AND OUT OF PROJECT AND SURROUNDING AREA
PUMPING FROM BASEMENTS IN AREA OF INTEREST
FALL PRECIP AND WINTER SNOWMELT, MIN RECHARGE
SOUTH BOULDER CREEK MINIMUM FLOW
SOUTH BOULDER CREEK
AQUIFER
PROJECT
BASEMENT SUMPS IN AREA OF INTEREST
NOTES
NOT TO SCALE
NORTH IS OUT OF PAGE
PROJECT: 320-100
TASK: -
PREPARED BY: TELESTO SOLUTIONS INCORPORATED
PREPARED FOR: BOULDER CREEK COMMONS, LLC.
FIGURE 4a
HYDROLOGIC CONCEPTUAL MODEL
FALL/WINTER CONDITIONS
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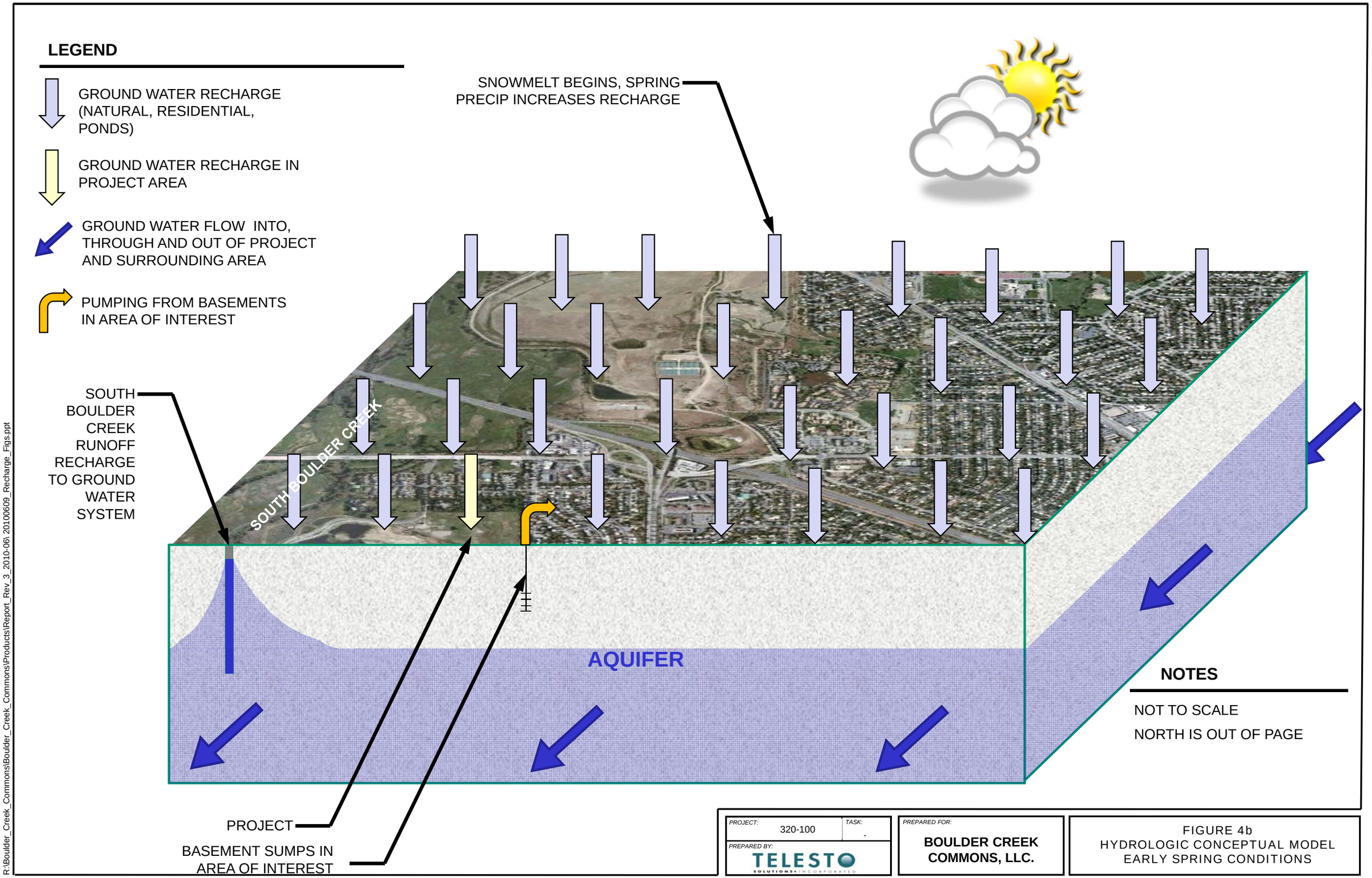
LEGEND
GROUND WATER RECHARGE (NATURAL, RESIDENTIAL, PONDS)
GROUND WATER RECHARGE IN PROJECT AREA
GROUND WATER FLOW INTO, THROUGH AND OUT OF PROJECT AND SURROUNDING AREA
PUMPING FROM BASEMENTS IN AREA OF INTEREST
SNOWMELT BEGINS, SPRING PRECIP INCREASES RECHARGE
SOUTH BOULDER CREEK RUNOFF RECHARGE TO GROUND WATER SYSTEM
SOUTH BOULDER CREEK
AQUIFER
PROJECT
BASEMENT SUMPS IN AREA OF INTEREST
NOTES
NOT TO SCALE
NORTH IS OUT OF PAGE
PROJECT: 320-100
TASK: -
PREPARED BY: TELESTO SOLUTIONS INCORPORATED
PREPARED FOR: BOULDER CREEK COMMONS, LLC.
FIGURE 4b
HYDROLOGIC CONCEPTUAL MODEL
EARLY SPRING CONDITIONS
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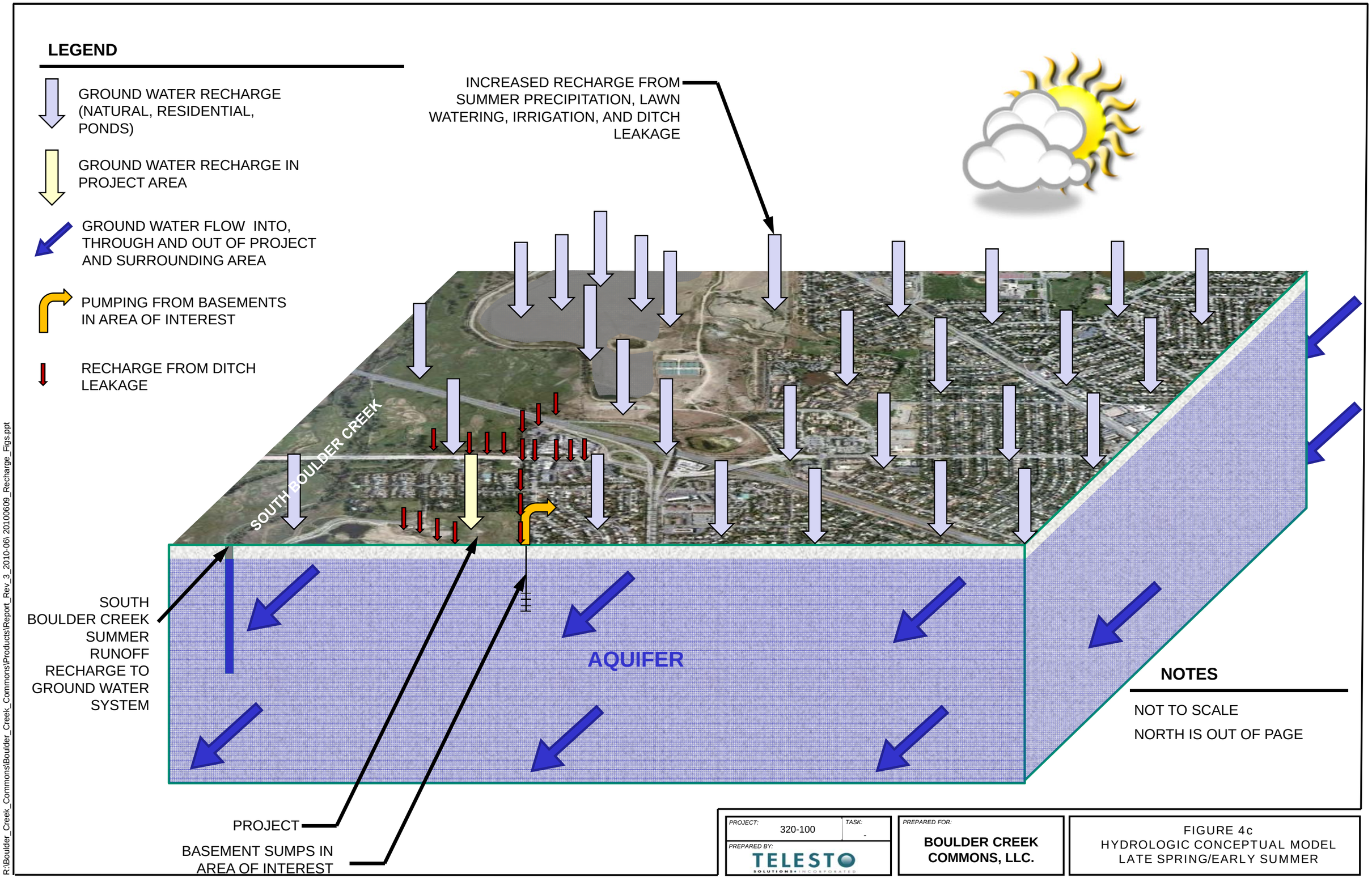

PROJECT: 320-100
TASK: -
PREPARED BY: TELESTO SOLUTIONS INCORPORATED

PREPARED FOR: BOULDER CREEK COMMONS, LLC.

