GROUND WATER EVALUATION FOR THE HOGAN-PANCOST PROPERTY BOULDER, COLORADO

November 2010

TELESTO SOLUTIONS • INCORPORATED

PREPARED FOR:
BOULDER CREEK COMMONS, LLC
1526 SPRUCE STREET, SUITE 260
BOULDER, COLORADO 80302

PREPARED BY:
TELESTO SOLUTIONS, INC.
2950 EAST HARMONY ROAD, SUITE 200
FORT COLLINS, COLORADO 80528

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1526 Spruce Street, Suite 260
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Prepared by:

Telesto Solutions, Inc.
2950 East Harmony Road, Suite 200
Fort Collins, Colorado 80528

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TELESTO
SOLUTIONS INCORPORATED

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1.0 INTRODUCTION

At the request of Boulder Creek Commons, LLC (BCC, LLC), Telesto Solutions Inc. (Telesto) prepared this report to document a ground water evaluation for the proposed development of the Hogan-Pancost Property (Project) located in Boulder, Colorado. The Project (approximately 19.5 acres) is located in the lowest portion of the South Boulder Creek watershed, which drains approximately 132 square miles from the headwaters on James Peak to its confluence with Boulder Creek northeast of Valmont and 55th Street. The Project and surrounding areas overlie a thin (10 to 30 feet thick) unconfined aquifer with a high water table that fluctuates seasonally. The fluctuating ground water table is affected by processes throughout the entire watershed. During spring, the aquifer water table rises due to snow melt and generally higher rainfall within the entire watershed. Locally, the high water table tends to persist through the summer due to ditch flows, local pond/reservoir leakage, residential lawn watering, and flood irrigation. 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 during this period. This pattern of a fluctuating water table exits prior to any development activities at the Project site.

Residents in the adjacent neighborhoods are concerned that development of residential housing in the Project area could cause the water table to rise higher and lead to increased basement sump pumping rates. In response to this concern, Telesto was commissioned by BCC, LLC 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 water shed area), and BCC, LLC 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 neighbor's basement pumping. The results of a numerical ground water flow model confirm Telesto's conclusions. The model incorporates the properties of the unconfined aquifer and important hydrologic features that can affect the ground water system. Of particular interest are the effects of: 1) seepage from unlined irrigation ditches, and 2) the change from current flood irrigation to residential lawn/shrub watering and storm water management within the Project area after development. 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.

Figure 1 is a site map showing the Project area, layout of adjacent residential neighborhoods, and boundaries of the study area. Figure 2 shows the important hydrologic features within the study area including ponds and irrigation ditches. The eastern boundary of the study area conforms to South Boulder Creek, which is a major perennial stream and in hydraulic connection with the unconfined aquifer. Also shown is the Area of Interest, within which are some houses that have had to use basement sumps during certain times of the year to control high water tables.

The evaluation presented herein, requires estimation of various flux rates under different land uses and conditions. The calculations and supporting documentation for parameters used in the analysis are presented in Attachment 1.

2.0 THE HYDROLOGIC PROCESS

Figure 3 (a through d) is a conceptual depiction of the hydrologic process near the Project and Area of Interest. This process is common along the Front Range and is prevalent throughout the west. In the late fall and during the winter (Figure 3a), 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 snow melt 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 does not intersect basement sumps in the Area of Interest, resulting in no pumping during this time.

In early spring (Figure 3b), 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 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 3c), 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 supplying the aquifer required to cause this rise in the water table is on the order of 10,000 gallons per minute (gpm) as indicated by the ground water model presented in Appendix A.

As summer progresses, South Boulder Creek no longer carries snowmelt from high in the basin and the flow is now sustained by the ground water stored in the aquifer, and South Boulder Creek begins to drain the aquifer (Figure 3d). Locally, the water table remains elevated in respect to winter conditions due to recharge from residential lawn watering, pasture watering, 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 3a).

Of the hydrologic processes described, precipitation recharge, ditch leakage and pasture watering occur currently on the Project site and are the only hydrologic variables on site that may be manipulated in order to affect minimal changes in the natural hydrologic process. As depicted in Figure 3, the Project is a small component of the overall hydrologic process. The entire recharge in the Project area from flood irrigation and ditch leakage is measured in tenths of a percent of the recharge in the area immediately surrounding the Area of Interest. The remainder of the report is intended to put this difference and the ability to affect changes on the ground water system into context. Also, the analyses provided herein are based on two different time periods (Winter Period – Figure 3a, and Summer Period – Figure 3d) as these two time periods represent the times where significant differences to basement sump pumping occur.

3.0 LOCAL MECHANISMS AFFECTING THE GROUND WATER SYSTEM

3.1 Area of Interest

Information exists to describe the annual response of the ground system under current conditions; that is, prior to any development in the Project area. Current conditions include snowmelt and higher rainfall in the spring, ditch flows, flood irrigation, and residential lawn watering during the summer.

During August 2005, Telesto sent questionnaires to residents within and adjacent to the Area of Interest. Respondents indicated that little or no basement sump pumping is required during the fall and winter, but pumping needs to be performed by some residences during the spring and summer. Based on qualitative analyses of the questionnaire results, the total spring/summer sump pumping rate within the Area of Interest is estimated to be about 40 gallons per minute (gpm) (See Attachment 1.1).

The Area of Interest exists on both side of Dry Creek Ditch #2, which typically flows from March through August. Because Dry Creek Ditch #2 is unlined, water likely seeps from the channel into the underlying ground water having localized impact on the ground water table. In addition, flood irrigation is currently practiced within the Project area (east of the Area of Interest) and intense sprinkler irrigation is 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 3d). 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.

3.2 Project Area – Pre-Development

Figure 4 shows the general hydrologic processes associated with the Project area in its current state (before development). Table 1 shows rainfall in the Boulder area from 1990 though November 2008. For this period, the average annual rainfall is 20.8 in/yr, of which 13.4 inches occurs from April through September (referred to in this report as the *Summer Period*) and 7.4 inches occurs from October through March (*Winter Period*). For the Front Range of Colorado natural recharge from precipitation falling on native ground (without irrigation) is about 10 percent of mean annual rainfall (See Attachment 1.2). Of the remaining 90 percent, the majority is used by vegetation through evapotranspiration and the remainder becomes storm water runoff (when large storms are prevalent or snowmelt is rapid).

Current summer recharge for the Project area is summarized in Table 2. The area to be developed currently has flood-irrigated pasture grass. The amount of net irrigation water (irrigation plus precipitation) is typically 3 feet (36 inches) per irrigation season (See Attachment 1.3). For inefficient flood irrigation, about one-half of the net irrigation water becomes deep percolation that recharges the underlying ground water (See Attachment 1.4).

3.3 Post-Project Development

Figure 5 show the anticipated hydrologic components after development of the Project area. Three large changes will occur when the site is developed: 1) storm water runoff within the Project area will drain to a series of bioswales that contain moderate water-use plants, 2) flood irrigation will cease and be replaced by efficient lawn watering and low water demand landscaping, and 3) impermeable surfaces (e.g., houses, driveways, sidewalks) will be added.

It is estimated that one-third of the storm water runoff entering the bioswales will evapotranspire to the atmosphere and two-thirds will percolate downward and provide seepage recharge to ground water (See Attachment 1.5). The bioswales are designed to contain all storm runoff within the Project area and prevent surface water flows to adjacent properties except during extreme rainfall events. Before development, storm water flows through and out of irrigation ditches and was removed from the Project area.

Within the Project area, impermeable features such as roads, driveways, and roofing will eliminate some of the infiltration that is now occurring over the entire Project area. It is estimated that 50% of the developed Project area will consist of impermeable features (Drexel Barrell & Company, personal communication). These features, however, will increase storm water runoff and snowmelt, which will be routed to the bioswales. Ninety percent of precipitation falling on impervious areas becomes runoff to the bioswales and becomes subject to the hydrologic process within the bioswales. No direct recharge to ground water takes place beneath impermeable areas.

Sprinkler-irrigated acreage includes turf and shrub areas within residential developments, parks, and ball fields. Due to covenants and deed restrictions that will be placed on the developed Project area, approximately 25% of the Project area will be irrigated lawn (turf) and shrubs. The remaining 25% of the Project area will consist of non-irrigated, low water-use plants. During the winter, both of these landscapes will provide recharge similar to that of natural vegetation. In the Front Range of Colorado, total turf irrigation application amount including rainfall is 30 inches per season, of which 10 inches becomes deep recharge that can reach the water table (See Attachment 1.6). Thus, during the summer months, approximately 10 inches of recharge will occur over the irrigated turf and shrub areas.

Table 3 provides a summary of the anticipated flows from the Project area after development for the winter and summer months. The table converts depths of water (as provided herein the discussion) into flow rates in gallons per minute for the ease of comparison. The equations for calculating the values in Table 3 are provided in Figure 5. The assumptions and parameters used in the equations are contained within this report section (Section 3.3).

4.0 DISCUSSION

Residential sump pumping occurs when the ground water table rises to the level of the drain/sump system installed just below the basement slab. As shown in Appendix A, the amount of water addition to the system in the area near the Project and Area of Interest is on the order of 10,000 gpm. The primary factors supplying this water, as shown in Figures 3c and 3d is recharge from South Boulder Creek, seepage from unlined irrigation ditches, and irrigation of pasture and residential lawns and shrubs. Until the sum of these mechanisms provide a significant amount of water, the ground water table does not rise sufficiently to invoke basement sump pumping in the Area of Interest.

Table 4 summarizes mechanisms contributing to ground water that can be affected by development of the Project area. For the winter period (Table 4a), there is no ditch seepage, and recharge conditions outside the Project area are the same for pre- and post-development. The only significant change is a nominal increase in recharge within the Project area associated with the use of bioswales for management of storm runoff and snow melt (an estimate change from 1.49 to 3.73 gpm). However, this estimate does not take into consideration that the bioswale channel bottom will be covered with loamy soils to retain water and facilitate vegetative growth. Since loamy soils are limited in their ability to transmit water (See Attachment 1.5), this is likely an overestimation of the change in recharge.

However, the magnitudes of both the pre- and post-development recharge values for the Project area are much smaller than summer values, and not nearly close to the magnitude of water required to raise the ground water levels to those that affect basement sump pumping. Thus, the improved storm water management system (bioswales) has a very 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 4b), there are only two mechanisms that change from pre- to post-development. The developer has agreed to pipe Dry Creek Ditch #2 along the western boundary of the Project area. This will totally eliminate the seepage that now occurs along this portion of the irrigation ditch, which causes localized increases in the ground water table. Within the Project area, conversion from flood irrigation to sprinkler irrigation and management of storm water using bioswales will significantly reduce recharge (as shown in Table 3). These changes will reduce the water contribution to the ground water system, which will tend to reduce localized effects on the water table elevation in the residential area and result in reduced basement sump pumping. Because all other summer mechanisms are unchanged, the only logical conclusion is that development in the Project area will lead to a reduction in basement sump pumping within the adjacent neighborhoods. There are simply no mechanisms associated with the development that could cause the summer pumping rates to increase.

5.0 CONFIRMATION OF RESULTS USING GROUND WATER MODELING

To quantify the effects of the housing development, a numerical ground water flow model was developed for the Project and adjacent area. A detailed description of the model is provided in Appendix A. Using the public-domain program MODFLOW, salient features of the flow system were incorporated including: natural and irrigation recharge, flood irrigation, seepage from unlined irrigation ditches, bioswale seepage, perennial South Boulder Creek, wetlands, etc.

For winter conditions, the model was calibrated to ground water levels measured at onsite and offsite wells, the known sump pumping rate of about 40 gpm at one residence south of the Project area, and the fact that residences within the Area of Interest do not generally sump pump during the winter. For summer conditions with higher recharge and seepage from irrigation ditches, model verification was performed so that the model continued to simulate the approximate 40 gpm pumping rate at the south residence and the estimated total sump pumping rate of about 40 gpm within the Area of Interest (See Attachment 1.1).

To evaluate post-development winter conditions, the only pertinent change to the model was an increase in recharge within the Project area from 1.49 to 3.73 gpm. This reflects a change from natural winter recharge to recharge associated with mixed-density housing and the use of bioswales for management of storm runoff and snow melt. After making this change, the model predicted that there will be no basement sump pumping within the Area of Interest, which is the same as the current situation.

To evaluate post-development summer conditions, the following changes were made to the model:

- Seepage from Dry Creek Ditch #2 was eliminated along the western boundary of the Project area, consistent with plans by the developer to pipe this segment of the ditch.
- Recharge within the Project area was reduced from 36.3 to 11.8 gpm, which reflects a change from current flood irrigation to recharge associated with mixed-density housing and the use of bioswales.

With these changes, the model predicted that within the Area of Interest, total basement sump pumping will decrease from 41.1 gpm (current) to 36.8 gpm (post-development). This result confirms the conclusion of the previous section that summer sump pumping will decrease after site development.

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 modest increase in total winter recharge within the Project area. However, there are large benefits of improved storm water management that far outweigh the increase in winter recharge. Also, the amount of recharge increase pales in comparison to the amount required to raise the water table to sump pumping elevations and thus, will not be noticed. Ground water modeling indicates that this increase will not lead to winter basement sump pumping in the neighborhoods adjacent to the proposed development.
- Compared to current summer conditions, the housing development will eliminate ditch seepage along the western boundary of the Project area and also decrease recharge within the Project area. Because all other hydrologic factors remain the same, the only logical conclusion is that the housing development will lead to a reduction in ground water recharge and thus a potential to reduce residential sump pumping.

- Ground water modeling predicts that after development, the total summer sump pumping flow rate will be about 4.3 gpm lower than the current pumping rate of about 41.1 gpm.

Based on this evaluation, it is Telesto's professional opinion that the proposed housing development will not adversely affect the basement sump pumping currently being performed by the residents and, in fact, will lead to a reduction in the total pumping rate. Telesto's opinion is contingent on the assumptions that: 1) two-thirds of storm runoff within the Project area is lost to the atmosphere by bioswale evapotranspiration, 2) turf and shrub irrigation rates are not higher than standard residential values associated with use of sprinklers, and 3) there is no change in the current operation of irrigation ditches, with the exception that Dry Creek Ditch #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 on the Hogan-Pancost Property can only lead to a decrease in sump pumping in nearby residences. This conclusion is based on accepted hydrologic principals and sound logic. The ground water flow model provides a quantitative estimate of the decrease in the sump pumping rate. Thus, two methods of analyses indicate the same results; that project development cannot logically lead to increased basement sump pumping.