FIGURE 4c
HYDROLOGIC CONCEPTUAL MODEL
LATE SPRING/EARLY SUMMER

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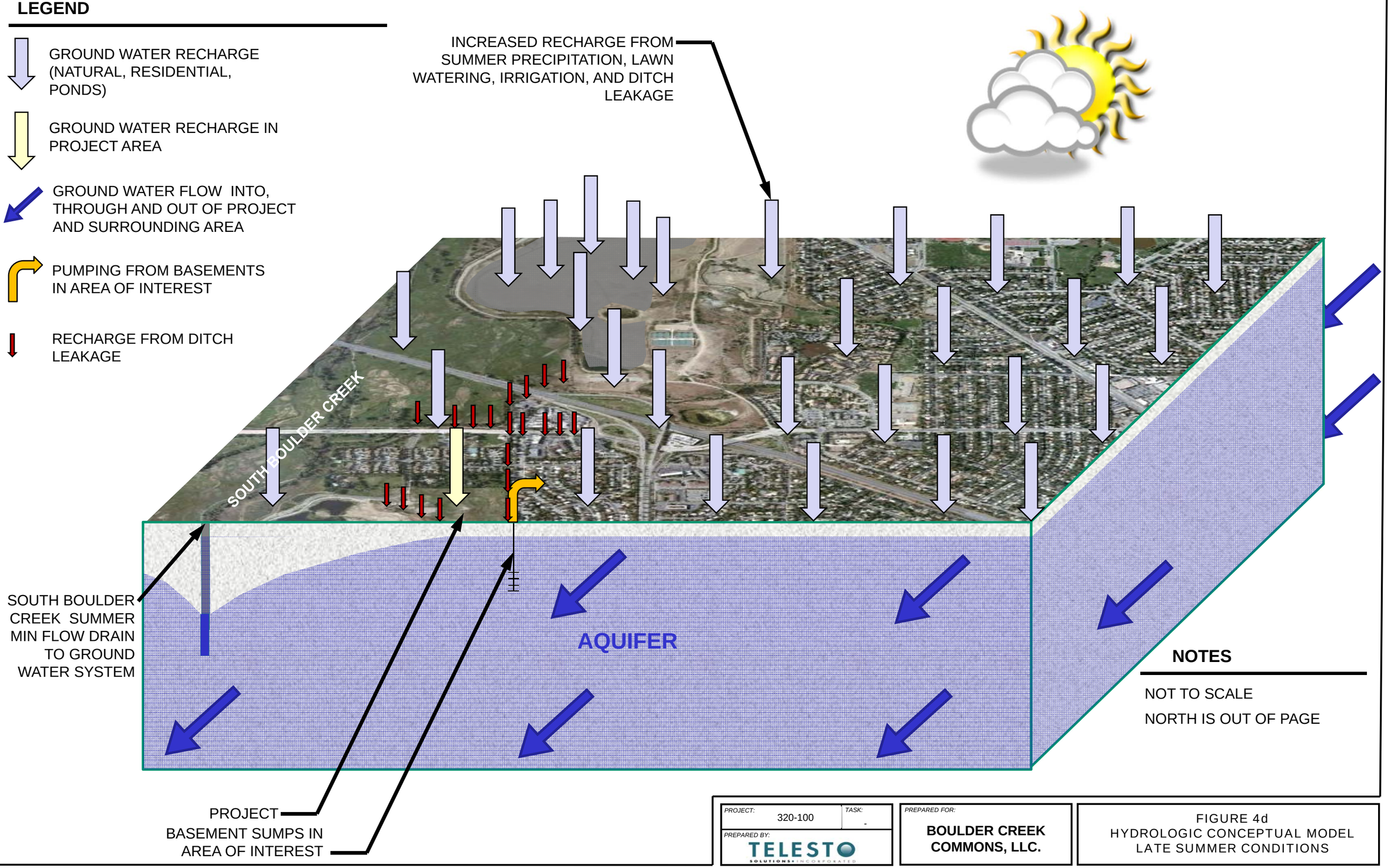
LEGEND

- GROUND WATER RECHARGE (NATURAL, RESIDENTIAL, PONDS)
- GROUND WATER RECHARGE IN PROJECT AREA
- GROUND WATER FLOW INTO, THROUGH AND OUT OF PROJECT AND SURROUNDING AREA
- PUMPING FROM BASEMENTS IN AREA OF INTEREST
- RECHARGE FROM DITCH LEAKAGE



NOTES

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PROJECT: 320-100	TASK: -	PREPARED FOR: BOULDER CREEK COMMONS, LLC.	FIGURE 4d HYDROLOGIC CONCEPTUAL MODEL LATE SUMMER CONDITIONS
PREPARED BY: TELESTO SOLUTIONS INCORPORATED			

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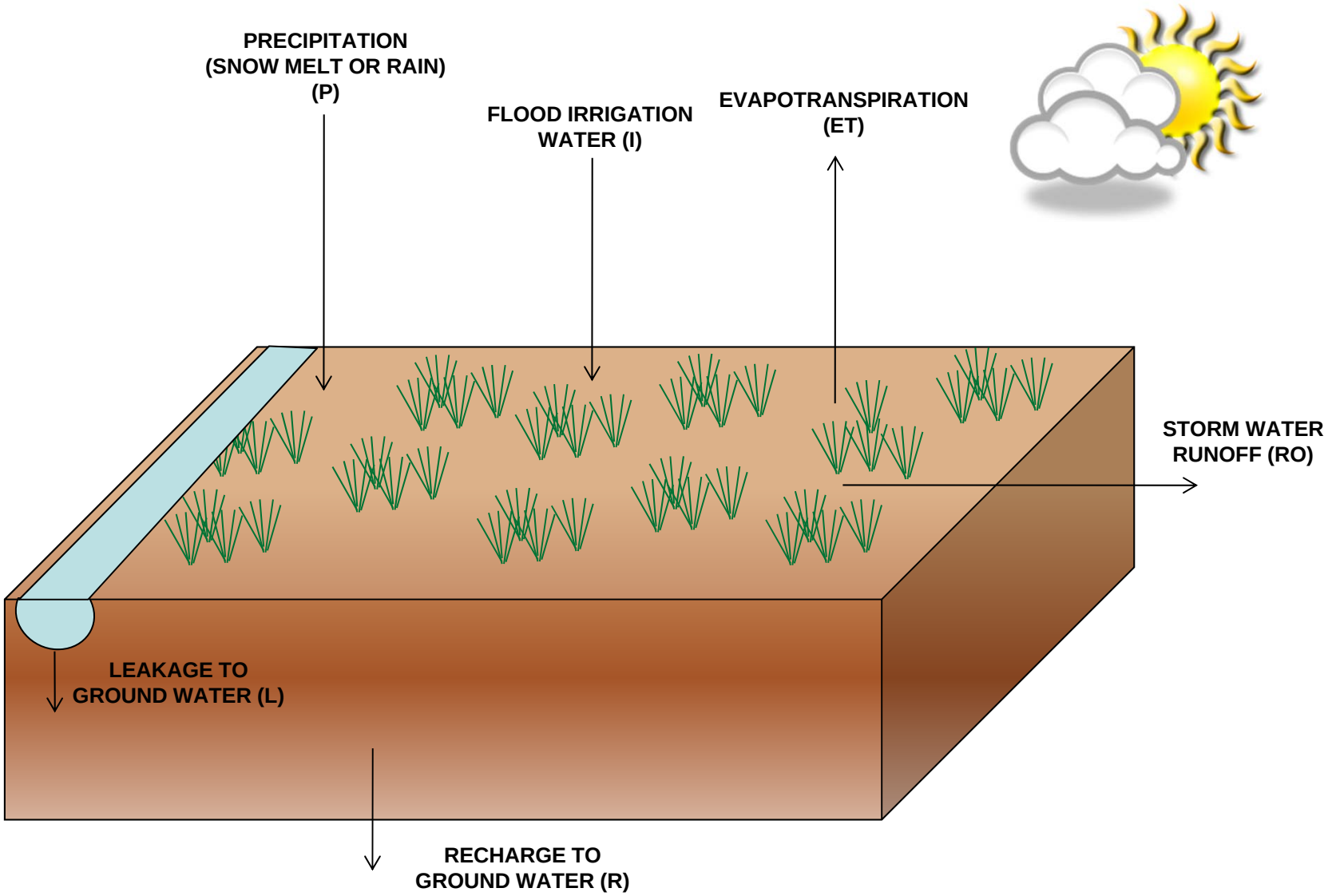
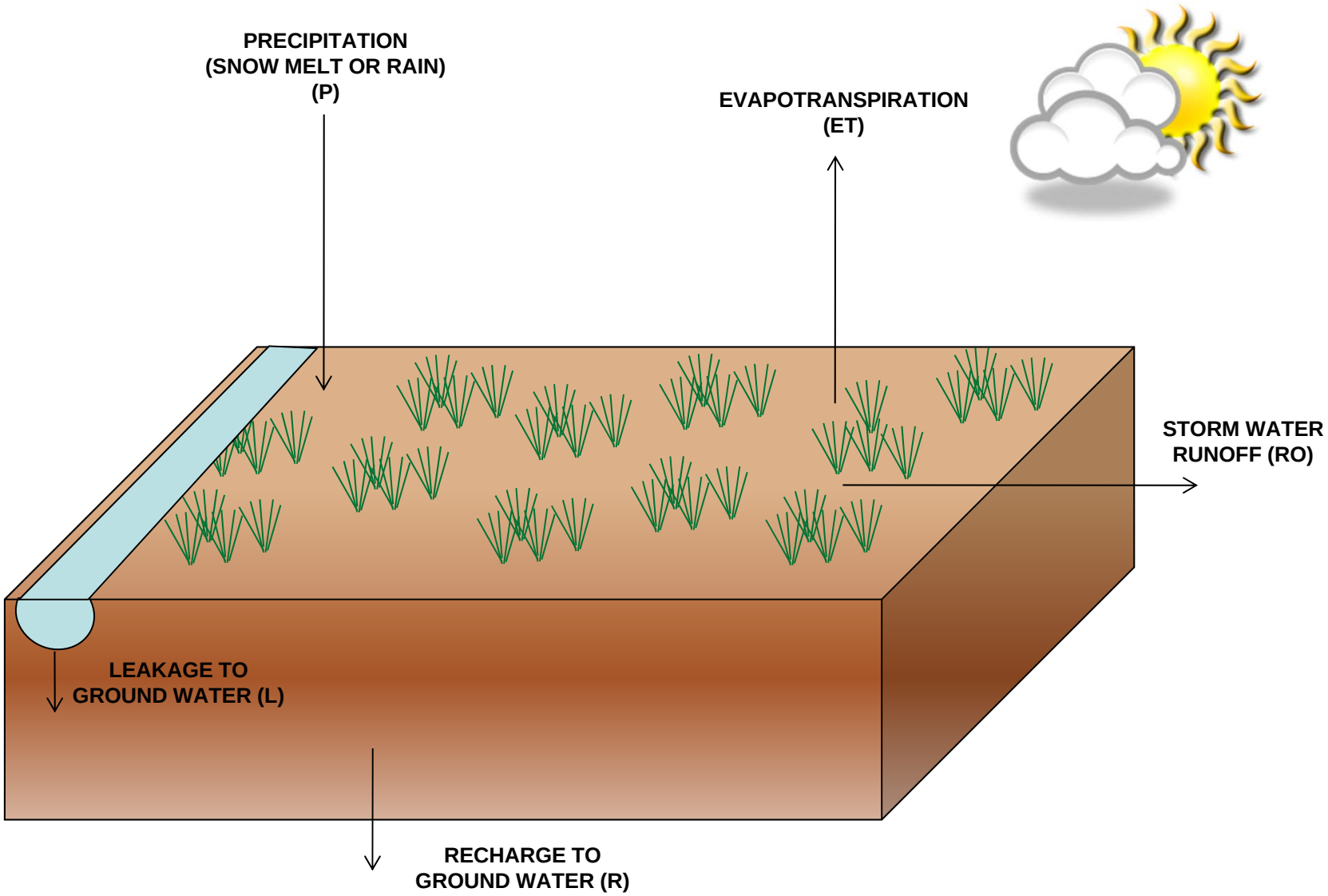


$$R = L + P + I - ET - RO$$

PROJECT: 320-100	TASK 1
PREPARED BY: TELESTO SOLUTIONS INCORPORATED	

FIGURE 5
PROJECT AREA HYDROLOGIC COMPONENTS BEFORE DEVELOPMENT
(FLOOD IRRIGATION)

PREPARED FOR:
BOULDER CREEK COMMONS, LLC.