TABLES

Table 1 Boulder Area Rainfall

Rainfall amounts in inches

	Winter Conditions						Summer Conditions					
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1990	0.96	1.60	0.75	1.04	1.32	4.55	2.16	1.73	0.39	4.23	1.13	1.84
1991	0.93	3.30	0.01	1.05	0.15	0.43	2.41	2.90	3.59	3.11	2.08	1.21
1992	0.79	2.56	0.84	0.67	0.00	5.17	0.46	1.70	0.96	1.13	3.08	0.02
1993	2.42	2.17	0.55	0.25	0.90	2.15	2.56	1.73	3.38	1.40	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	2.70	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	1.50	1.60	1.53	2.09	0.72	2.51
2001	0.40	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	1.50	0.20	3.20	1.18	0.09	1.44	1.52
2003	0.45	0.80	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	2.80	0.34	0.43	1.40	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	2.10	1.68	0.86	1.69	2.24	1.79	0.38	0.80	1.82	1.92
2008	1.18	0.13	n/a	0.46	0.63	1.47	1.13	4.21	1.58	0.09	2.97	1.84
Monthly Average	1.48	1.36	0.76	0.84	0.78	2.20	3.03	2.68	2.04	1.72	2.19	1.70
Seasonal Average	**7.4**						**13.4**					
Annual Average	**20.8**											

Table 2 Recharge within the Project Area before Development

	Inflow to Area	Outflow from Area			
Period	Inflow (P + I) (inch)	ET (inch)	Runoff (R_o) (inch)	Recharge (R) (inch)	Average Flow (R, gpm)
Winter	7.4	4.995	1.665	0.74	1.49
Summer	36	13.5	4.5	18	36.27

Table 3 Recharge within the Project Area after Development

Period	Inflow to Area				Outflows					
	Winter									
	Precip on Impervious Areas (P_{im})	Precip on Turf and Shrub Areas (P_{ts})	Irrigation on Turf and Shrub Areas (I_{ts})	Precip on Non-Irrigated Landscape (P_{ni})	Runoff from Impervious (RO_{im})	ET of Precip from Turf and Shrub Area (ET_{pts})	ET of Irrigation from Turf and Shrub Area (ET_{its})	Precip Runoff from Turf and Shrub Area (RO_{ts})	ET from Non-Irrigated Landscape (ET_{ni})	Runoff from Non-Irrigated Landscape (RO_{ni})
Area	50%	25%		25%						
Inches	7.4	7.4	0	7.4						
Flow (gpm)	7.46	3.73	0.00	3.73	6.71	2.24	0.00	1.12	2.24	1.12
		BioSwale Inflow (RO_{im}+RO_{ts} +RO_{ni})			ET Bioswale (ET_{bs})	Recharge Bioswale (R_{bs})	Precip Recharge from Turf and Shrub Area (R_{pts})	Irrigation Recharge from Turf and Shrub Area (R_{its})	Recharge from Non-Irrigated Landscape (R_{ni})	Recharge Average Flow (R)
Flow (gpm)		8.95			5.96	2.98	0.37	0.00	0.37	3.73
Period	Summer									
	Precip on Impervious Areas (P_{im})	Precip on Turf and Shrub Areas (P_{ts})	Irrigation on Turf and Shrub Areas (I_{ts})	Precip on Non-Irrigated Landscape (P_{ni})	Runoff from Impervious (RO_{im})	ET of Precip from Turf and Shrub Area (ET_{pts})	ET of Irrigation from Turf and Shrub Area (ET_{its})	Precip Runoff from Turf and Shrub Area (RO_{ts})	ET from Non-Irrigated Landscape (ET_{ni})	Runoff from Non-Irrigated Landscape (RO_{ni})
Area	50%	25%		25%						
Inches	13.4	13.4	30	13.4						
Flow (gpm)	13.50	6.75	15.11	6.75	12.15	4.05	10.08	2.03	4.05	2.03
		BioSwale Inflow (RO_{im}+RO_{ts} +RO_{ni})			ET Bioswale (ET_{bs})	Recharge Bioswale (R_{bs})	Precip Recharge from Turf and Shrub Area (R_{pts})	Irrigation Recharge from Turf and Shrub Area (R_{its})	Recharge from Non-Irrigated Landscape (R_{ni})	Recharge Average Flow (R)
Flow (gpm)		16.20			10.80	5.40	0.68	5.04	0.68	11.79

Table 4 Effect of Proposed Development on Basement Sump Pumping

a. Winter Period

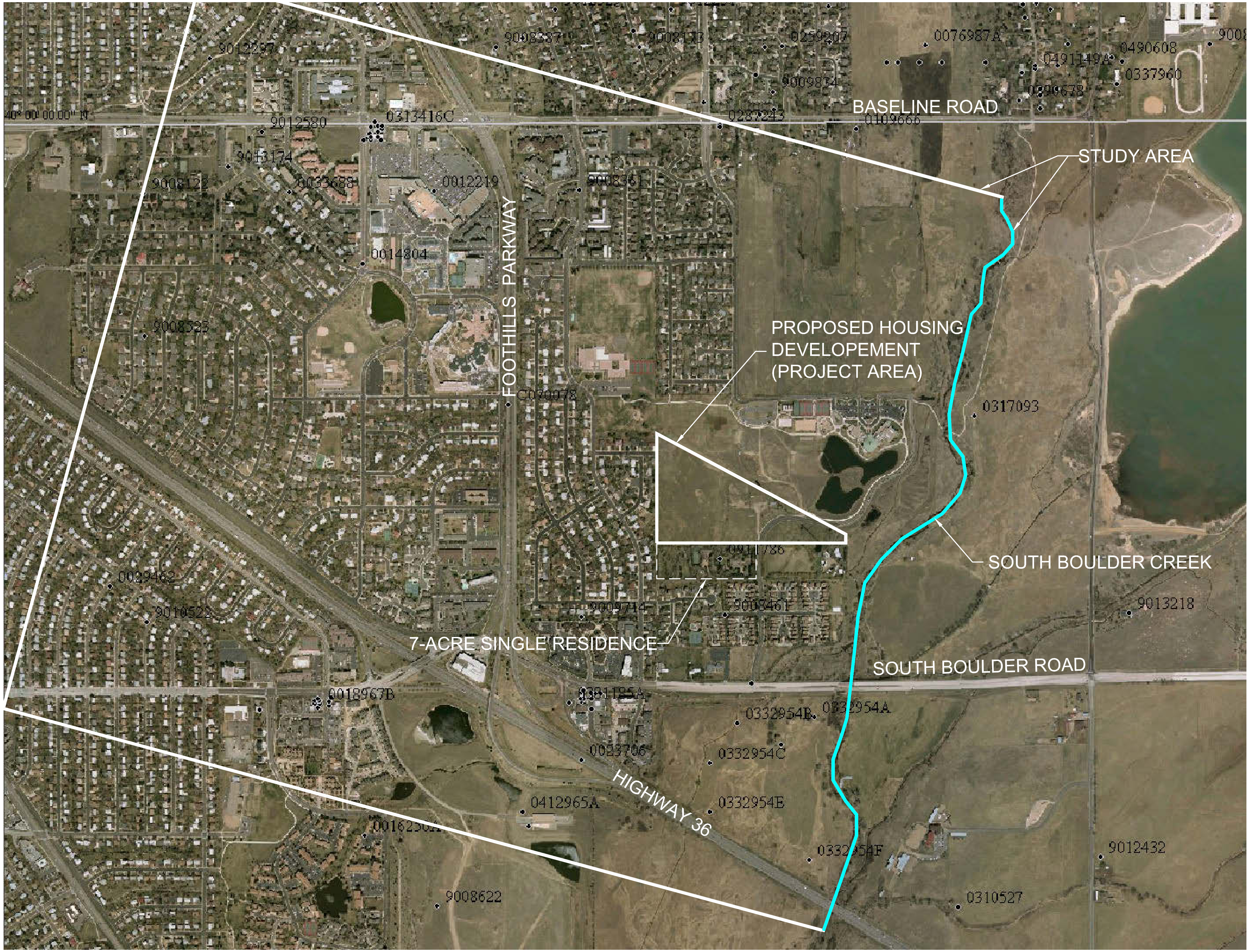
Description	Pre-Development	Post-Development	Effect on Basement Sump Pumping	Conclusion
Recharge within Project area	0.000338 ft/day	0.000838 ft/day	Increased recharge not sufficient to result in sump pumping (a)	Development will not cause basement sump pumping within the Area of Interest
Dry Creek Ditch #2 seepage along west Project area boundary	None	None	No change	
Seepage from other irrigation ditches	None	None	No change	
Recharge within 7-Acre property	0.000304 ft/day	0.000304 ft/day	No change	
Residential areas	Variable recharge	Variable recharge	No change	
Parks and commercial	Variable recharge	Variable recharge	No change	

(a) Confirmed by numerical ground water flow model

b. Summer Period

Description	Pre-Development	Post-Development	Effect on Basement Sump Pumping	Conclusion
Recharge within Project area	0.00822 ft/day	0.00251 ft/day	Decrease will tend to reduce sump pumping	Development will reduce basement sump pumping within the Area of Interest
Dry Creek Ditch #2 seepage along west Project area boundary	Significant	None	Decrease will tend to reduce sump pumping	
Seepage from other irrigation ditches	Variable	Variable	No change	
Recharge within 7-Acre property	0.00740 ft/day	0.00740 ft/day	No change	
Residential areas	Variable recharge	Variable recharge	No change	
Parks and commercial	Variable recharge	Variable recharge	No change	

FIGURES



N

SCALE IN FEET

0 1000

FIGURE 1
SITE MAP

PROJECT: 320100	TASK: 02	PREPARED FOR: HOGAN-PANCOST
PREPARED BY: TELESTO SOLUTIONS INCORPORATED		

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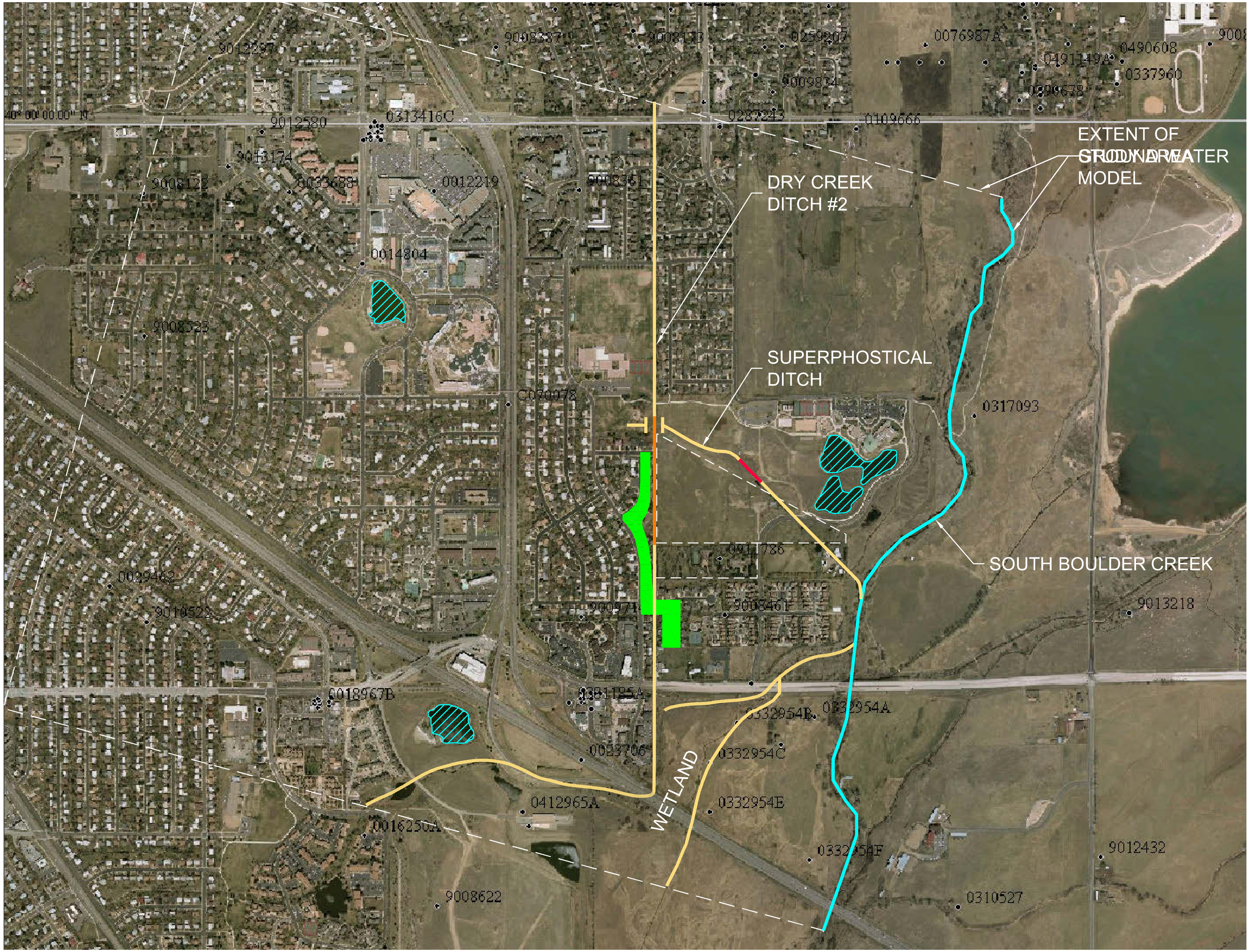

LEGEND

- PERENNIAL STREAM
- IRRIGATION DITCH
- PORTION OF IRRIGATION DITCH CURRENLY LINED
- PORTION OF IRRIGATION DITCH TO BE LINED OR PIPED
- POND
- AREA OF INTEREST