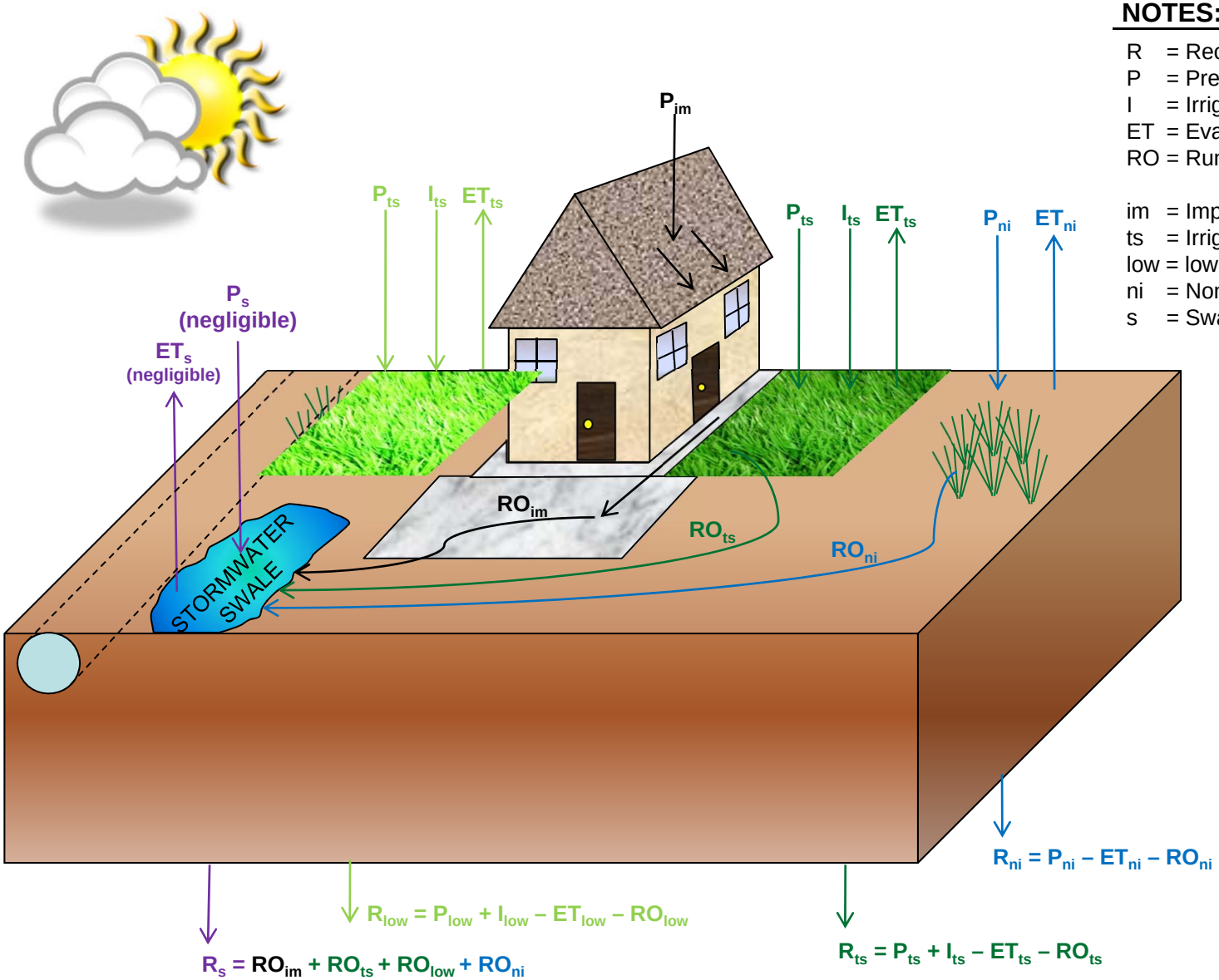


$$R = L + P - ET - RO$$

PROJECT: 320-100	TASK 1
PREPARED BY: TELESTO SOLUTIONS INCORPORATED	

FIGURE 6
PROJECT AREA HYDROLOGIC COMPONENTS BEFORE DEVELOPMENT
(NO IRRIGATION)

PREPARED FOR:
BOULDER CREEK COMMONS, LLC.



NOTES:

R = Recharge to ground water
P = Precipitation (rain & snow)
I = Irrigation
ET = Evapotranspiration
RO = Runoff

im = Impervious Areas
ts = Irrigated turf and shrubs
low = low water use plants
ni = Non-Irrigated vegetation
s = Swale

PROJECT: 320-100	TASK 1
PREPARED BY: TELESTO SOLUTIONS INCORPORATED	

FIGURE 7
PROJECT AREA HYDROLOGIC COMPONENTS AFTER DEVELOPMENT

PREPARED FOR:
BOULDER CREEK COMMONS, LLC.

APPENDIX A

Calculations and Supporting Documentation for Parameters Used in the Areal Recharge Analysis

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1.0 EVAPOTRANSPIRATION

The United Nations Food & Agriculture Organization recommends the Penman-Monteith method for determining reference evapotranspiration (ET_r). Once the reference evapotranspiration is determined, the evapotranspiration rates for other crops can be estimated by scaling the reference ET_r (in this case, alfalfa), using crop coefficients and growing season data (Table 1).

The Crop Coefficient (Kc) is the fraction of water lost from the crop relative to reference crop evapotranspiration. The crop coefficient is used with evaporation from a reference crop (e.g. ETr = alfalfa) to estimate crop specific evapotranspiration rates. The crop coefficient is a dimensionless number (usually between .1 and 1.2) that is multiplied by the standardized surface evapotranspiration value (ETr) to arrive at a crop specific evapotranspiration (ETc) estimate.

Crop Coefficients Kc and Growing Season Dates

Crop	Turfgrass (cool-season)	Turfgrass (warm-season)	Pasture Grasses	Kentucky Blue Grass	Low Water Use Plants
Reference	1	1	2	3	4
Season Length	183	182	204	200	204 [b]
Start of irrigation/germination	2-Apr	2-Apr	25-Mar	27-Mar [b]	25-Mar [b]
Initial Season	17-May	17-May	1-Apr [a]	16-Apr [a]	1-Apr [b]
Rapid Growth Season	2-Jul	2-Jul	1-Jun [a]	6-May [a]	1-Jun [b]
Mid Season	17-Aug	16-Aug	5-Jul [a]	5-Jul [a]	5-Jul [b]
End of irrigation/harvest	1-Oct	1-Oct	15-Oct	13-Oct	15-Oct [b]
Initial Season Kc	0.80	0.60	0.875	0.6	0.375 [d]
Rapid Growth Season Kc					
Mid Season Kc	0.80	0.60	0.83	0.78	0.375 [d]
End of irr/harvest Kc	0.80	0.60	1.09	0.74	0.375 [d]

References:

1. http://biomet.ucdavis.edu/irrigation_scheduling/bis/BIS.htm BISe.xls
2. Part 683 - Water Requirements CO683.50(p) Longmont, Co TR-21 Blaney Criddle Method
3. IDS Consumptive Use Model Version 3.3.127 (http://www.ids.colostate.edu)
4. Water Use Category: Low Percentage of Reference ET = 25-50% (http://www.greenco.org/bmp_downloads/BMP_Manual_Appendices.pdf)

Notes:

a. Initial, Rapid Growth, and Mid-season dates estimated based on monthly Kc values.
b. Assumed to be same as pasture grasses and modified for 200 day growing season.
c. Assumed to be same as pasture grasses.
d. Average of 25%-50%

2.0 SCS CURVE NUMBER METHOD FOR ESTIMATING RUNOFF

The SCS Runoff Curve Number (CN) method using the following equation to estimate runoff:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where:

Q = runoff (in)

P = rainfall (in)

S = potential maximum retention after runoff begins (in) and

I_a = initial abstraction (in)

Initial abstraction (I_a) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated with soil and cover parameters. Through studies of many small agricultural watersheds, I_a was found to be approximated by the following empirical equation:

$$I_a = 0.2S$$

By removing I_a as an independent parameter, this approximation allows use of a combination of S and P to produce a unique runoff amount. Substituting for I_a gives:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$S = \frac{1000}{CN} - 10$$

Curve Number Determination

Reference: Reference: USDA Urban Hydrology for Small Watersheds TR-55

Hydrologic Soil Group:

NRCS web soil survey: According to NRCS, Hogan-Pancost is covered by 0”-14” of “Niwot and Similar Soils” which are described as a “loam” Hydrologic Soil Group “C”

2008 Soils Report: Topsoil, clayey, silty to very silty, sandy, dark brown

HSG Soil textures (TR-55, p. A-1)

A = Sand, loamy sand, or sandy loam
B = Silt loam or loam
C = Sandy clay loam
D = Clay loam, silty clay loam, sandy clay, silty clay, or clay.

Note: NRCS web soil survey indicates a HSG “C” for this area. Based on Site specific soils report and field observations the top soil is assumed to be HSG “B”. Choosing HSG B over C will result in lower CN, less runoff, and an increased estimate of recharge.

Hydrologic Condition: Good (Good hydrologic condition indicates that the soil usually has a low runoff potential for that specific hydrologic soil group, cover type, and treatment.

Curve Numbers:

Pre-Development: CN = 61

- TR-55 Table 2-2c Runoff curve numbers for other agricultural lands Pasture, grassland, or range—continuous forage for grazing
- HSG B
- Hydrologic Condition = Good: > 75% ground cover and lightly or only occasionally grazed.

Post-Development:

CN = 61 (lawns)

- TR-55 Table 2-2a Runoff curve numbers for urban areas Fully developed urban areas (vegetation established) Open space (lawns, parks, golf courses, cemeteries, etc.)
- HSG B
- Hydrologic Condition = Good condition (grass cover > 75%).

CN = 98 (impervious areas)

TR-55 Table 2-2a Runoff curve numbers for urban areas. Fully developed urban areas (vegetation established) Impervious areas: Paved parking lots, roofs, driveways, etc. Streets and roads: Paved; curbs and storm sewers.