N

SCALE IN FEET
0 1000

FIGURE 2
STUDY AREA HYDROLOGIC FEATURES

PROJECT: 320100	TASK: 02	PREPARED FOR: HOGAN-PANCOST
PREPARED BY: TELESTO SOLUTIONS INCORPORATED		

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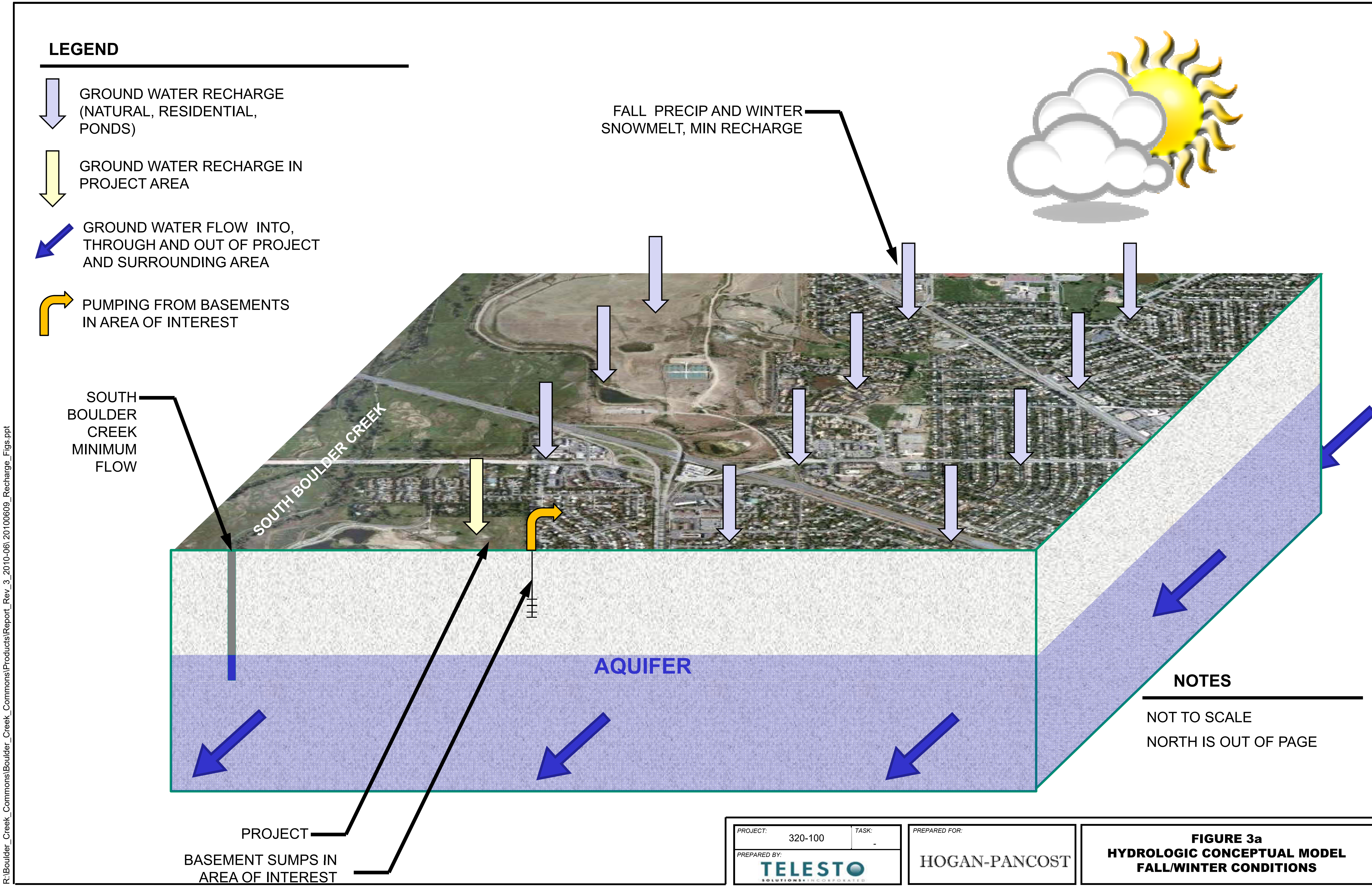