Open space (lawns, parks, golf courses, cemeteries, etc.):

Hydrologic Soil Group	A	B	C	D
Poor condition (grass cover < 50%)	68	79	86	89
Fair condition (grass cover 50% to 75%)	49	69	79	84
Good condition (grass cover > 75%)	39	61	74	80

TR-55 Table 2-2c Runoff curve numbers for other agricultural lands

Pasture, grassland, or range—continuous forage for grazing

HSG	A	B	C	D
Poor	68	79	86	89
Fair	49	69	79	84
Good	39	61	74	80

Poor: <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

3.0 MEASURED SUMP PUMPING RATES

The total summer sump pumping rate of 28 gpm within the Area of Interest is derived from average sumping rate measured at 260 Cimmaron Way between May 6, 2011 and September 23, 2011 of 4.67 gpm (Table 1) multiplied by the number of homes adjacent to the west property line (6, 210, 220, 220, 230, 240, 250, 260 Cimmaron Way).

Table 1.1 Measured Sumping Rates at 260 Cimmaron Way

Date	Sump 1 Vol (gal)	Sump 1 Cycle (min)	Sump 1 Rate (gpm)	Sump 1 Rate (gpd)	Sump 2 Vol (gal)	Sump 2 Cycle (min)	Sump 2 Rate (gpm)	Sump 2 Rate (gpd)	Total (gpd)	Total (gpm)	Note
4/7/11	4.35	-	-	-	3.94	-	-	-	0	0.0	(1)
5/4/11	4.35	-	-	-	3.94	-	-	-	0	0.0	(1)
5/5/11	4.35	4.0	1.1	1565	3.94	4.0	1.0	1418	2983	2.1	(1)
5/6/11	4.35	1.75	2.5	3577	3.94	11.0	0.4	515	4093	2.8	(1)
5/20/11	4.35	1.0	4.3	6260	3.94	4.0	1.0	1418	7678	5.3	(1)
5/27/11	4.35	1.5	2.9	4173	3.94	3.0	1.3	1890	6063	4.2	(1)
6/23/11	4.35	1.1	4.0	5691	3.94	-	-	-	5691	4.0	(2)
7/12/11	4.35	1.1	4.0	5726	3.94	0.9	4.2	6000	11726	8.1	(2)
8/23/11	4.35	0.9	5.1	7298	3.94	2.1	1.9	2703	10001	6.9	(2)
9/1/11	4.35	2.2	2.0	2834	3.94	6.9	0.6	819	3653	2.5	(2)
9/23/11	4.35	1.7	2.5	3587	3.94	4.5	0.9	1262	4850	3.4	(2)
10/21/11	4.35	6.5	0.7	963	3.94	-	-	-	963	0.7	(1)
10/25/11	4.35	8.0	0.5	779	3.94	-	-	-	779	0.5	(2)
4/27/12	4.35	3.0	1.5	2107	3.94	-	-	-	2107	1.5	(2)
5/2/12	4.35	3.7	1.2	1705	3.94	-	-	-	1705	1.2	(2)

(1) Ron Craig, Resident 260 Cimmaron Way

(2) Telesto Solutions, Inc.

4.0 FLOOD IRRIGATION APPLICATION RATE

Net irrigation water (irrigation plus precipitation) of 36 inches per irrigation season was estimated by scaling the recommended irrigation level for urban lawns (30 in/yr), presented in Table 4.14 of Water Requirements for Urban Lawns (Danielson, 1980), to the amount required for pasture grasses (36.6 in/yr). The scale factor is based on the ratio of the estimated potential evapotranspiration for pasture grasses (23.46 in/yr) to Kentucky bluegrass (19.25). Potential evapotranspiration was estimated based on:

- The stochastic weather generator CLIGEN was used to generate a daily weather data set for Boulder including precipitation, precipitation duration, temperature, solar radiation, wind velocity, and dew point.
- Daily potential evaporation was calculated using the Penman-Monteith equation.
- Daily potential evaporation was adjusted (reduced) using the crop coefficients for pasture grasses and Kentucky bluegrass.

5.0 IRRIGATION RATE

Net irrigation water of 30 inches per irrigation season is consistent with the recommended irrigation level for urban lawns presented in Water Requirements for Urban Lawns (Danielson, 1980). In Table 4.14, the recommended irrigation level for urban lawns in Longmont, CO at 80% of maximum irrigation is 30.5 inches May through October.

The assumption that 10 inches of 30 inches (33%) of the total applied water (irrigation and rainfall) becomes recharge (deep percolation) is approximately three times the amount of recharge that would be estimated using the Cottonwood Curve.

The Cottonwood Curve is the most widely used method for estimating deep percolation in lawn irrigation along the Front Range and has been accepted by the Colorado Water Court and the Office of the State Engineer for estimating deep percolation. The applicability of the Cottonwood Curve in estimating deep percolation has been corroborated by the work of Ramchand Oad and Michael DiSpigno (1996) who stated: "With respect to deep percolation, the CSU lysimetry research gave essentially similar results as the linear portion of the Cottonwood Curve and as the Gronning Line."

The Cottonwood Curve is based on a lysimeter study performed by W.W. Wheeler and Associates at the request of the Cottonwood Water and Sanitation District to quantify the amount of deep percolation from lawn irrigation. The Cottonwood Curve was developed based on the measured data from forty lysimeters installed in Cherry Creek and southeast metropolitan Denver and demonstrates a relationship between water application, deep percolation and potential consumptive use of turf grass.

6.0 REFERENCES

CLIGEN USDA Water Erosion Prediction Project (WEPP) Climate Input Data Generator Version 5.22564

Danielson, Robert E. 1980. Water Requirements for Urban Lawns in Colorado. Colorado Water Resources Research Institute Completion Report No. 97. August 1980.

Natural Resource Conservation Service Web Soil Survey. Map Unit Description: Niwot soils–Boulder County Area, Colorado (http://websoilsurvey.nrcs.usda.gov).

Oad, R. and M. DiSpigno. 1996. Consumptive use and Return Flows in Urban Water Use. Colorado Water Resources Research Institute Completion Report No. 189. December 1996.

Telesto (Telesto Solutions, Inc.). 2010. Ground Water Evaluation for the Hogan-Pancost Property Boulder, Colorado, June 2010.

APPENDIX B
DRY CREEK DITCH No. 2
RECHARGE ESTIMATE

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Introduction

An analytical element model was used to simulate the Project area ground water system and estimate the leakage rate from Dry Creek Ditch No. 2 that would be eliminated once the ditch is piped across the Project area (Figure B-1).

Calculations were performed using the publicly available program TWODAN 5.0 (Fits Geosolutions), which was configured to simulate two-dimensional (horizontal) ground water flow in an unconfined aquifer with a constant-base elevation. The model is centered on the Project area and incorporates the relevant hydrologic components including prescribed head boundaries associated with the Howard Superphostical Ditch, transient flux boundaries associated with Dry Creek Ditch No. 2 and Bodam Lateral, and pumping from nearby residential sump pumps.

Model

TWODAN is a multi-functional analytic element model used for simulating two-dimensional ground water flow. TWODAN includes a suite of modeling features that allow for simulating simple or complex systems. The aquifer modeled can consist of one or two hydraulically connected confined and/or unconfined layers. In addition, the model allows for both steady-state and transient simulations (implemented using transient injection or extraction wells). The model also allows for discharge-specified and head-specified linesinks. Head-specified linesinks are typically used to represent constant-head boundaries. Discharge-specified linesinks can be used to model infiltration trenches. However, only steady state linesinks are allowed. Therefore, transient wells must be used to simulate time-dependent discharge boundaries (i.e., Dry Creek Ditch No. 2).

Approach

Annual changes in water level at the site have been measured for two periods, March 2006 through May 2007, and May 2011 through May 2012 (Table B-1). On April 25, 2012, flow in Dry Creek Ditch No. 2 was observed to start flowing across the Project area. Over the next two days, water levels across the site were measured, during which time

there was no precipitation. Therefore, the change (increase) in water levels in wells located near Dry Creek Ditch No. 2, in particular monitoring well B-3, can be directly attributed to leakage from the ditch. Water level changes observed at wells potentially influenced by neighborhood sump pumping (e.g., B-1) and those located further from the ditch (e.g., B-2, B-4, PVC-SW, and PVC-SE) exhibit less influence from Dry Creek Ditch No. 2. Due to the close proximity of monitoring well B-3 to Dry Creek Ditch No. 2, and the absence of nearby sumps, the monitoring well B-3 water level data were used as the primary basis of the analysis.

The approach used to estimate the Dry Creek Ditch No. 2 leakage rate was to:

- Create a steady state model and calibrate the model to data measured on April 25, 2012 (day ditch flow started).
- Add transient recharge from Dry Creek Ditch No. 2 to the model and calibrate to the transient data measured on April 26, 2012 and April 27, 2012.
- Keeping all model parameters consistent with the transient model, validate the model using transient data measured between May 6, 2011 and July 12, 2011.

The following sections describe the model configuration, calibration, and validation.

Model Input

The calibrated model inputs are summarized in Table B-2.

Aquifer Description

TWODAN requires basic information on the ground water system configuration including the aquifer bottom elevation, layer thickness, and hydraulic conductivity.

The aquifer was split into two layers, a lower layer representing sand and gravel, and an upper layer representing surface loam. The aquifer bottom elevation was set equal to the bedrock elevation observed at monitoring well B-1. Total aquifer thickness of 10.67 feet was estimated based on the average of depth-to-bedrock measurements for monitoring wells B-1, B-2, and B-3. Based on the NRCS soil description for the site, the upper loam layer was assumed to average 14-inches (1.167 feet) and have a hydraulic conductivity of

0.1 ft/day (6.0 in/hr). The lower layer of 9.5-feet was based on the total aquifer thickness minus the thickness of the overlying loam.

The hydraulic conductivity of the lower layer was based on operation of the Boulder Community Hospital dewatering system. The hospital is situated above the same unconfined aquifer that exists in the Project area. Operation of the dewatering system provides reliable data for estimating the hydraulic conductivity of the unconsolidated materials that comprise the unconfined aquifer. Based on analyses developed for hospital dewatering system, the hydraulic conductivity of the lower unconfined aquifer layer was set at 100 ft/day.

Reference Head

TWODAN requires specification of a *Reference Head* at one point in the flow domain outside the area of interest. The head at the reference point is set such that heads and gradients outside of the outermost features of the model are reasonable. The reference head used here was positioned ~4300 feet SSE of the southwest property corner. The reference head is located beyond the model boundaries and once set does not affect the simulation inside the model area.

Storativity / Transmissivity

In order to evaluate the transient response of the aquifer the aquifer storage properties must be specified. Storativity (specific yield in unconfined aquifers) is the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in hydraulic head.

The aquifer material of the west parcel has described as clayey sand and clayey gravel. In unconsolidated deposits specific yield may range from a minimum of 0.03 for sandy clay (mud) to a maximum value of 0.35 for coarse sand, gravelly sand or fine sand[1]. During the transient calibration, a reasonable match was obtained between and measured

[1] Johnson, A.I. 1967. Specific yield. U.S. Geological Survey Water Supply Paper 1662-D. 74 p.

simulated water levels using a fixed specific yield value of 0.20. This is comparable to the values commonly used by the Colorado Office of the State Engineer which range from 15% to 25% (2 CCR 410-1 5.7). TWODAN uses the ratio of Storativity / Transmissivity where transmissivity is equal to the hydraulic conductivity multiplied by the saturated thickness. The values used to estimate transmissivity are described in the following section.

Uniform Flow

The uniform flow defines a uniform cross flow (aquifer discharge) in the model. Both the magnitude of uniform aquifer discharge and the angle of the discharge are defined. The magnitude of the discharge (12.933 ft^2/day) is equal to the transmissivity multiplied by the hydraulic gradient. Coupled with the hydraulic conductivity of 100 feet/day, the data measured at monitoring wells B-1 and B-3 on April 25, 2012 and April 27, 2012 were used to estimate the saturated thickness (11.5 feet) and hydraulic gradient (0.011246 ft/ft).

Aerial Recharge

Based on the water balance analyses presented in the main report, during the summer period (April through September) the sum of runoff and evapotranspiration exceeds precipitation under current (2012) non-irrigated conditions. Therefore, recharge for the summer period within the Project area was set to zero in the model.

Model Features

The Project area is surrounded by irrigation ditches on all sides (Figure B-1). Dry Creek Ditch No. 2 is located along the west boundary, the Howard-Superphostical ditch is located along the northeast property boundary, and the Bodam Lateral is located along the west parcel south property boundary. There is also an Unnamed Ditch along the south property boundary of the east parcel (Figure B-2). With the exception of the Bodam Lateral, all ditches are unlined and are in hydraulic connection with the underlying ground water system. When water levels in the Bodam Lateral are high, water also spills over a portion of the ditch lining and recharges the ground water system.

Steady State Calibration

The steady state model was calibrated using the following information:

- Measured water levels April 25, 2012 for six Project Area monitoring wells.
- Dry Creek Ditch No. 2 is dry.
- Superphostical Ditch contains flowing water at the elevations surveyed on May 9, 2012.
- Bodam Lateral is dry.
- The Unnamed Ditch is dry.
- Houses in the Area of Interest do not perform basement sumping, so the water table is below the basement elevations.
- No basement sumping at the house south of the Project area (assumed).

To perform the calibration, the model was run in steady-state mode using an aquifer hydraulic conductivity of 100 ft/day. Based on the water balance, the summer recharge rate was set to zero.

The steady state model was calibrated by adjusting prescribed heads along the north and south boundaries of the model. A reasonable calibration was achieved by making only slight changes to the north and south prescribed head boundaries. The water levels simulated by the calibrated steady state model are shown in Figure B-2, and a comparison of calibration targets with model predictions is provided in Table B-3.

Transient Calibration

The steady state model was calibrated using the following information:

- Measured water levels April 26, 2012 and April 27, 2012 for six Project area monitoring wells.
- No precipitation during the observation period.
- Dry Creek Ditch No. 2 contains flowing water.
- Superphostical Ditch contains flowing water at the elevations surveyed on May 9, 2012.
- Bodam Lateral contains flowing water.
- The Unnamed Ditch contains flowing water at an elevation approximately equal to the ground surface elevation.
- Houses in the Area of Interest perform basement sumping at the rate measured on April 27, 2012 at 260 Cimmaron Way.

- House south of the Project area has four sumps each pumping at a rate equal to the 260 Cimmaron Way pumping rate.

There was no precipitation during the observation period. Therefore, the change (increase) in water level at monitoring well B-3, which is located near Dry Creek Ditch No. 2, is directly attributable to leakage from Dry Creek Ditch No. 2.

Water level changes observed at wells located further from the ditch (e.g., B-2, B-4, PVC-SW, PVC-SE), and those potentially influenced by neighborhood sump pumping (e.g., B-1), exhibit less influence from Dry Creek Ditch No. 2. The data from these wells are useful for model water level calibration but are less useful for estimating the Dry Creek Ditch No. 2 leakage rate.

Transient wells were added to the steady state model to simulate the transient recharge from Dry Creek Ditch No. 2. Transient wells were also added to simulate a small amount of recharge from the Bodam Lateral leakage due to water overtopping a portion of the liner. All other model values were kept consistent with the steady state model.

The transient model was calibrated by adjusting transient well recharge rates until a reasonable match was obtained with the observation period calibration targets. Because of its close proximity to Dry Creek Ditch No. 2, and the absence of nearby sumps, special consideration was given to matching the time dependent water levels measured at monitoring well B-3 during calibration.

A Dry Creek Ditch No. 2 steady leakage rate of 64.7 gpm was found to be sufficient to calibrate the transient model. The results of the model calibration are shown in Figure B-3. A comparison of daily calibration targets with model predictions is provided in Tables B-4a, B-4b, and B-4c. A summary of the average difference between measured and simulated water levels over the three day calibration period is provided in Table B-4d. Table B-5 shows a comparison of the measured and simulated water levels at monitoring well B-3. As can be seen from Tables B-4(a-d), B-5, and Figure B-3, the transient model reasonably simulates the change in water level during the observation period.

Transient Validation

The transient model was validated using the following information:

- Measured water levels May 6, 2011 and July 12, 2011 for six Project area monitoring wells.
- Dry Creek Ditch No. 2 was assumed to start flowing on May 6, 2011.
- Superphostical Ditch contains flowing water at the elevations surveyed on May 9, 2012.
- Bodam Lateral contains flowing water.
- The Unnamed Ditch contains flowing water at an elevation approximately equal to the ground surface elevation.
- Houses in the Area of Interest perform basement sumping at the average rate measured between May 6, 2011 and July 12, 2011 at 260 Cimmaron Way.
- House south of the Project area has four sumps each with a sumping rate equal to the average rate measured between May 6, 2012 and July 12, 2011 at 260 Cimmaron Way.

The model was run for a period of 67 days (May 5, 2011 to July 12, 2011) while keeping all model values unchanged from the transient model calibration. The water levels simulated by the model are shown in Figure B-5. A comparison of measured and simulated water levels at monitoring well B-3 demonstrates that the calibrated model reasonably simulates the change in water levels (Figure B-6) during the 2011 validation period. Based on the results of the model validation, the model is sufficiently accurate for evaluating the Dry Creek Ditch No. 2 leakage rate.

Discussion and Conclusions

Validation of the model using the 2011 data set demonstrates that the model reasonably simulates the change in water levels at the start of the irrigation season. Thus, the estimated leakage rate of approximately 64.7 gpm from Dry Creek Ditch No. 2 is also considered reasonable for the first start of the irrigation season.

The estimated leakage rate of 64.7 also corresponds well to the average rate used by the ditch company for estimating ditch leakage. When using the ditch company's leakage rate of 20%, and a flow rate equal to the piped ditch design capacity (28 gpm), the average leakage rate across the Project area is calculated to be approximately 51.5 gpm.

Although this rate is slightly lower, it is consistent with the estimated leakage rate of 64.7 gpm.

The ditch leakage rate would be expected to vary over time in response to changes in ditch water level and ground water levels. When the difference between the ditch water level and ground water level is larger, the leakage rate will be relatively higher. When the water level difference is smaller, the leakage rate will be relatively lower.

The model was calibrated and validated using data from time periods where the initial water level difference was relatively large. Therefore, the estimated rate likely represents an upper bound. However, it demonstrates that leakage from Dry Creek Ditch No. 2 can contribute significant recharge to the ground water system (up to 2.8 million gallons/month) during the initial part of the ditch irrigation season. If Dry Creek Ditch No. 2 is piped as proposed, this significant source of recharge to ground water across the Project area will be removed. Thus, piping of Dry Creek Ditch No. 2 will benefit the neighbors to the west of the Project area by significantly reducing this source of recharge to ground water.

TABLES

Table B-1 Measured Water Level Data

Date	B-1	B-2	B-3	B-4	PVC--SE	PVC-SW
3/31/2006	5312.0	5317.5	5319.9	5321.5	-	-
4/7/2006	5312.0	5317.6	5320.4	5321.4	-	-
4/14/2006	5312.2	5317.8	5320.7	5322.7	-	-
4/20/2006	5312.8	5318.4	5321.0	5323.2	-	-
4/28/2006	5313.1	5319.2	5321.4	5323.8	-	-
5/5/2006	5313.6	5319.4	5321.4	5323.9	-	-
5/12/2006	5314.7	5319.5	5321.5	5323.9	-	-
5/19/2006	5315.0	5319.8	5321.7	5324.0	-	-
5/29/2006	5314.9	5319.9	5321.7	5324.0	-	-
6/5/2006	5314.9	5321.9	5321.6	5323.9	-	-
6/21/2006	5314.8	5321.9	5321.5	5323.7	-	-
7/7/2006	5314.7	5321.9	5321.7	5323.4	-	-
7/19/2006	5314.3	5321.9	5321.8	5322.8	-	-
8/19/2006	5313.4	5321.4	5320.3	5322.5	-	-
9/29/2006	5312.9	5318.7	5319.5	5320.7	-	-
10/20/2006	5312.4	5318.3	5319.1	5321.8	-	-
11/22/2006	5312.6	5319.1	5319.3	5322.0	-	-
12/15/2006	5312.2	5319.1	5318.8	5322.0	-	-
1/4/2007	5312.1	5318.8	-	5323.3	-	-
1/11/2007	5313.2	5320.0	5321.4	5323.9	-	-
2/15/2007	5314.3	-	5321.6	5323.6	-	-
3/9/2007	5313.8	5320.9	5321.3	5322.9	-	-
4/19/2007	5313.2	5320.1	5320.3	5322.3	-	-
5/15/2007	5314.1	5320.0	5320.4	5323.9	-	-
5/22/2007	5314.5	5319.7	5320.9	5323.5	-	-
5/29/2007	5314.7	5319.4	5321.2	5322.4	-	-

Table B-1 Measured Water Level Data (continued)

Date	B-1	B-2	B-3	B-4	PVC--SE	PVC-SW
5/6/2011	-	-	-	-	5320.4	5319.7
5/16/2011	-	-	5321.2	-	5323.0	5321.9
5/22/2011	-	-	5320.5	-	5324.1	5323.0
5/23/2011	5314.7	5319.4	5321.5	-	5324.0	5323.0
5/23/2011	5314.8	5319.4	5321.5	5323.4	5324.2	5322.8
5/31/2011	5314.4	5319.8	5321.4	5322.4	5323.5	5322.6
6/8/2011	5314.3	5319.4	5321.1	5321.5	5322.9	5322.2
6/14/2011	5314.3	5319.2	5321.44	5321.43	5323.0	5322.1
6/23/2011	5314.3	5318.9	5321.2	5321.1	5323.0	5322.1
7/12/2011	5313.9	5318.6	5321.5	5323.7	5323.9	5322.7
8/23/2011	5313.5	5317.6	5320.9	5322.0	5322.6	5321.6
9/23/2011	5313.4	5318.3	5320.4	5322.1	5322.9	5321.7
10/25/2011	5312.2	5318.0	5319.2	5320.6	5321.5	5320.7
11/21/2011	5312.1	5318.2	5318.8	5321.3	5321.5	5320.7
12/21/2011	5311.7	5317.7	5318.2	5321.1	5320.9	5320.1
1/25/2012	5311.9	5318.1	5318.8	5321.7	5321.4	5320.4
2/22/2012	5311.7	5317.8	5318.4	5322.5	5321.2	5320.1
3/22/2012	5312.1	5318.3	5319.1	5321.6	5322.1	5319.7
4/25/2012	5312.15	5317.86	5319.36	5321.42	5321.25	5320.71
4/26/2012	5312.18	5317.84	5319.77	5322.08	5321.56	5320.75
4/27/2012	5312.35	5317.82	5319.94	5322.05	5321.76	5320.80
5/2/2012	5312.64	5317.74	5320.16	5321.55	5322.08	5320.94
5/9/2012	5313.08	5317.76	5320.52	5322.76	5322.30	5322.03