PROJECT: 320-100 TASK: -

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

PREPARED FOR: HOGAN-PANCOST

FIGURE 3a
HYDROLOGIC CONCEPTUAL MODEL
FALL/WINTER CONDITIONS

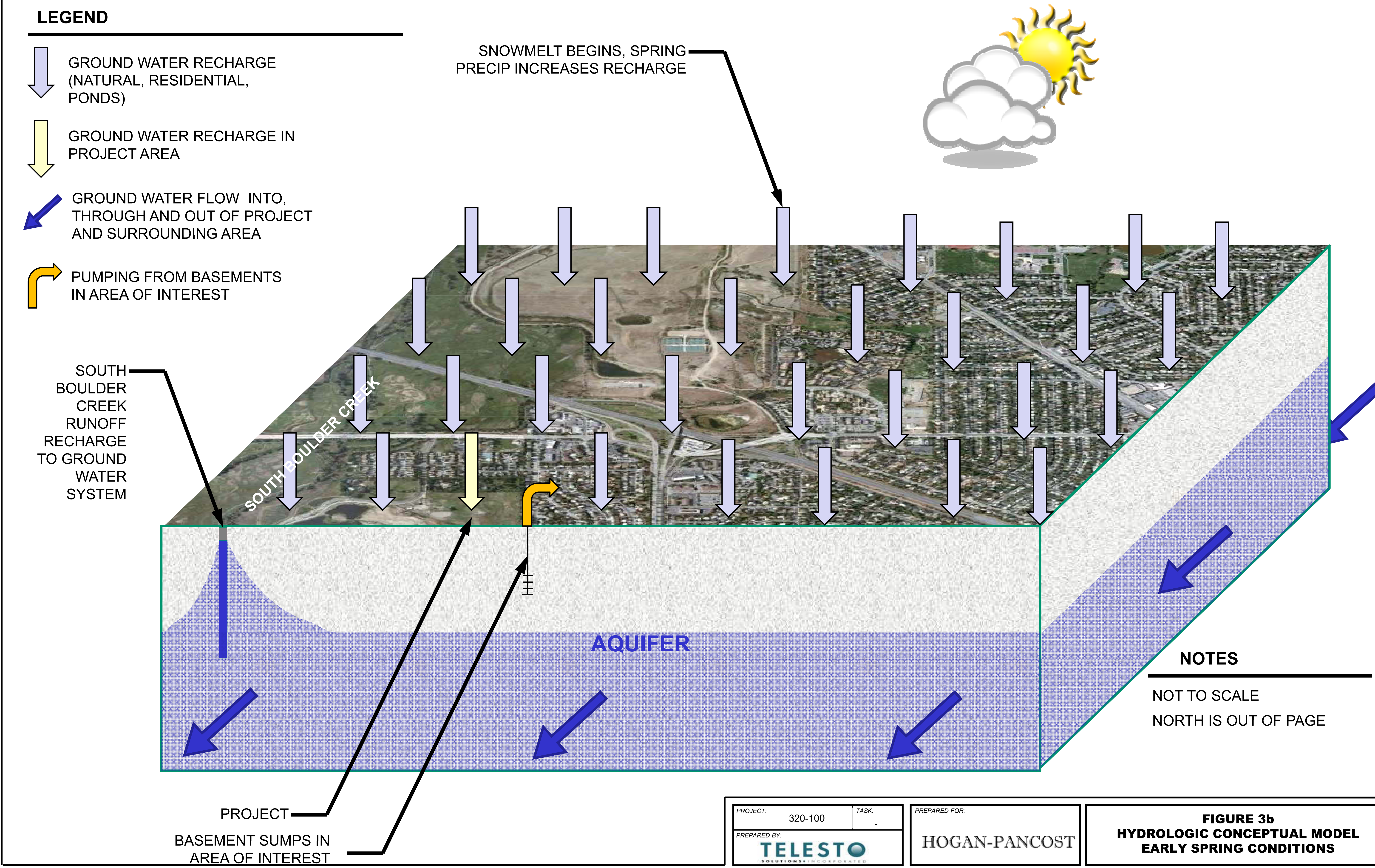

FIGURE 3b
HYDROLOGIC CONCEPTUAL MODEL
EARLY SPRING CONDITIONS

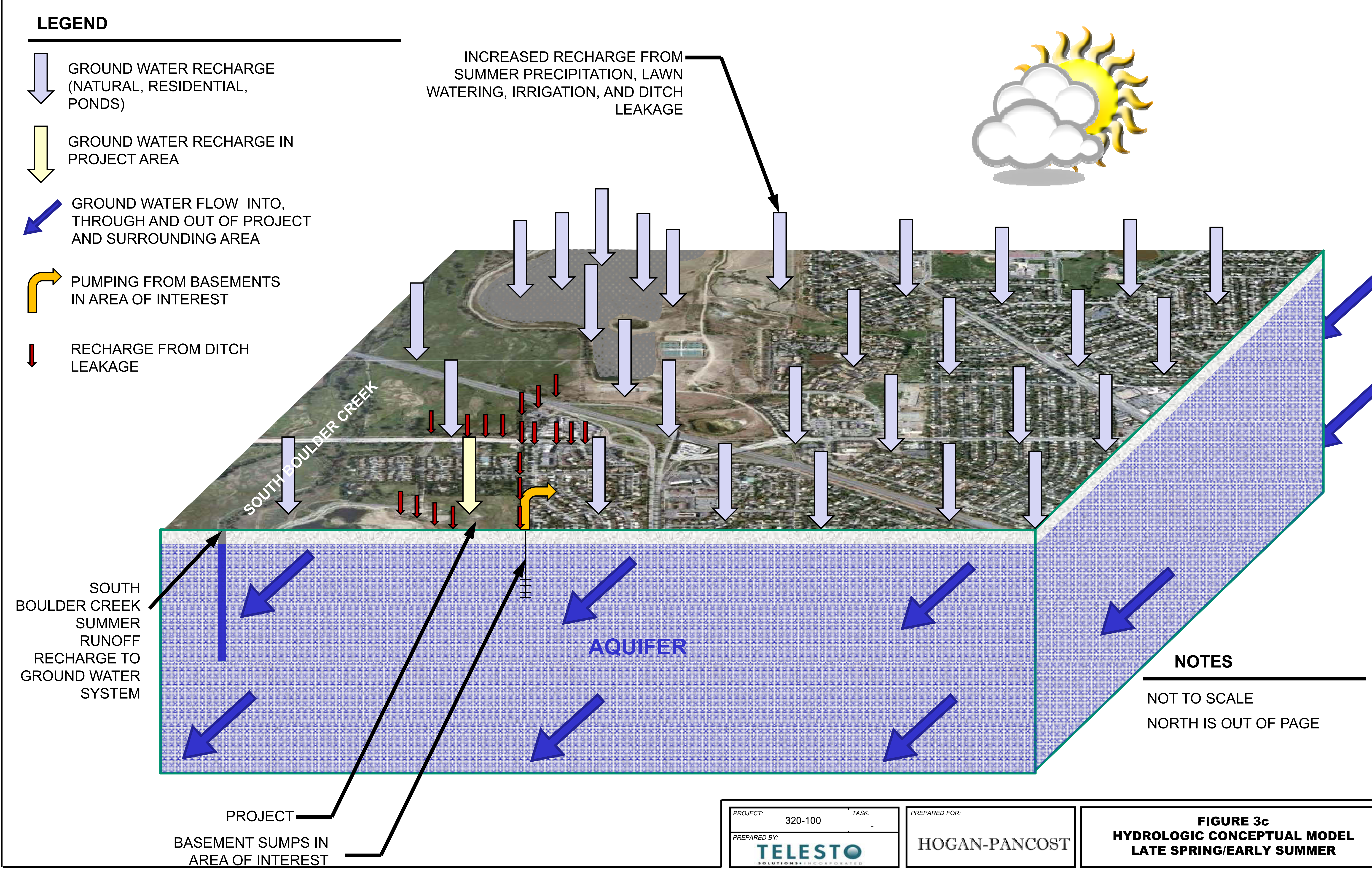

FIGURE 3c
HYDROLOGIC CONCEPTUAL MODEL
LATE SPRING/EARLY SUMMER

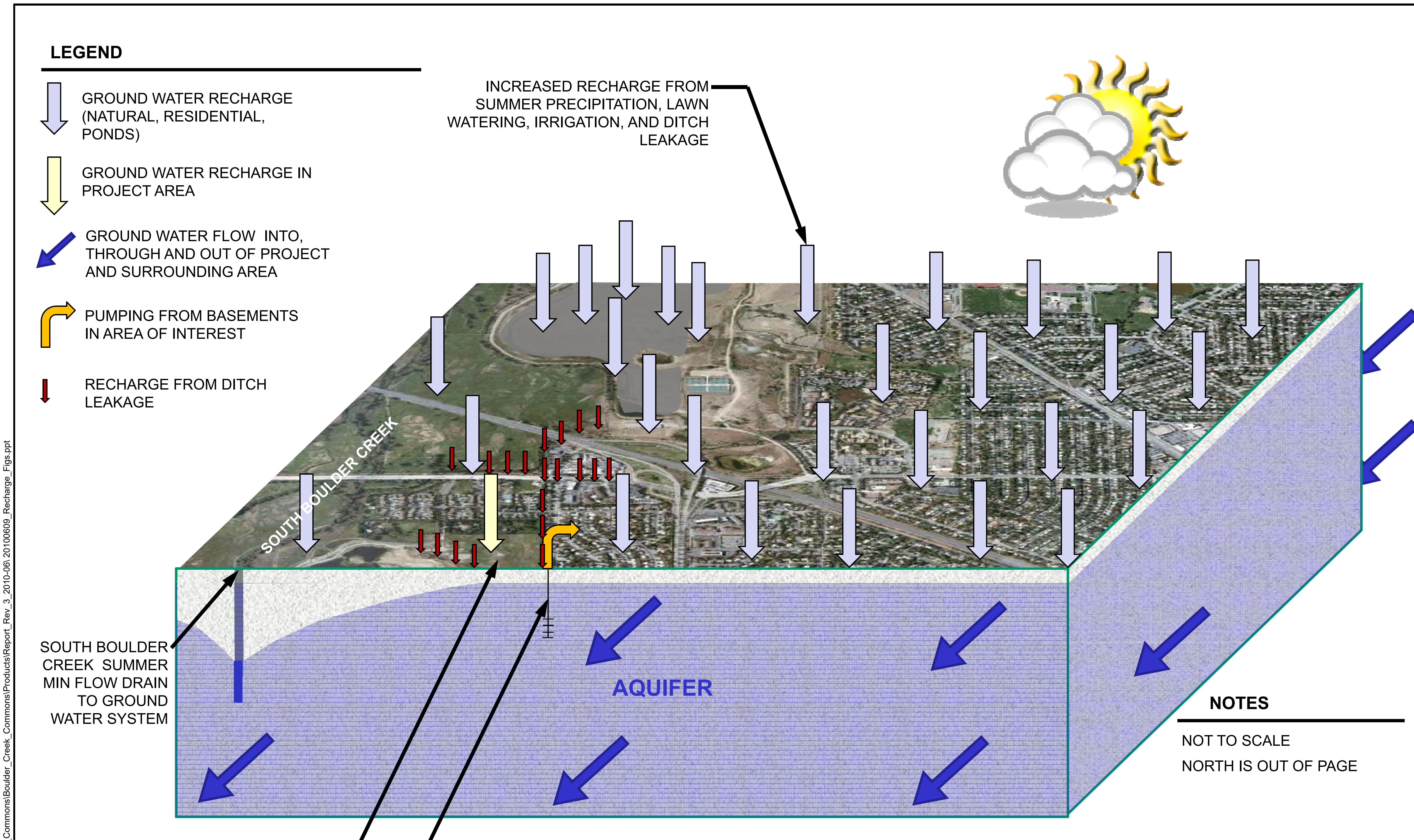

FIGURE 3d
HYDROLOGIC CONCEPTUAL MODEL
LATE SUMMER CONDITIONS

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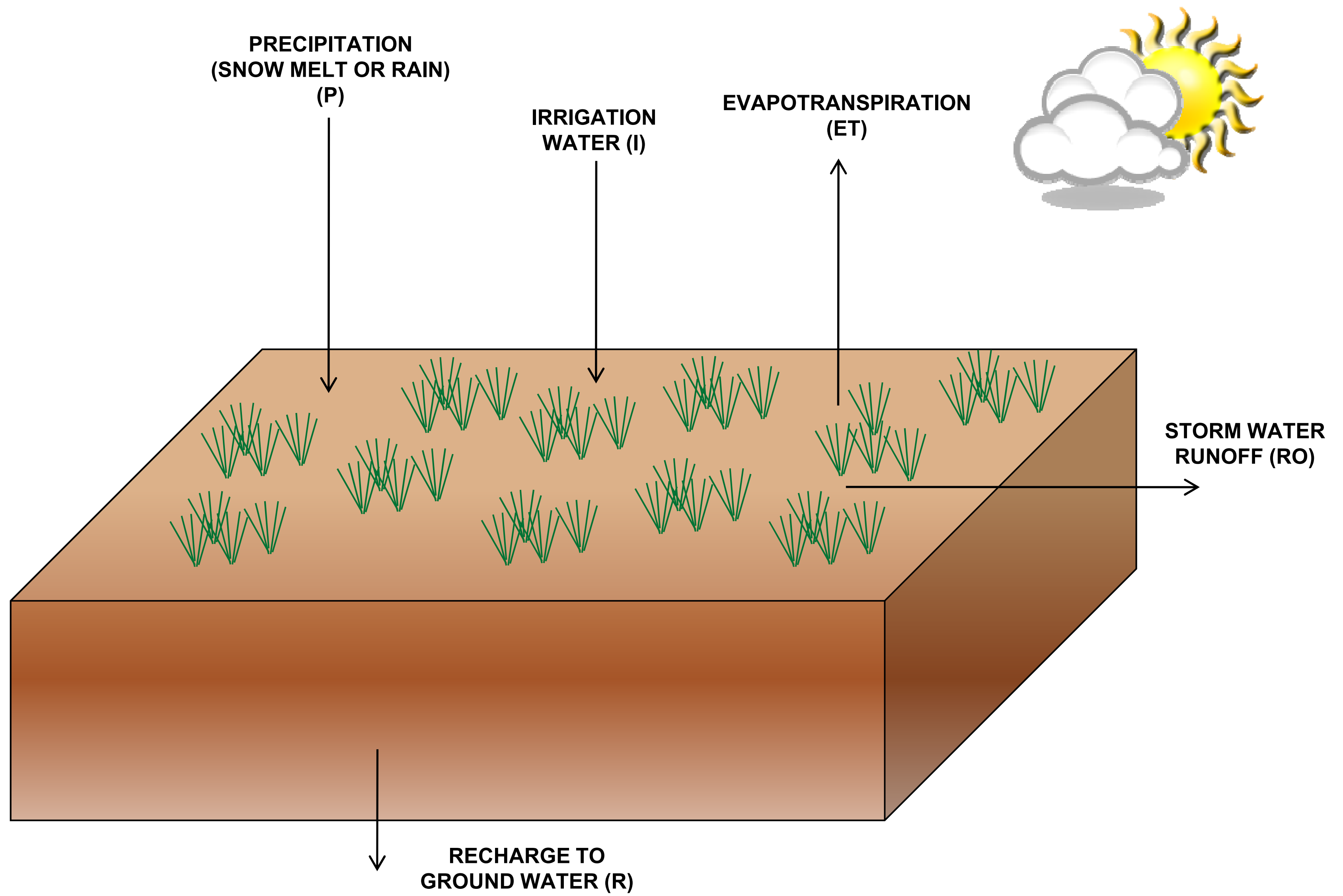

R = P + I – E – RO

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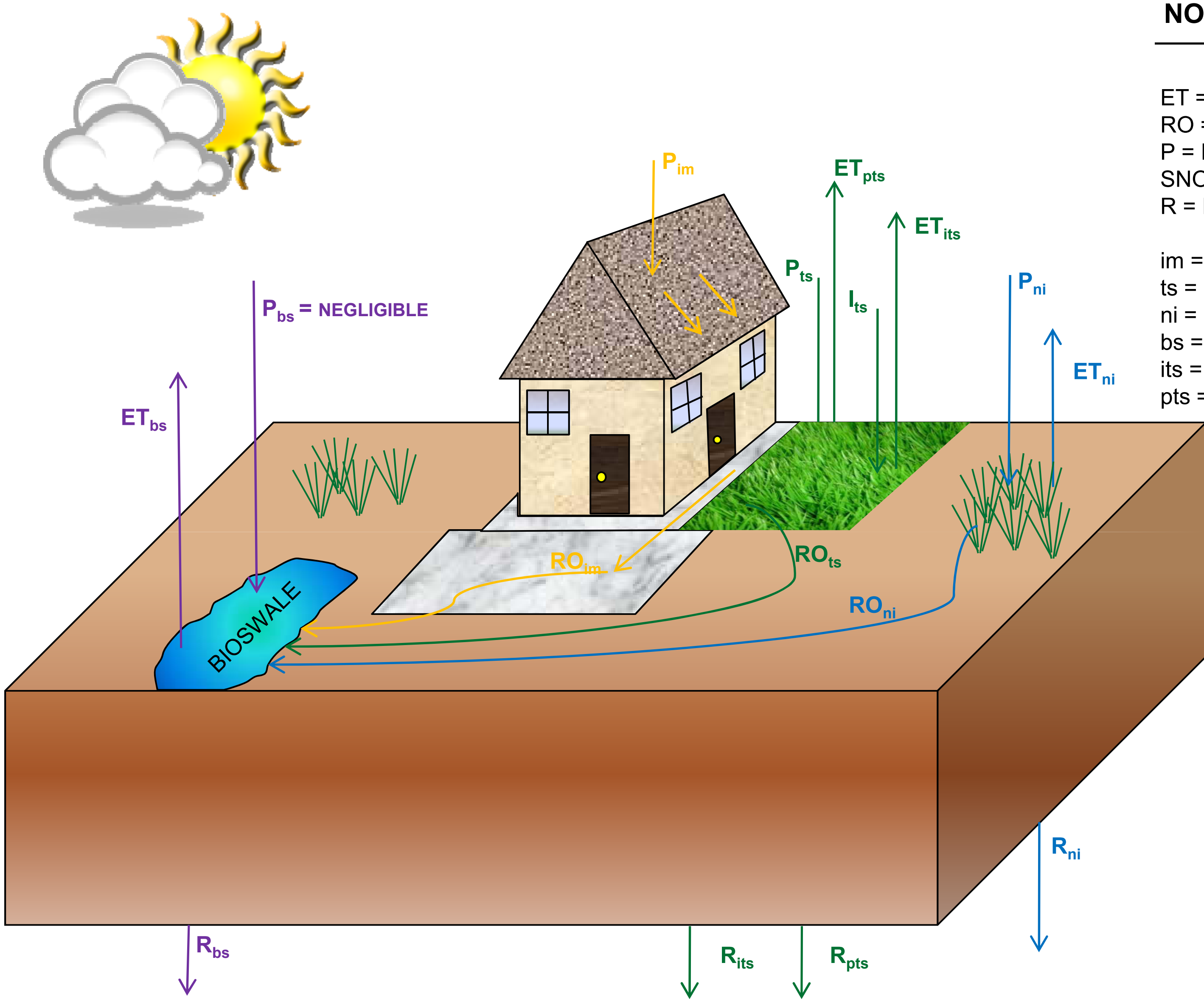
PROJECT:	TASK
320100	02

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

FIGURE 4
PROJECT AREA RECHARGE ESTIMATE BEFORE DEVELOPMENT

PREPARED FOR: HOGAN-PANCOST



NOTES:

ET = EVAPOTRANSPIRATION
RO = RUNOFF
P = PRECIPITATION (RAIN AND SNOW)
R = RECHARGE TO GROUND WATER

im = IMPERVIOUS AREAS
ts = IRRIGATED TURF AND SHRUBS
ni = NON-IRRIGATED VEGETATION
bs = BIOSWALE
its = IRRIGATION ON ts
pts = PRECIPITATION ON ts

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PROJECT: 320100	TASK 02
PREPARED BY: TELESTO SOLUTIONS INCORPORATED	

FIGURE 5
PROJECT AREA RECHARGE ESTIMATES AFTER DEVELOPMENT

PREPARED FOR: HOGAN-PANCOST

APPENDIX A
GROUND WATER FLOW MODEL

Introduction

A numerical ground water flow model was used to quantify the effects that bioswales and lawn/shrub watering in the Project area could have on water levels and sump rates in neighborhoods adjacent to the Project site. The extent of the ground water model is shown on Figure A-1. The evaluation focused on the Area of Interest shown on Figure A-2, because some houses in this area have historically operated sumps during the summer period. The model was used to evaluate if future conditions in the Project area and proposed ditch lining/piping will cause the sump pumping rates to increase or decrease from historical values.

Calculations were performed using the publicly available program MODFLOW, which was configured to simulate two-dimensional (horizontal) ground water flow in an unconfined aquifer with a variable-elevation base. The model allowed for spatially variable recharge, the prescribed head boundary associated with South Boulder Creek, ponds, irrigation ditches, and operation of basement drains (sumps).

Finite Difference Mesh and External Boundary Conditions

The extent of the ground water model is shown on Figures A-1 and A-2. As indicated, the Project area is located in the east-central portion of the model. Figure A-3 shows the finite difference mesh used to discretize the modeled area. Separate flow models, using the same mesh, were developed to simulate winter and summer conditions within and adjacent to the Project area.

The same external boundary conditions were used by the models for winter and summer conditions. As shown on Figure A-3, the external boundaries consist of the following:

Western model boundary – no-flow.
Northern model boundary – prescribed uniform head conforming to the estimated regional ground water level in the unconfined aquifer.
Southern model boundary – prescribed spatially variable head conforming to estimated regional ground water levels in the unconfined aquifer.

Eastern model boundary – prescribed spatially variable head conforming to the water level in South Boulder Creek (creek water level was assumed approximately 2 feet below the adjacent ground surface). Modeled as river cells.

Note that on Figure A-3, the black cells east of South Boulder Creek are inactive and not used in the MODFLOW calculations.

Ground Surface

For an unconfined ground water system, ground surface is effectively the top of the aquifer. Based on the U.S. Geological Survey (USGS) Digital Elevation Model (DEM), interpolated surface elevations were assigned to each cell in the finite difference mesh. When compared with surveyed elevations in the Project area, it was found that the DEM surface could be lower than actual ground surface by up to several feet.

Aquifer Base

The configuration of the aquifer base was interpolated from depth-to-bedrock estimates in existing boreholes. The depth-to-bedrock values were inferred from total depth measurements available in the Colorado Department of Water Resources water well database. A subset of the wells within the model area with total depths greater than 10 feet and less than 30 feet were included in the interpolation. This is because geologic information indicated that the unconsolidated sediments are 10 to 30 feet thick throughout the study area and most water wells in the unconfined aquifer are terminated at the bedrock/sediment contact. Additional borings were available from geotechnical investigations conducted in the Project and adjacent areas. Based on ground surface elevations provided by the DEM, the depth-to-bedrock values were converted to top-of-bedrock elevations. Figure A-4 shows the locations of boreholes used to evaluate bedrock and the interpolated elevation contours for the top-of-bedrock. Bedrock is known to have very low hydraulic conductivity, so the elevation contours shown on Figure A-4 are assumed to represent the base of the unconfined aquifer. Using this map, interpolated aquifer-base elevations were assigned to each cell in the finite difference model.

Aerial Recharge

Based on the analyses presented in the main report, the ground water model was divided into recharge zones conforming to (1) natural ground, (2) the Project area, (3) commercial buildings and parking lots, (4) irrigated ball fields and parks, and (5) existing residential areas. The recharge zones are shown on Figure A-5 and the recharge fluxes applied to these areas are summarized in Table A-1.

Internal Model Features

Internal features of the numerical model consisted of river cells and drain cells.

A river cell considers the existence of surface water in a river channel or pond, and allows ground water recharge or discharge depending on the ground water level within the cell. If the ground water level is above the specified river elevation, there is discharge of ground water to surface water. If the ground water level is below the river elevation, the ground water system receives recharge at the river cell. The amount of ground water discharge or recharge is controlled by a river conductance factor, and the elevation difference between the specified river level and the ground water level. The conductance factor is commonly interpreted to represent a flow resistance (i.e., reduced permeability) along the bed of the stream channel. At a river cell, the basic equation controlling flow into or out of the ground water system is as follows:

$$Q_R = C_R \left[H_R - \max\left(E_b, H_G\right)\right]$$

where:

Q_R = flow rate of recharge (+) to or discharge (-) from the underlying ground water system [ft^3/day]; computed by model

C_R = river conductance factor [ft^2/day]; specified input

H_R = fixed river water-level elevation [ft msl]; specified input

E_b = stream channel bottom elevation [ft msl]; specified input

H_G = ground water system hydraulic head [ft msl]; computed by model

The river conductance factor (C_R) is related to other parameters as follows:

$$C_R = \frac{K_b \; L_R \; W_R}{b}$$

where:

K_b = hydraulic conductivity of the channel bed [ft/day]

L_R = length of the river channel within the cell [ft]

W_R = width of the river channel within the cell [ft]

b = channel bed thickness [ft]

In the MODFLOW model, river cells were used to simulate the effects of ponds and flowing irrigation canals, principally Dry Creek Ditch #2, and the Superphostical Ditch.

A drain cell operates as prescribed head cell if the water table in adjacent cells is higher than a specified drain elevation for the cell. In this case ground water discharge occurs at the cell. If the adjacent water table is lower than the specified drain elevation, the cell operates as a continuity cell with no discharge from, or recharge to, the ground water system. Drain cells can lead to ground water discharge, but cannot provide any recharge to the aquifer. In the MODFLOW model drain cells were used to simulate the effects of basement sumps.

Internal features associated with the winter model are shown on Figure A-6. River cells were specified for ponds and several irrigation ditches that were observed to flow during the winter. Drain cells were also situated along a known wetland area in the southeast portion of the model. A property owner located south of the Project area (not within the Area of Interest) indicated that he has four sumps that discharge year round. One finite difference cell located at his property was specified as a drain cell for both winter and summer conditions. No drain cells were specified within the Area of Interest because residents indicated that their sumps do not generally operate during the winter months.

Internal features for the summer model are shown on Figure A-7. Drain cells were specified within Area of Interest, and the winter drain cell located south of the Project area was retained. Also retained were the drain cells situated along the known wetland area in the southeast portion of the model. River cells were specified for ponds and along the alignment of flowing irrigation ditches, including Dry Creek Ditch #2 and the Superphostical Ditch, both located along the Project boundary. Depending on the water table elevation, ground water can either discharge to a ditch or be recharged from a ditch. Note that a currently lined portion of the Superphostical Ditch was not modeled with river cells.