Table B-2 Model Input Summary

	Units	Steady-State Calibration	Transient Calibration	Transient Validation	1.0 COMMENT
Aquifer					
Model Bottom	ft	5306.13	5306.13	5306.13	B-1 Bedrock Elev
Layer 1 Thickness	ft	1.167	1.167	1.167	NRCS
Layer 1 Hydraulic Cond.	ft/day	12	12	12	NRCS
Layer 2 Thickness	ft	9.5	9.5	9.5	Total depth minus layer 1 thickness
Layer 2 Hydraulic Cond.	ft/day	100	100	100	BCH Dewatering System
Reference Head			0	0	
X	ft	0	0	0	-
Y	ft	0	0	0	-
Z	ft	5330	5330	5330	Assumed
S/T		0.000174	0.000174	0.000174	
Storativity		0.2	0.2	0.2	Assumed
Transmissivity	ft2/day	1150	1150	1150	=K*b = 100 * 11.5
Uniform_Flow			0	0	
Gradient	ft/ft	0.01124	0.01124	0.01124	Avg. 4/25/12 & 4/27/12
Transmissivity	ft2/day	1150	1150	1150	=K*b = 100 * 11.5
Qo (= T * I)	ft2/day	12.93	12.933	12.933	Avg. 4/25/12 & 4/27/12
Angle	deg	88.26	88.26	88.26	B-3 to B-1
Global_Rech.	ft/day	0	0	0	Summer Water Balance
Prescribed Head Boundaries					
South Boundary Condition	ft	5334.5	5334.5	5334.5	Calibrated
North Boundary Condition	ft	5308.13	5308.13	5308.13	Calibrated
Howard Superphostical – SE	ft	5319.4	5319.4	5319.4	5/9/12 Survey
Howard Superphostical - E	ft	5318.2	5318.2	5318.2	5/9/12 Survey
Howard Superphostical - NW	ft	5312.1	5312.1	5312.1	5/9/12 Survey
East		0	5324	5324	Topo mid-point
No Flow Boundaries					
West	-	-	-	-	-
East - South Boulder Creek	-	-	-	-	-
Transient Wells					
Dry Creek Ditch No. 2	gpm	-	-64.7	-64.7	Calibrated Recharge
Bodam Lateral	gpm	-	-6.2	-6.2	Calibrated Recharge
220 Cimmaron Way	gpm	-	1.5	4.90	Assumed same as 260 Cimmaron Way
230 Cimmaron Way	gpm	-	1.5	4.90	Assumed same as 260 Cimmaron Way
240 Cimmaron Way	gpm	-	1.5	4.90	Assumed same as 260 Cimmaron Way
250 Cimmaron Way	gpm	-	1.5	4.90	Assumed same as 260 Cimmaron Way
260 Cimmaron Way	gpm	-	1.5	4.90	Measured 4/27/12 Average Measured 5/6/11 - 7/12/11
Bodam Sumps (x4)	gpm	-	1.5	4.90	Estimated at 4x 260 Cimmaron Way

Table B-3 Steady State Calibration Targets (Measured 4/12/25)

Monitoring Well	x	y	Observed	Simulated	Difference
B-1	3161.4	5921.3	5312.1	5312.7	0.59
B-2	3600.0	5453.4	5317.9	5317.9	0.08
B-3	3100.0	5266.2	5319.4	5319.4	0.01
B-4	4195.4	5170.9	5321.4	5319.9	-1.47
PVC-SE	3796.9	5107.3	5321.6	5321.2	-0.39
PVC-SW	3498.1	5189.2	5320.8	5320.4	-0.34
				Mean (modeled - observed) =	-0.25
				Standard deviation =	2.77
				Sum of squared =	2.77

Table B-4a Transient Calibration Targets (Measured 4/25/2012)

Monitoring Well	x	y	Observed	Simulated	Difference
B-1	3161.4	5921.3	5312.2	5312.8	0.61
B-2	3600.0	5453.4	5317.8	5318.2	0.37
B-3	3100.0	5266.2	5319.8	5319.5	0.19
B-4	4195.4	5170.9	5322.1	5321.1	-0.36
PVC-SE	3796.9	5107.3	5321.6	5322.1	0.53
PVC-SW	3498.1	5189.2	5320.8	5320.9	0.10
				Mean (modeled - observed) =	0.24
				Standard deviation =	0.35
				Sum of squared =	0.96

Table B-4b Transient Calibration Targets (Measured 4/26/2012)

Monitoring Well	x	y	Observed	Simulated	Difference
B-1	3161.4	5921.3	5312.2	5312.8	0.60
B-2	3600.0	5453.4	5317.8	5318.2	0.39
B-3	3100.0	5266.2	5319.8	5319.7	-0.03
B-4	4195.4	5170.9	5322.1	5321.1	-1.02
PVC-SE	3796.9	5107.3	5321.6	5322.1	0.53
PVC-SW	3498.1	5189.2	5320.8	5320.9	0.11
				Mean (modeled - observed) =	0.10
				Standard deviation =	0.60
				Sum of squared =	1.85

Table B-4c Transient Calibration Targets (Measured 4/27/2012)

Monitoring Well	x	y	Observed	Simulated	Difference
B-1	3161.4	5921.3	5312.3	5312.8	0.48
B-2	3600.0	5453.4	5317.8	5318.2	0.41
B-3	3100.0	5266.2	5319.9	5319.9	0.00
B-4	4195.4	5170.9	5322.1	5321.1	-1.00
PVC-SE	3796.9	5107.3	5321.8	5322.1	0.33
PVC-SW	3498.1	5189.2	5320.8	5320.9	0.08
				Mean (modeled - observed) =	0.05
				Standard deviation =	0.55
				Sum of squared =	1.50

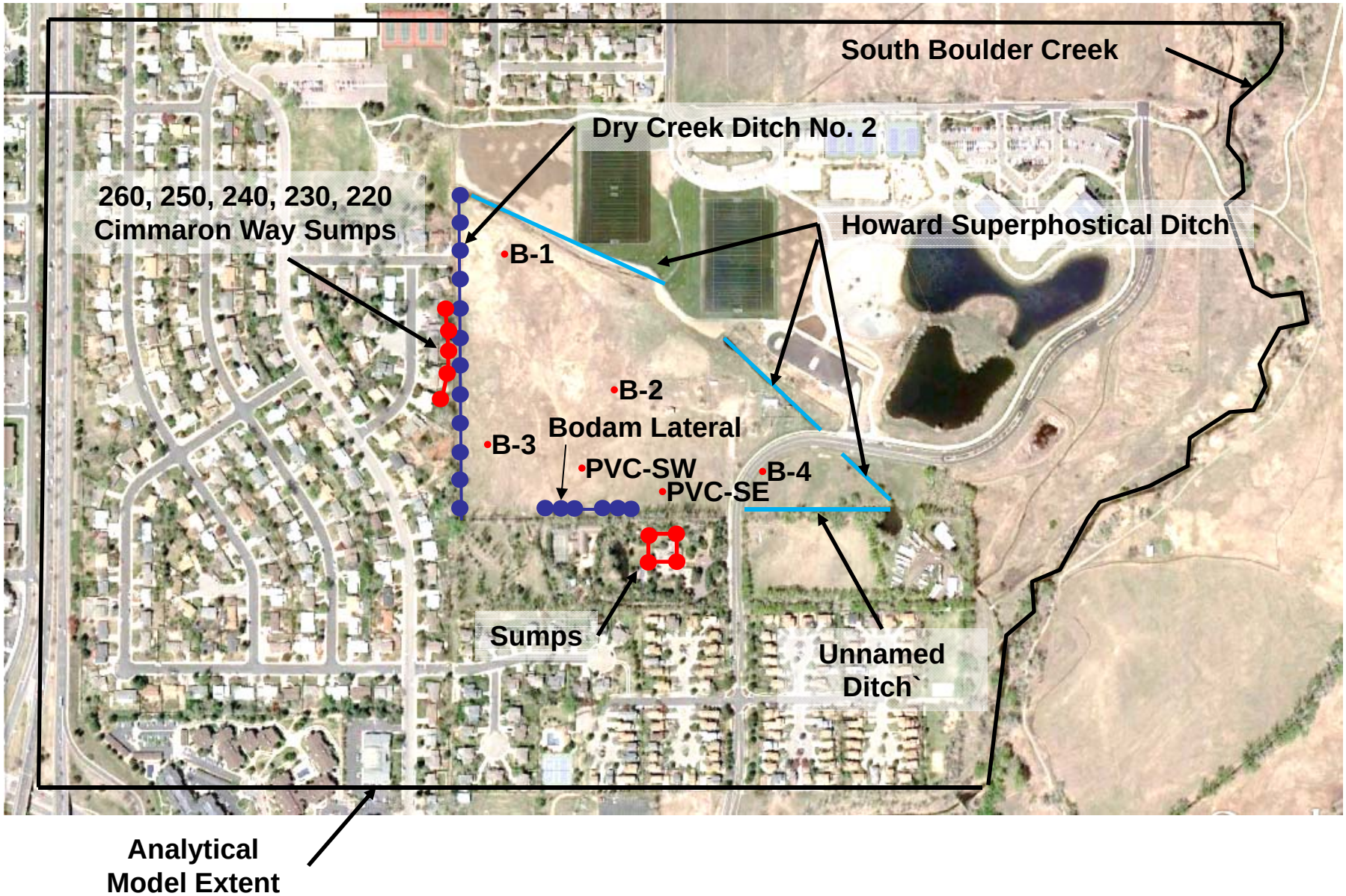
Table B-4d Transient Calibration Targets (Measured 4/25/2012-4/27/2012)

Monitoring Well	x	y	Observed	Simulated	Difference
B-1	3161.4	5921.3	variable	variable	0.56
B-2	3600.0	5453.4	variable	variable	0.39
B-3	3100.0	5266.2	variable	variable	0.05
B-4	4195.4	5170.9	variable	variable	-0.79
PVC-SE	3796.9	5107.3	variable	variable	0.46
PVC-SW	3498.1	5189.2	variable	variable	0.09
				Mean (modeled - observed) =	0.13
				Standard deviation =	0.50
				Sum of squared =	1.33