Initial Hydraulic Properties

Telesto previously designed and implemented a dewatering system for the Boulder Community Hospital facility located at the northeast corner of Arapahoe Road and Foothills Parkway, which is about 1.25 miles northeast of the Project. 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 that project, the initial best-estimate hydraulic conductivity of the unconfined aquifer was set at 100 ft/day.

Specific yield is another parameter associated with unconfined aquifers. However, because specific yield affects the transient response of an aquifer, it was not relevant to the steady-state model runs used for this evaluation.

The initial conductance of a river cell representing an irrigation ditch was based on a bed hydraulic conductivity (K_b) of 100 ft/day (same as the aquifer), channel length (L_R) equal to the average cell dimension, channel width (W_R) ranging between 5 and 10 feet based on field observations, and bed thickness (b) equal to 1 foot. The river level elevation (H_R) was assumed to be 1 foot higher than the channel bottom elevation (E_B). The initial conductance for a river cell representing a pond was computed in a similar manner except L_R and W_R were equal to the actual length and width of the cell.

Winter Model Calibration

The winter model was calibrated using the following information:

- Estimated water levels in four water wells outside the Project area
- Winter 2006 and winter 2007 water levels measured in four piezometers located within the Project area
- Dry Creek Ditch #2 is dry and the Superphostical Ditch contains a small amount of flowing water
- Two ditches in the southeast portion of the study area were observed to have flowing water which drains to South Bounder Creek
- The water level elevation in a wet pond is similar to the water table elevation in the adjacent ground water
- Houses in the Area of Interest do not perform basement sumping, so the water table is below the basement elevations
- Estimated flow to the sump located south of the Project area is about 40 gpm.

To perform the calibration, the winter model was run in steady-state mode using the best-estimate aquifer hydraulic conductivity of 100 ft/day and current winter recharge fluxes provided in Table A-1 for Run 1. Water levels in wet ponds were set at or near the adjacent DEM ground elevations.

The winter model was calibrated by adjusting (1) aquifer hydraulic conductivity, (2) river conductances, (3) water level elevations at wet ponds, ditches, and South Boulder Creek, and (4) prescribed heads along the north and south boundaries of the model. The calibration targets were estimated ground water level elevations in the four wells identified in the Colorado Department of Water Resources water well database and four piezometers installed within the Project area (see Figure A-6). The ground water elevation at each water well was computed by subtracting the reported depth-to-water measurement from the DEM ground surface elevation. The water level elevation in each piezometer was computed by subtracting the depth-to-water measurement from a surveyed measuring point elevation (top of standpipe). An additional calibration target was the approximate 40 gpm sump pumping rate in the drain cell representing the property owner located south of the Project area.

A reasonable calibration was achieved by (1) retaining the initial aquifer hydraulic conductivity value of 100 ft/day, (2) making no adjustments to the river cell conductances, (3) making slight changes to water level elevations at wet ponds, ditches, and South Boulder Creek, and (4) making slight changes to the north and south prescribed head boundaries. The hydraulic head distribution simulated by the calibrated winter model is shown on Figure A-8, and a comparison of winter calibration targets with model predictions is provided in Table A-2.

Summer Model Verification

The only information available regarding the flow to sumps was anecdotal in that residents pump in the summer but not in the winter, and only general information on the pumping times and quantities from two households were obtained. Quantitative information on the sumps such as elevation and measured pumping rates were not available.

Therefore, in the summer model, the elevation of each drain cell within the Area of Interest was set to less than 0.1 foot above the water-table elevation simulated by the winter model at the same location. This was a conservative measure in that any appreciable rise in the water table for summer conditions would lead to ground water discharge in the drain cells used to represent the basement sumps. Recharge fluxes were set equal to the summer values shown in Table A-1 for Run 3. The summer model was then verified using the following information:

- Water levels measured during summer 2006 and summer 2007 in the four piezometers installed within the Project area
- Estimated total sump pumping rate within the Area of Interest of about 40 gpm based on anecdotal information (See Attachment 1.6)
- Estimated sump rate of 40 gpm at the known sump located south of the Project area
- Historical observation of wet ground (water table at ground surface) in certain portions of the study area during the summer.

Summer verification consisted of a series of steady-state model runs that included minor adjustments to river cell conductance. The data used to verify the model were: (1)

measured water levels in the four water wells and four piezometers discussed previously, (2) estimated total sumping flow rate of about 40 gpm within the Area of Interest, and (3) estimated flow rate of 40 gpm in the sump located south of the Project area (See Attachment 1.6).

A reasonable verification was achieved by making relatively small adjustments to the conductances for river cells representing Dry Creek Ditch #2, Superphostical Ditch, and two wet ponds located near the north boundary of the Project area. The distribution of hydraulic head simulated by the summer model is shown on Figure A-9, and a comparison of summer known and model-simulated values is provided in Table A-2. In the verified summer model, the total sumping rate within the Area of Interest was computed to be 41.1 gpm.

It should be noted that the focus of the study was to estimate the change in flow to the sumps as a result of the proposed development. Therefore, it is the relative change in the sump pumping rate and not the absolute magnitude of the simulated flow that is of primary importance to the evaluation.

The final input parameters used in the calibrated model are summarized in Table A-3. Following verification calibration, it was Telesto's opinion that the model was sufficiently accurate for evaluating the impacts of the housing development on water table elevations and basement sump flows.

Simulation of Post-Development Conditions

To simulate post-development winter conditions, the calibrated winter model was run with a Project area recharge flux of 0.000883 ft/day, which is 2.6 times higher than the pre-development (current) recharge flux of 0.000338 ft/day. At the higher winter recharge flux, the water table rise within the project area was negligible and there was no discharge to drains representing the basement sumps in the Area of Interest. Thus, the model predicts that the housing development will not lead to basement sumping during the winter months, which is the current situation.

To evaluate post-development summer conditions, the calibrated summer model was modified by (1) decreasing recharge flux in the Project area from the summer pre-development value of 0.00822 ft/day (flood irrigation) to the post-development value of 0.00251 ft/day and (2) eliminating river cells along the segment of Dry Creek Ditch #2 to be lined/piped by the developer. With no changes to any other inputs, the model was then run in steady-state mode. In this manner, the model was used to predict the change in water table elevation due to future housing development, and the degree to which development would change basement sumping rates during the summer period. The hydraulic head distribution simulated by the post-development summer model is shown on Figure A-10.

A comparison of results for the calibrated summer model (current conditions) and the modified summer model (post-development conditions) is provided in Table A-4. As shown, the water table within the Project area is predicted to rise or fall by no more than 0.7 feet for post-development summer conditions, which is not significant with regard to building foundations and wetlands.

From pre- to post-development summer conditions, the total basement sumping flow rate within the Area of Interest is predicted to decrease from 41.1 to 36.8 gpm. This decrease of 4.3 gpm is attributed to the effects of piping Dry Creek Ditch #2 and ending flood irrigation within the Project area.

TABLES

Table A-1 Aerial Recharge Used in Ground Water Model

Recharge Zone	Figure A-5 Map Color	Winter Recharge (ft/day)		Summer Recharge (ft/day)	
		Current	Post-Development	Current	Post-Development
		Run 1	Run 2	Run 3	Run 4
Project Area (a)	Yellow	0.000338	0.000838	0.00822	0.00251
Natural Ground	Green	0.000338		0.000612	
Commercial	Dark Blue	0		0	
Ball Fields and Parks	Light Blue	0.000338		0.00457	
Existing Residential Development (b)	Red	0.000203		0.00274	
7-Acre Residence South of Project Area	Light Green	0.000304		0.00740	

(a) Currently a pasture that is flood-irrigated in the summer. Future mixed-density housing with turf/shrubs, low water-use plants, and bioswales

(b) Medium-density housing

Table A-2 Calibration Targets

Calibration Target Description	Pre-Development Winter Model		Pre-Development Summer Model	
	Target Value	Model-Simulated Value (Difference from Target)	Target Value	Model- Simulated Value (Difference from Target)
		Run 1		Run 3
Sump flow rate in Area of Interest (gpm)	0.0	0.0	Not measured. Estimated to be about 40 gpm based on anecdotal information	41.1
Flow rate to known sump south of Project area (gpm)	Approximately 40 gpm based on anecdotal information	39.0	Approximately 40 gpm based on anecdotal information	43.9
Well 1 water level [(a)] (ft msl)	5285.0	5287.6 (+2.6)	5285.0	5290.2 (+5.2)
Well 2 water level [(a)] (ft msl)	5323.5	5318.1 (-5.4)	5323.5	5320.3 (-3.2)
Well 3 water level [(a)] (ft msl)	5319.8	5325.3 (+5.5)	5319.8	5327.6 (+7.8)
Well 4 water level [(a)] (ft msl)	5343.8	5338.0 (-5.8)	5343.8	5346.7 (+2.9)
Boring 1 water level [(b)] (ft msl)	5309.0	5310.2 (+1.2)	5311.8	5310.2 (-1.6)
Boring 2 water level [(b)] (ft msl)	5314.9	5315.7 (+0.8)	5316.1	5316.5 (+0.4)
Boring 3 water level [(b)] (ft msl)	5315.4	5317.2 (+1.8)	5318.3	5318.7 (+0.4)
Boring 4 water level [(b)] (ft msl)	5318.5	5318.9 (+0.4)	5320.5	5319.2 (-1.3)

(a) Based on depth-to-water measurement reported in the Colorado Division of Water Resources water well database and estimated ground surface elevation

(b) Measured by Drexel Barrell & Company during 2006 and 2007

Table A-3 Calibrated Model Input

Category	Parameter	Units	Value(s) and/or Description
Aquifer hydraulic properties	Aquifer hydraulic conductivity	ft/day	100
	Aquifer specific yield	--	(a)
Model lateral boundaries	East boundary conforming to South Boulder Creek	ft msl	Prescribed head. Head values approximately 2 feet below adjacent ground surface
	West boundary		No flow
	North boundary	ft msl	Prescribed constant head of 5,272 ft msl based on regional aquifer water levels and slight changes made during model calibration (see Figure A-9)
	South boundary	ft msl	Prescribed variable head ranging between 5,346 and 5,397 ft msl based on regional ground water levels and slight changes made during model calibration (see Figure A-9)
Internal features	Drain cells in Area of Interest	ft msl	Drain bottom elevation set to less than 0.1 feet above the simulated winter ground water level elevation
	River cells used for irrigation ditches	ft msl	Channel bottom elevation at or near the adjacent ground surface. River level in cell approximately 1 foot higher than channel bottom; modified slightly during calibration
	River cells used for ponds	ft msl	Pond water level elevation at or near the adjacent ground surface.
	River cells used for South Boulder Creek	ft msl	River elevation approximately 2 feet lower than adjacent ground surface.
	River cell conductance used to simulate flowing ditches.	ft^2/day	Conductance (C_R) computed using the following parameters: Channel width (W_R) = 10 ft. Channel length (L_R) equal to longest dimension of cell (50 or 100 ft). Bed thickness (b) = 1 ft. Channel bed hydraulic conductivity (K_b) = 50 ft/day for Dry Creek Ditch #2. K_b = 3.5 ft/day for the Superphostical Ditch. K_b = 50 ft/day for ditches located in southeast portion of the study area.
	River cell water level used to simulate flowing ditches	ft msl	Bed elevation (E_b) at or near the adjacent ground surface. River level (H_R) generally 1 foot higher than bed elevation; adjusted slightly during calibration.
	River cells used to simulate ponds		Specified water level (H_R) similar to ground surface. Conductance set to very high value so the cell is effectively a fixed head feature, with head equal to H_R
Aquifer vertical boundaries	Ground surface	ft msl	Based on USGS digital elevation model (DEM).
	Aquifer base	ft msl	No flow. Variable elevation based on DEM and water well - geotechnical boring data. See Figure A-3.
Sources and sinks	Aerial recharge	ft/day	See Table A-1

(a) Steady-state simulations; aquifer specific yield (storage coefficient) not applicable

Table A-4 Effect of Housing Development and Ditch Lining/Piping on Summer Conditions

Description	Units	Pre-development (calibrated summer model)	Post-development (modified summer model)	Change attributed to residential development and ditch piping
		Run 3	Run 4	
Project Area recharge	gpm	36.3	11.1	- 25.2
Total sump pumping flow rate in Area of Interest	gpm	41.1	36.8	- 4.3
Project area borehole 1 water level	ft	5310.2	5310.6	+ 0.4
Project area borehole 2 water level	ft	5316.5	5316.2	- 0.3
Project area borehole 3 water level	ft	5318.7	5318.0	- 0.7
Project area borehole 4 water level	ft	5319.2	5319.0	- 0.2

FIGURES

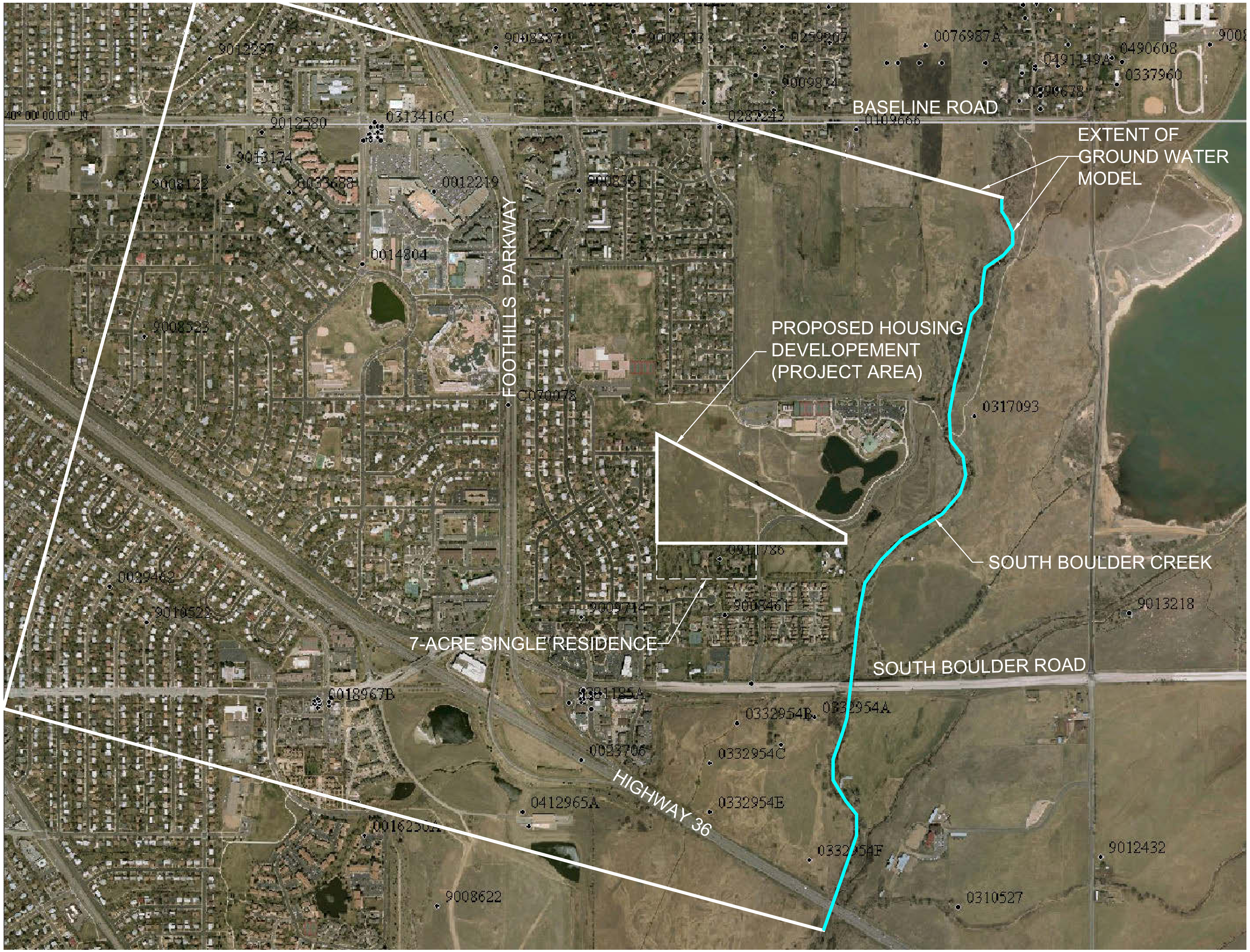

FIGURE A-1
SITE MAP

PROJECT: 320100
TASK: 02
PREPARED BY: TELESTO SOLUTIONS INCORPORATED
PREPARED FOR: HOGAN-PANCOST

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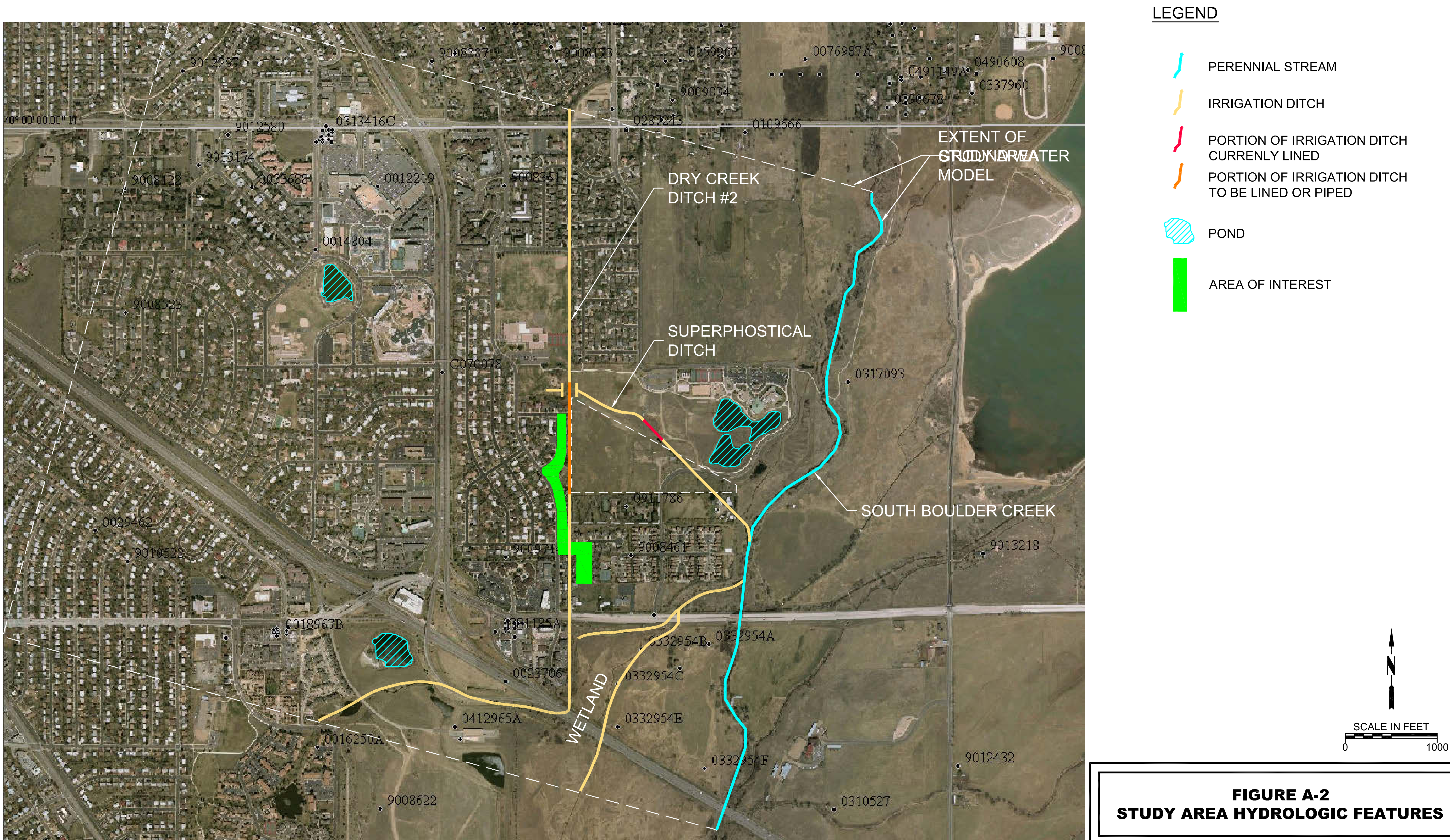

FIGURE A-2
STUDY AREA HYDROLOGIC FEATURES

PROJECT: 320100	TASK: 02	PREPARED FOR: HOGAN-PANCOST
PREPARED BY: TELESTO SOLUTIONS INCORPORATED		

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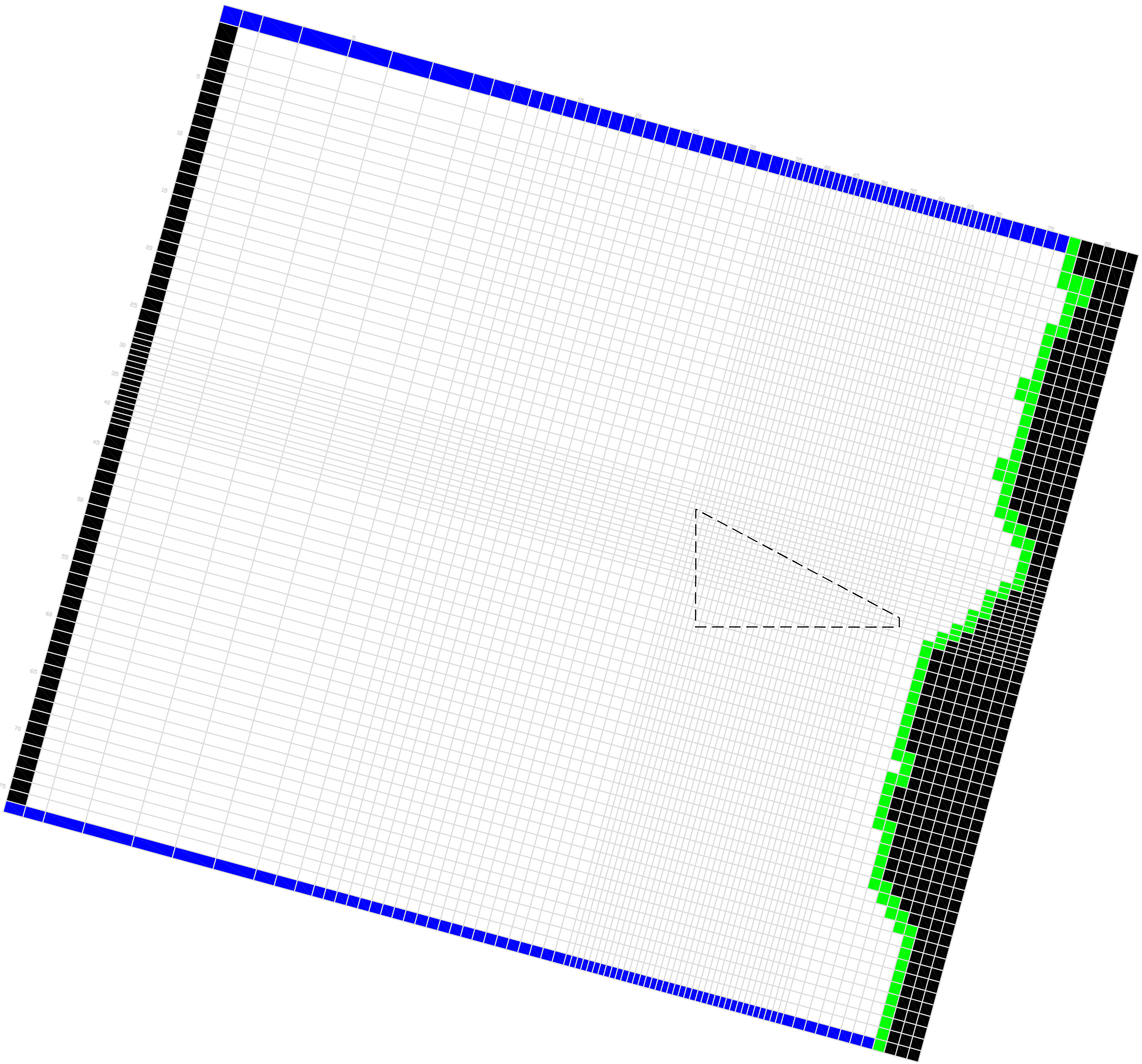


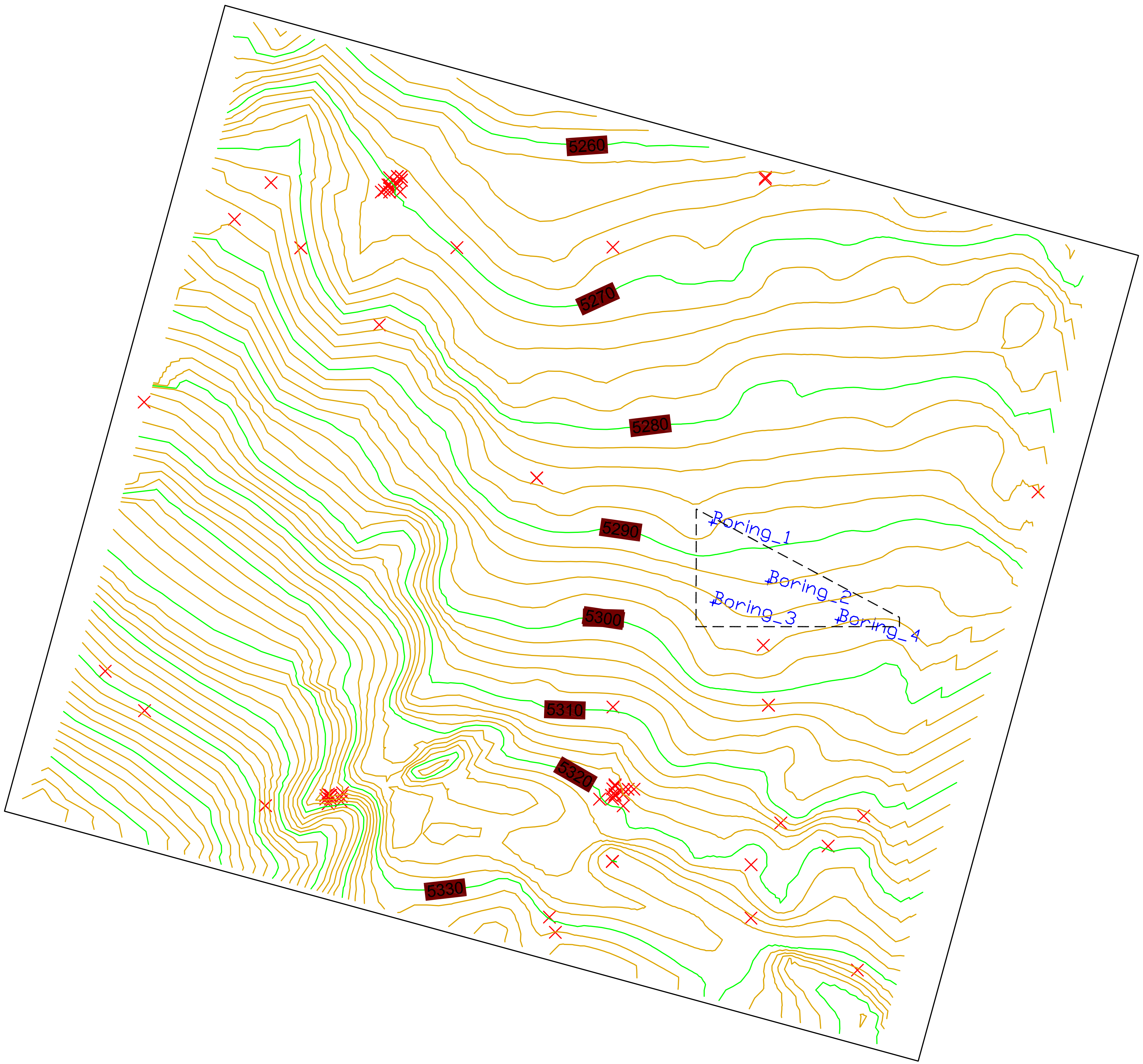
LEGEND

FIGURE A-3
FINITE DIFFERENCE MESH AND EXTERNAL BOUNDARIES

PROJECT: 320100 | TASK: 02

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

PREPARED FOR: HOGAN-PANCOST



LEGEND

AQUIFER BASE ELEVATION CONTOURS (FT. MSL)