Table B-5 Transient Validation (Well B-3)

Date	Observed	Simulated	Difference
5/16/2011	5321.2	5320.603	-0.58
5/23/2011	5321.5	5320.873	-0.59
5/31/2011	5321.4	5321.069	-0.32
6/8/2011	5321.1	5321.207	0.07
6/14/2011	5321.44	5321.289	-0.15
6/23/2011	5321.2	5321.389	0.18
7/12/2011	5321.5	5321.546	0.06
		Mean (modeled - observed) =	-0.2
		Standard deviation =	0.31
		Sum of squared =	0.86

FIGURES

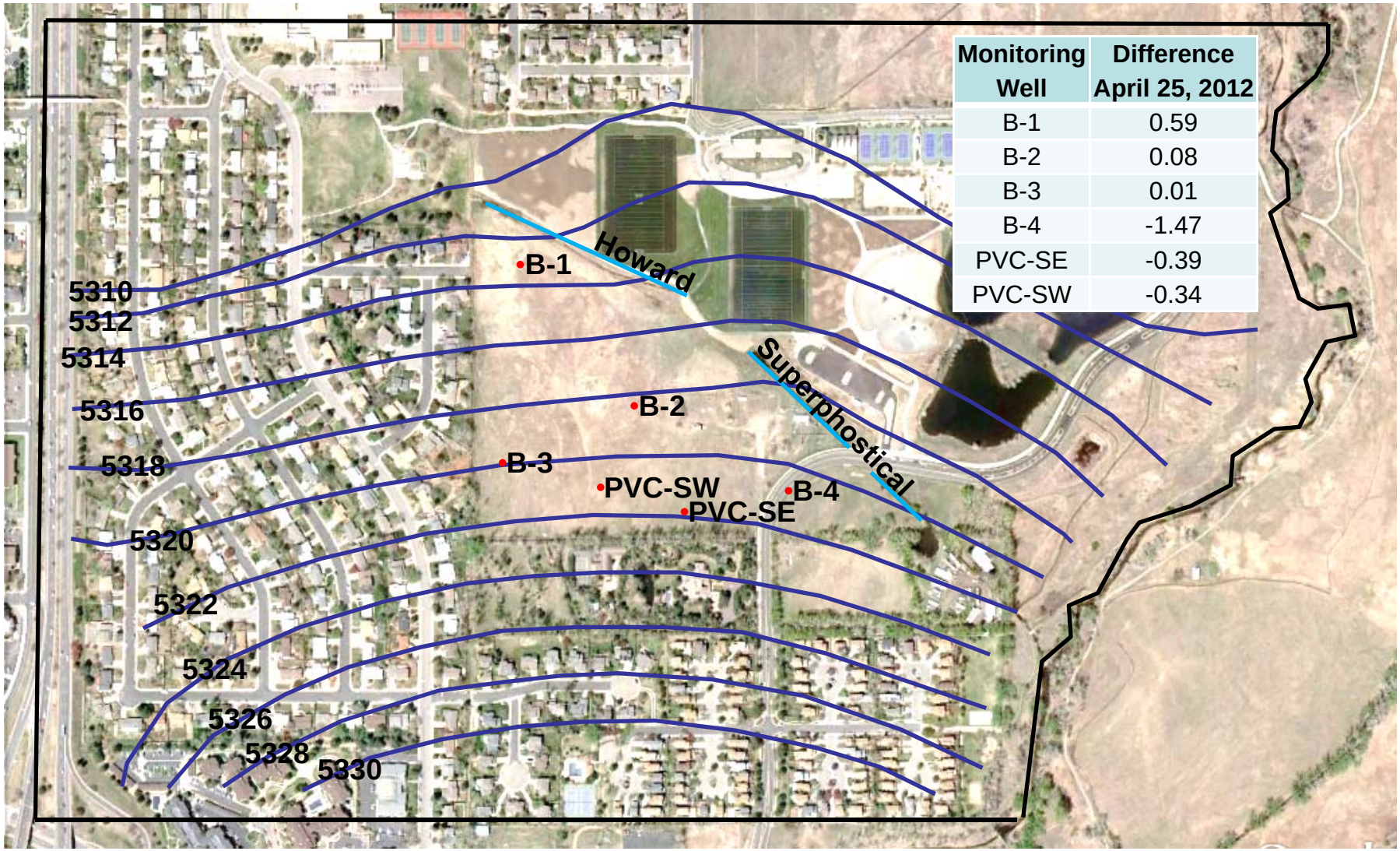


PROJECT:	TASK
320-100	1

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

FIGURE B-1
ANALYTICAL ELEMENT MODEL EXTENT & FEATURES

PREPARED FOR:
BOULDER CREEK COMMONS, LLC.



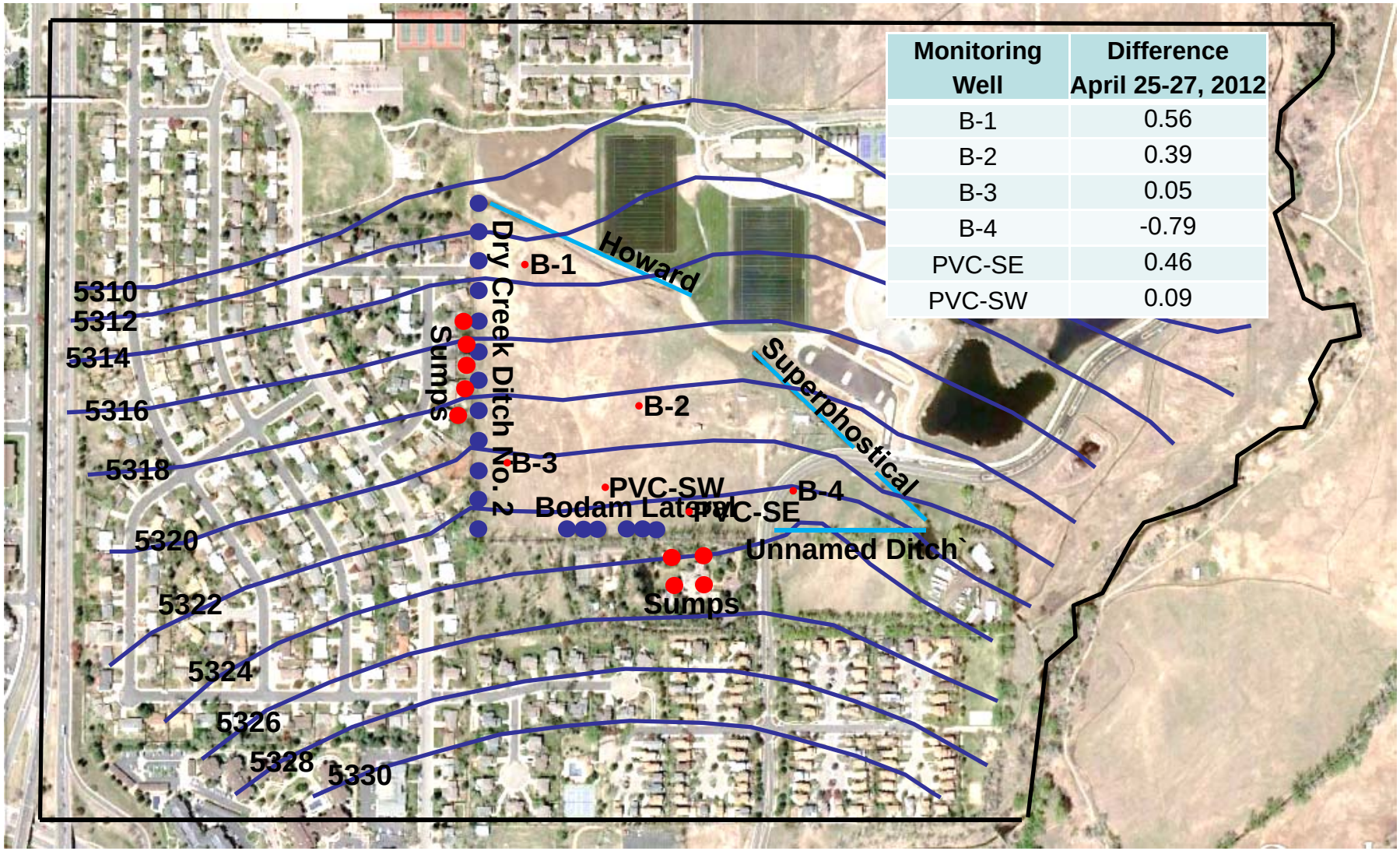
Monitoring Well	Difference April 25, 2012
B-1	0.59
B-2	0.08
B-3	0.01
B-4	-1.47
PVC-SE	-0.39
PVC-SW	-0.34

PROJECT: 320-100 | TASK 1

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

FIGURE B-2
STEADY STATE MODEL SIMULATED WATER LEVELS

PREPARED FOR: BOULDER CREEK COMMONS, LLC.



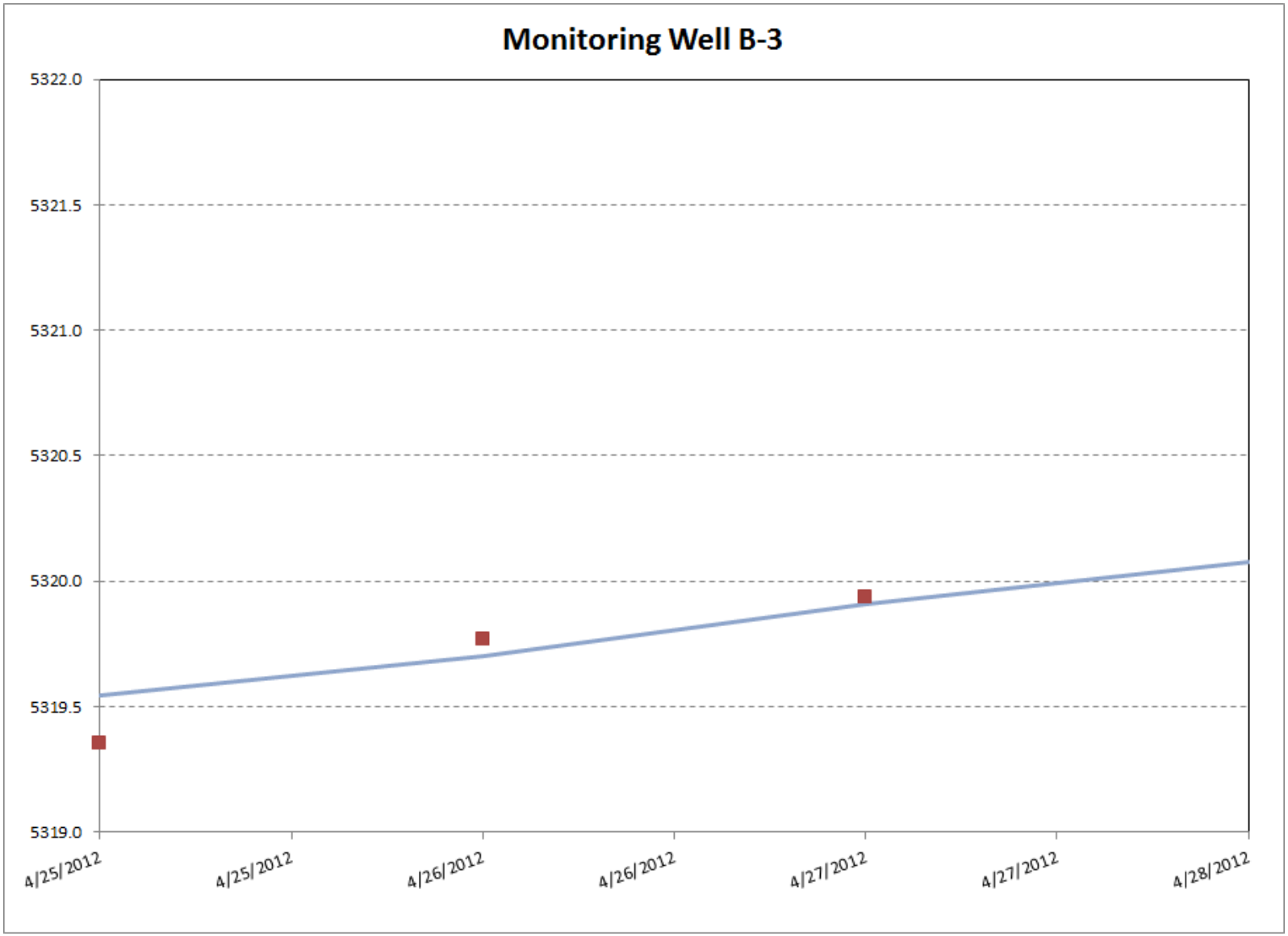
Monitoring Well	Difference April 25-27, 2012
B-1	0.56
B-2	0.39
B-3	0.05
B-4	-0.79
PVC-SE	0.46
PVC-SW	0.09

PROJECT:	TASK
320-100	1

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

FIGURE B-3
TRANSIENT MODEL SIMULATED WATER LEVELS

PREPARED FOR:
BOULDER CREEK COMMONS, LLC.

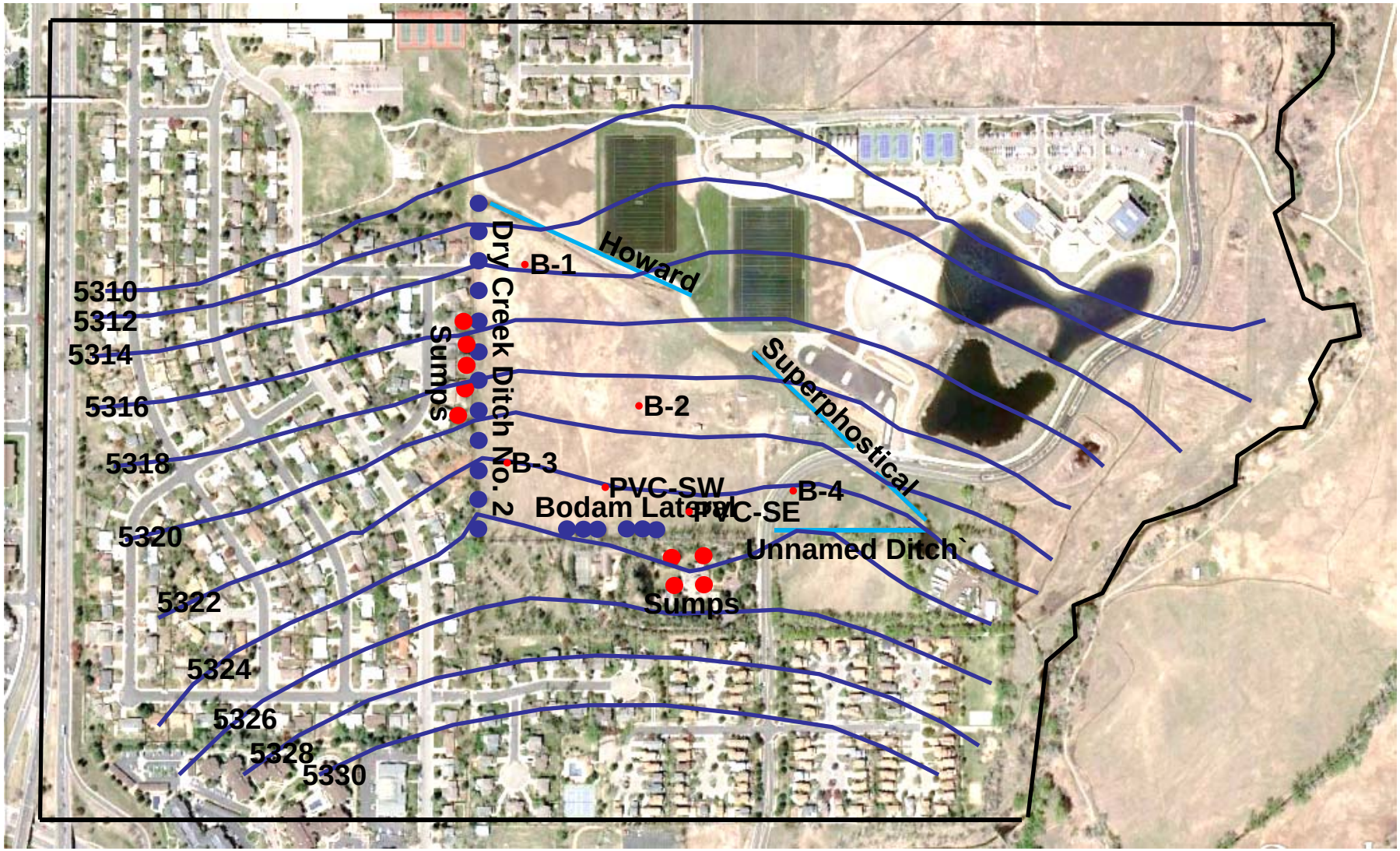


PROJECT:	TASK
320-100	1

PREPARED BY:
TELESTO SOLUTIONS INCORPORATED

FIGURE B-4
2012 SIMULATED WATER LEVELS AT MONITORING WELL B-3

PREPARED FOR:
BOULDER CREEK COMMONS, LLC.

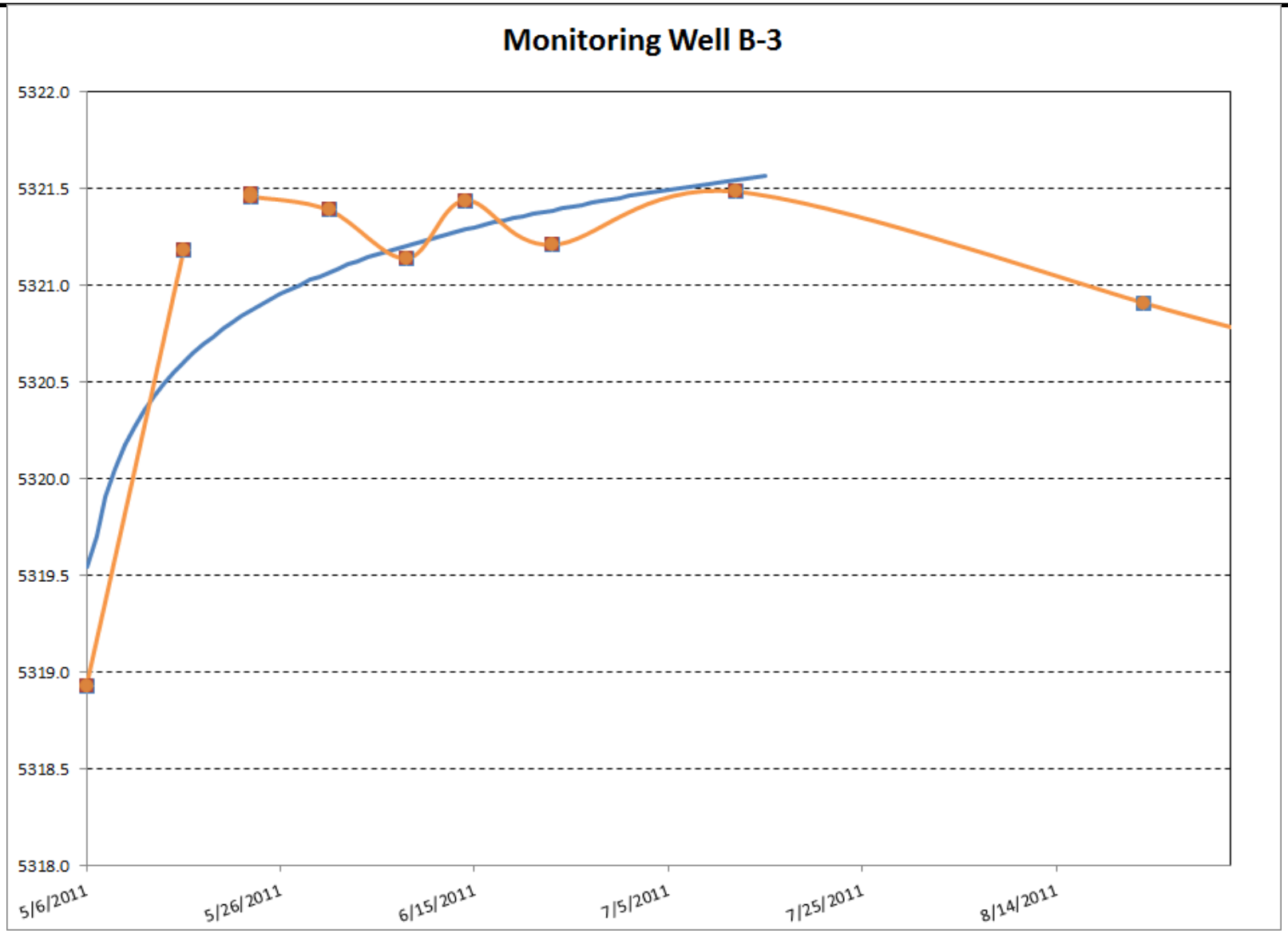


PROJECT:	TASK
320-100	1

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

FIGURE B-5
TRANSIENT VALIDATION MODEL SIMULATED WATER LEVELS
FOR JULY 12, 2011

PREPARED FOR:
BOULDER CREEK COMMONS, LLC.



Note: The data shown for B-3 on 5/6/11 (5318.9 ft) was estimated based on the PVC-SW elevation for 5/6/11 (5319.68 ft) minus the difference (0.8 ft) between the two locations measured on 5/16/11.

PROJECT:	TASK
320-100	1

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

FIGURE B-6
2011 SIMULATED WATER LEVELS AT MONITORING WELL B-3

PREPARED FOR:
BOULDER CREEK COMMONS, LLC.