WELL USED FOR ELEVATION CONTROL

GEOTECHNICAL BORING WITHIN PROJECT AREA

N

SCALE IN FEET

0 1000

FIGURE A-4
BASE OF UNCONFINED AQUIFER

PROJECT: 320100	TASK: 02	PREPARED FOR: HOGAN-PANCOST
PREPARED BY: TELESTO SOLUTIONS INCORPORATED		

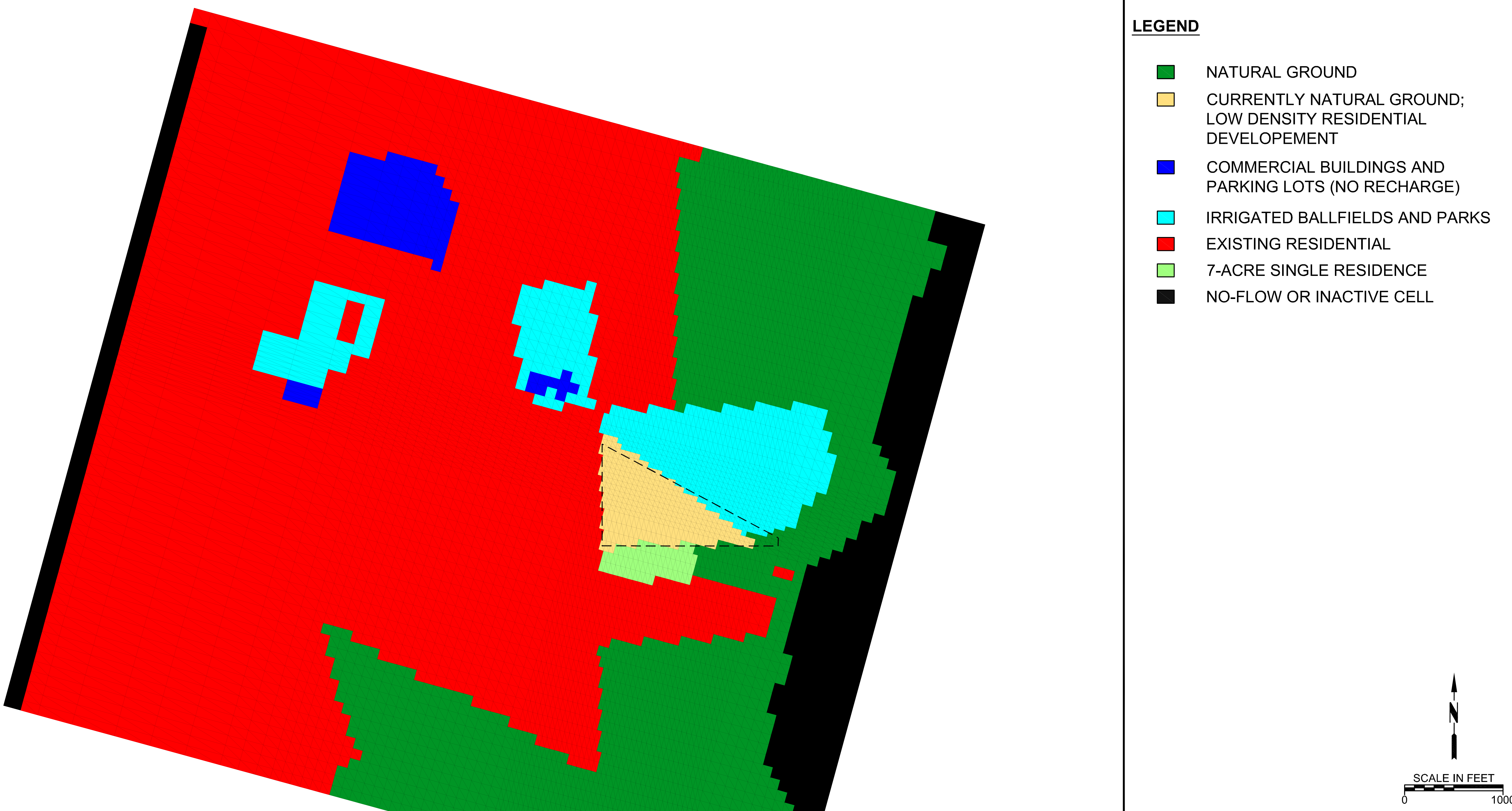


FIGURE A-5
RECHARGE ZONES

PROJECT: 320100 TASK: 02
PREPARED BY: TELESTO SOLUTIONS INCORPORATED
PREPARED FOR: HOGAN-PANCOST

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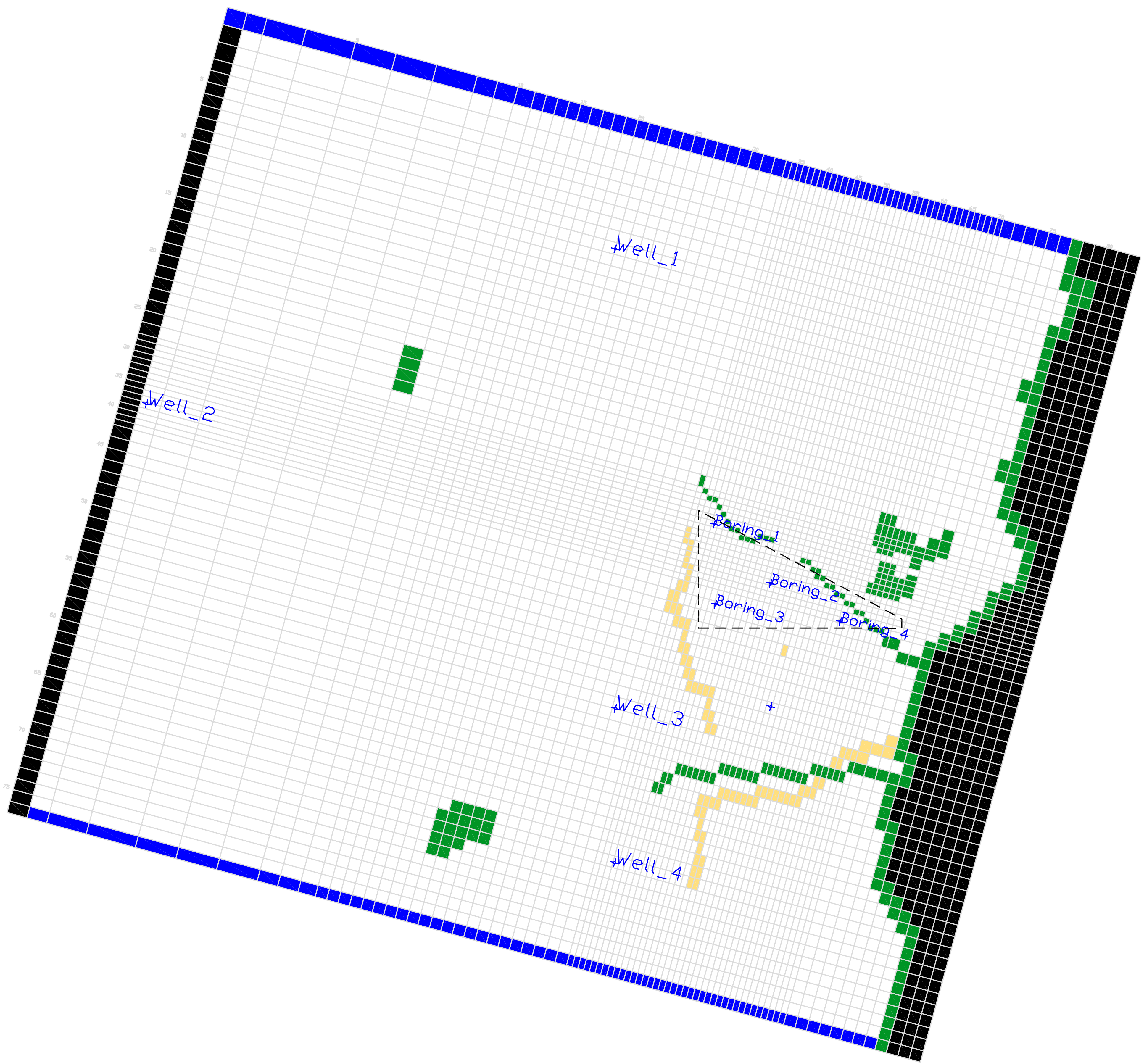

LEGEND

- FINITE DIFFERENCE MESH
- RIVER CELL (STREAM, IRRIGATION DITCH, OR POND)
- DRAIN CELL (RESIDENTIAL SUMP OR WETLAND)
- PRESCRIBED HEAD CELL
- NO-FLOW OR INACTIVE CELL
- WELL USED FOR CALIBRATION

N

SCALE IN FEET
0 1000

FIGURE A-6
WINTER MODEL INTERNAL FEATURES

PROJECT: 320100	TASK: 02
PREPARED BY: TELESTO SOLUTIONS INCORPORATED	PREPARED FOR: HOGAN-PANCOST

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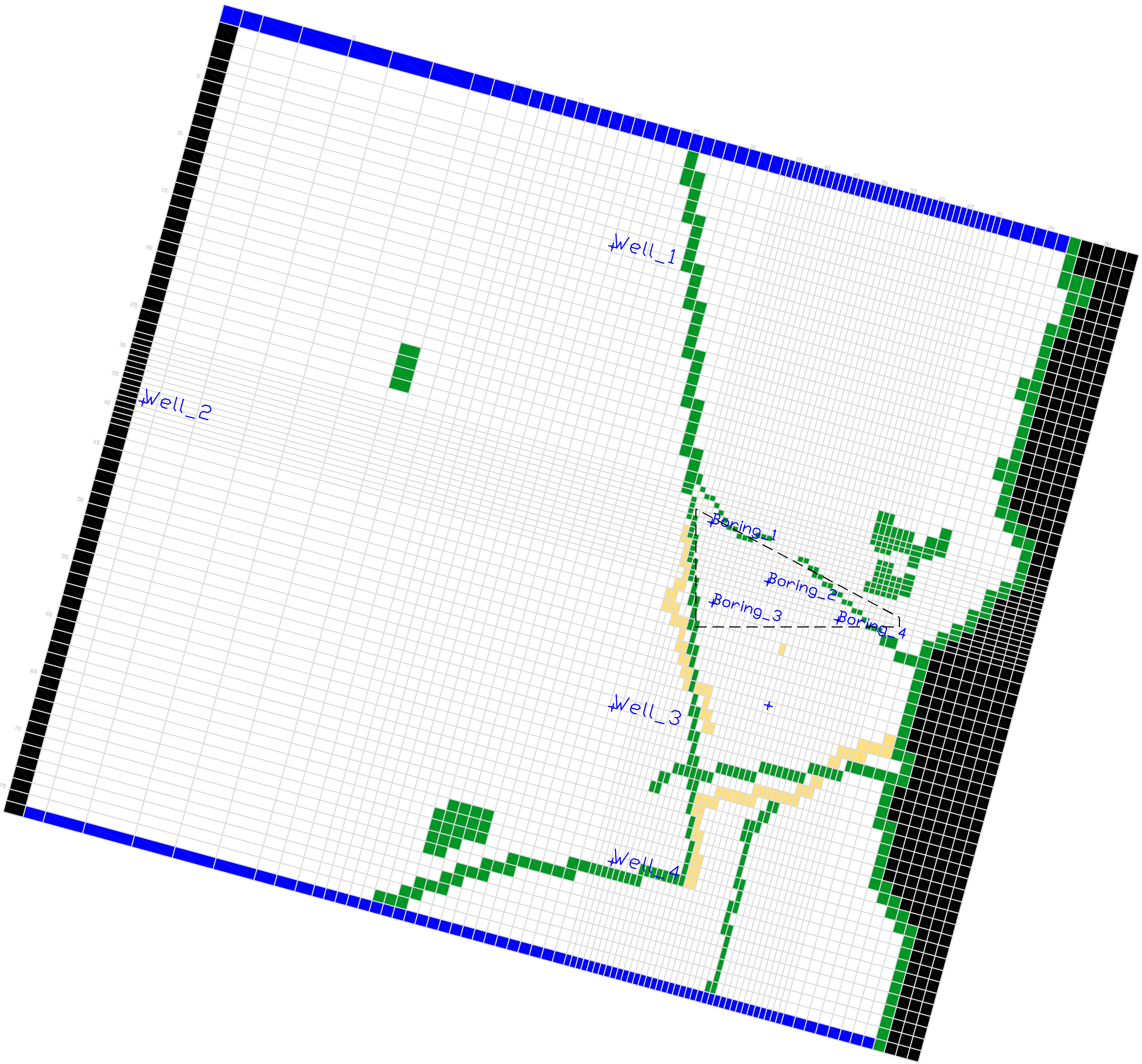


LEGEND

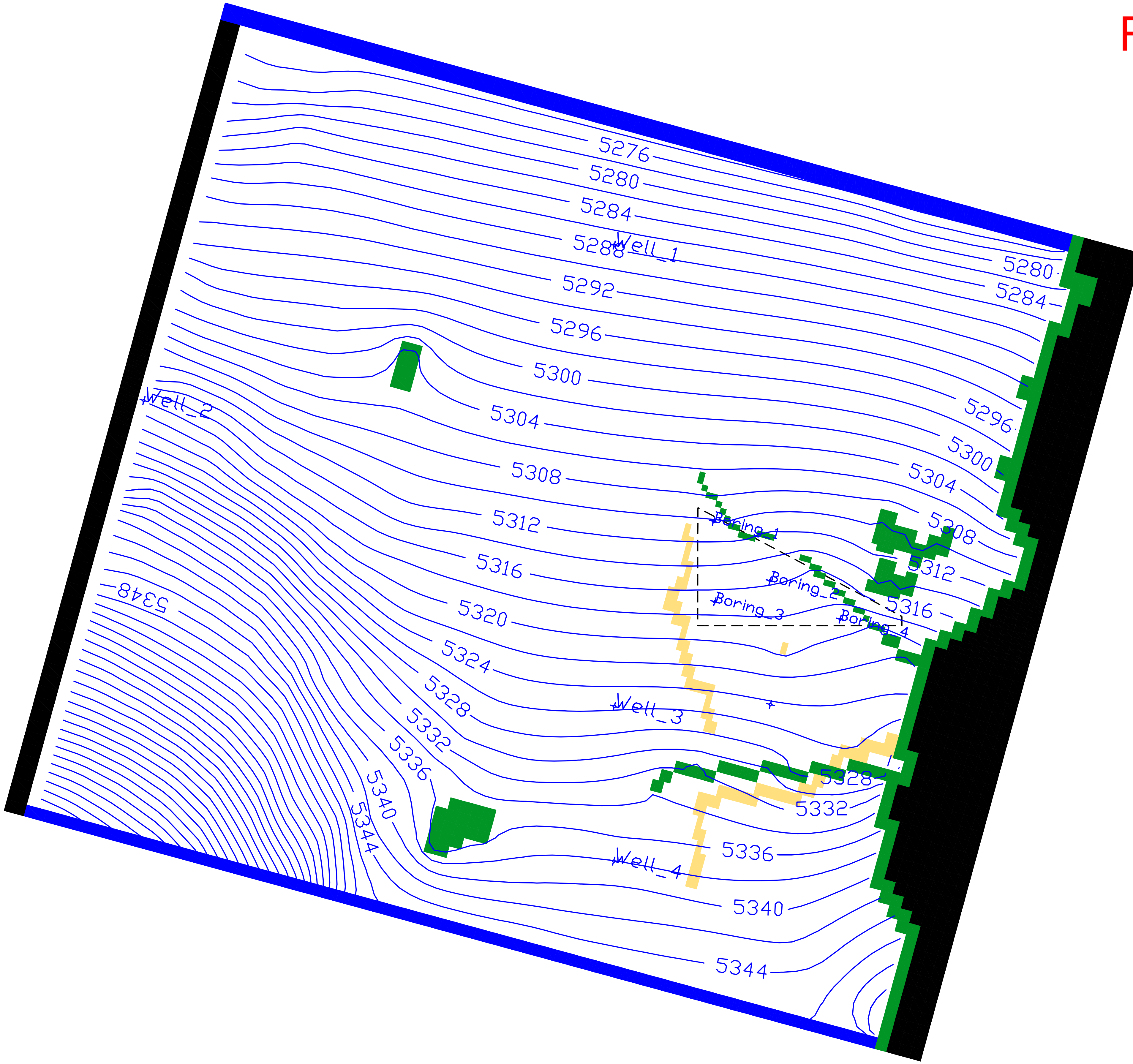
- FINITE DIFFERENCE MESH
- RIVER CELL (STREAM, IRRIGATION DITCH, OR POND)
- DRAIN CELL (RESIDENTIAL SUMP OR WETLAND)
- PRESCRIBED HEAD CELL
- NO-FLOW OR INACTIVE CELL
- WELL USED FOR CALIBRATION

N

SCALE IN FEET
0 1000

FIGURE A-7
SUMMER MODEL INTERNAL FEATURES

PROJECT: 320100	TASK: 02	PREPARED FOR: HOGAN-PANCOST
PREPARED BY: TELESTO SOLUTIONS INCORPORATED		



RUN 1

LEGEND

5332 — GROUND WATER ELEVATION CONTOUR (FT. MSL)

RIVER CELL (STREAM, IRRIGATION DITCH, OR POND)

DRAIN CELL (RESIDENTIAL SUMP OR WETLAND)

PRESCRIBED HEAD CELL

NO-FLOW OR INACTIVE CELL

\+ WELL USED FOR CALIBRATION

N

SCALE IN FEET

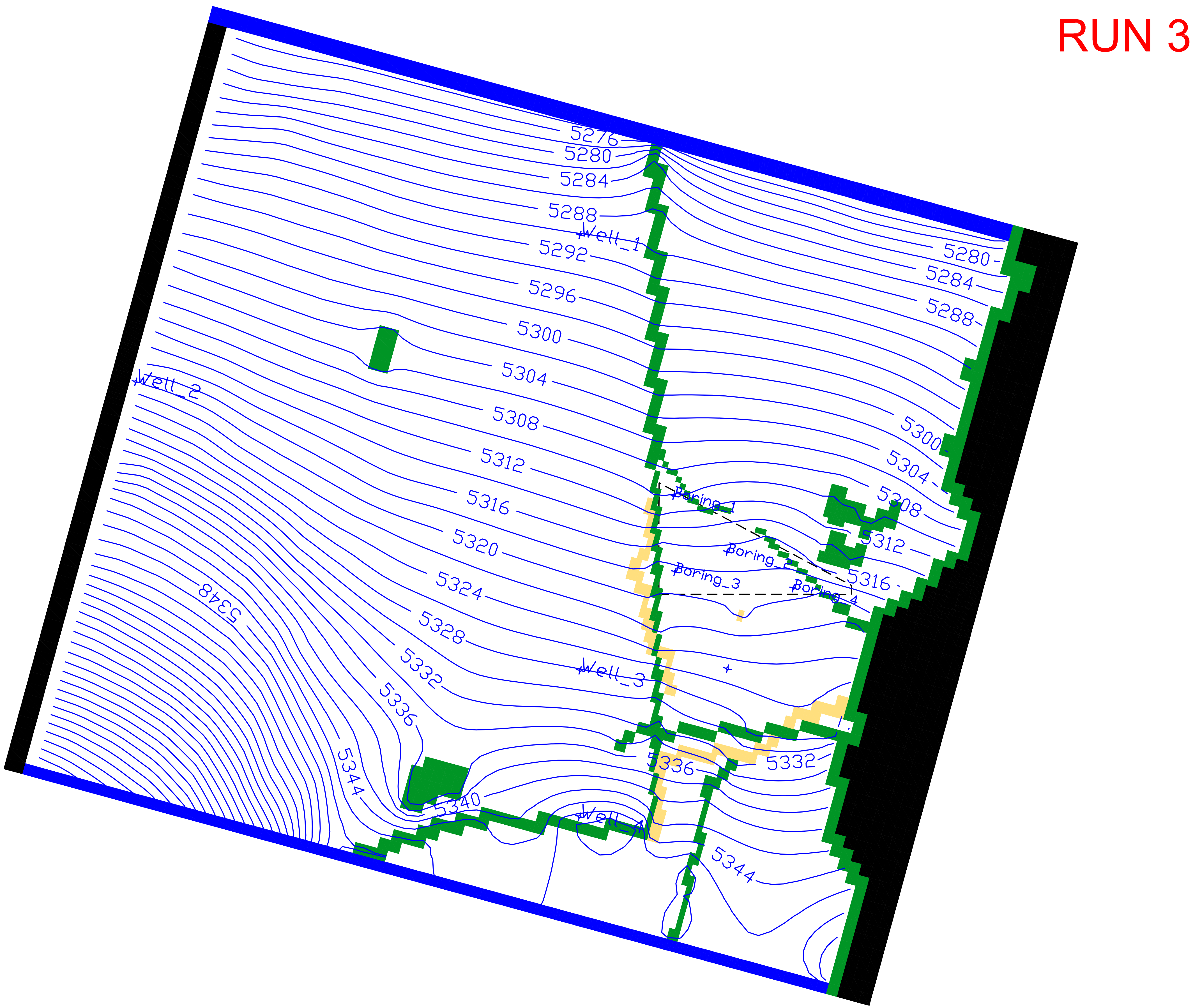
0 1000

FIGURE A-8
CALIBRATED PRE-DEVELOPMENT WINTER MODEL SIMULATED HEAD DISTRIBUTION

PROJECT: 320100 TASK: 02

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

PREPARED FOR: HOGAN-PANCOST



LEGEND

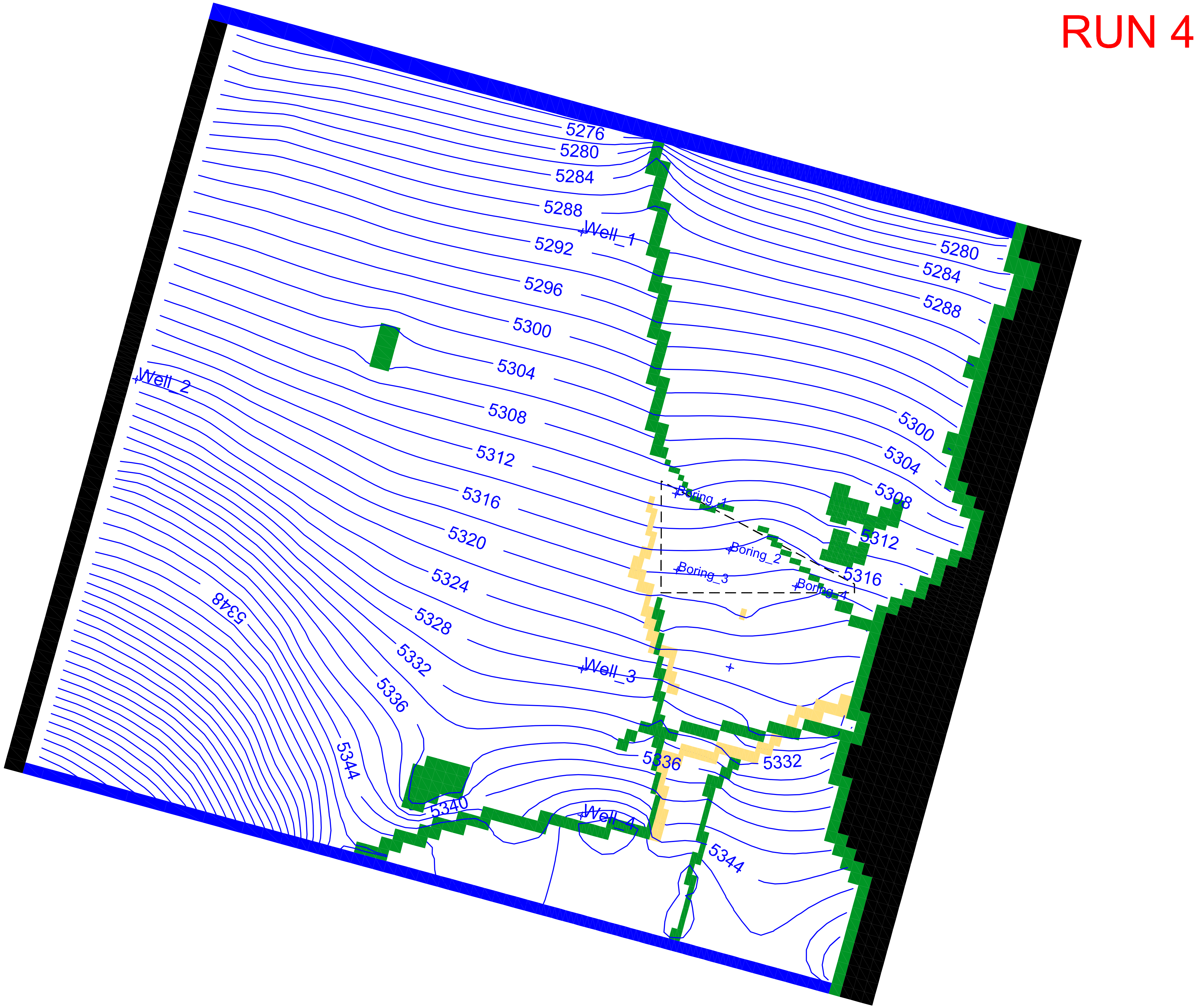
- 5332 — GROUND WATER ELEVATION CONTOUR (FT. MSL)
- RIVER CELL (STREAM, IRRIGATION DITCH, OR POND)
- DRAIN CELL (RESIDENTIAL SUMP OR WETLAND)
- PRESCRIBED HEAD CELL
- NO-FLOW OR INACTIVE CELL
- + WELL USED FOR CALIBRATION

N

SCALE IN FEET
0 1000

FIGURE A-9
VERIFIED PRE-DEVELOPMENT SUMMER MODEL - SIMULATED HEAD DISTRIBUTION

PROJECT: 320100	TASK: 02	PREPARED FOR: HOGAN–PANCOST
PREPARED BY: TELESTO SOLUTIONS INCORPORATED		



LEGEND

- GROUND WATER ELEVATION CONTOUR (FT. MSL) (5332)
- RIVER CELL (STREAM, IRRIGATION DITCH, OR POND)
- DRAIN CELL (RESIDENTIAL SUMP OR WETLAND)
- PRESCRIBED HEAD CELL
- NO-FLOW OR INACTIVE CELL
- WELL USED FOR CALIBRATION

N

SCALE IN FEET
0 1000

FIGURE A-10
POST-DEVELOPMENT SUMMER MODEL - SIMULATED HEAD DISTRIBUTION

PROJECT: 320100	TASK: 02	PREPARED FOR: HOGAN-PANCOST
PREPARED BY: TELESTO SOLUTIONS INCORPORATED		

ATTACHMENT 1

Calculations and Supporting Documentation for Parameters Used in the Analysis

1.1 Sump Pumping

For reference, the total sump pumping rate of 40 gpm within the Area of Interest is derived from anecdotal information reported by the resident of 260 Cimmaron Way:

> *"Maximum water (estimate) pumped from basement has been 5-6 gal every 22 seconds [~18 gpm]. Presently, (Aug 05) about 5-6 gpm every 5 minutes [~1 gpm]."*

Averaging the estimated pumping rates (9.5 gpm) and multiplying by the number of residents adjacent to the property along Cimmaron Way (5) yields a total estimated pumping rate of 42.5 gpm which is similar to the model simulated sump pumping rate of 43.9 gpm. Also, the averaged pumping rate is consistent with the anecdotal flow reported by the resident of 260 Cimmaron Way:

"May2003 – snow & rain (Mar, Apr) water in basement. Ditch about ½ full pumping over 15,000 gpd [10.4 gpm]."

1.2 Native Ground Recharge Rate

The assumption that 10% of mean annual rainfall becomes recharge (deep percolation) is higher than what would be expected based on the precipitation and vegetation consumptive use.

Assuming native ground is populated with pasture grasses, the potential evapotranspiration is 24.3 in/yr. Annual precipitation is approximately 20.8 in/yr, or about 86% of the potential evapotranspiration. Potential evapotranspiration exceeds precipitation during the growing season and recharge during the growing season is zero.

During the winter frost period of December through February, approximately 2.6 inches of precipitation occurs. The ground is frozen so this precipitation is removed through runoff, evaporation or sublimation. During the winter non-frost period months (October, November, and March) the soil within the root zone of native vegetation has the potential to store approximately 4.4 inches of the winter precipitation (NRCS, Map Unit Description for Niwot Soils). Native vegetation has adapted to the dry climate and uses the all available water very efficiently.

Using a water balance approach and assuming that 2.6 inches of the winter precipitation is removed through runoff, evaporation / sublimation and 4.4 inches is stored within the native vegetation root zone, the maximum recharge to the aquifer is 0.7 inches or 3.3% of annual precipitation. Thus, the assumption that 10% of the mean annual rainfall becomes recharge is an over estimation of the amount of recharge in these areas.

1.3 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.

1.4 Flood Irrigation Recharge Rate

The assumption that 50% of the net irrigation water for flood irrigation becomes deep percolation is consistent with the typical application efficiencies of irrigation systems listed in Colorado State University Extension Bulletin 514 (Bauder, T.A. and R.M. Waskom and A. Andales, 2008). Table 1 of the bulletin lists the efficiency of flood irrigation as being 20% to 50% (e.g., 50% of the net irrigation water was used by the plants). For purposes of this study, it was assumed that the flood irrigation was 50% efficient and the remainder becomes deep percolation to the aquifer. This assumption results in higher recharge to the aquifer because it assumes that evaporation from water surfaces and runoff losses are zero.

1.5 Bioswale ET and Recharge Rate

The estimate that one-third of the storm water runoff entering the bioswales will evapotranspire to the atmosphere and two-thirds will percolate downward and provide seepage recharge to ground water is supported by a mass balance calculation on the inflows and outflows from the bioswale (Table 1). Recharge to aquifer from the bioswale was estimated using the following equation:

$$\begin{aligned} \text{Recharge} = {} & \text{Precipitation}_{\text{bioswale}} \\ & + \text{Irrigation}_{\text{bioswale}} \\ & + \text{Runoff}_{\text{landscaped and impervious areas}} \\ & - \text{Evapotranspiration}_{\text{bioswale}} \end{aligned}$$

The calculation was based on the following:

- CLIGEN was used to generate a daily weather data set for Boulder.
- Assumed total water application rate of 30 inches (including precipitation) during the growing season.
- Runoff was calculated using the SCS curve number method:
  - Impervious area CN = 98
  - Landscaped area CN = 69
  - All runoff was assumed to enter the bioswale.
  - During the winter frost period, it is assumed that frozen ground prevents infiltration and all precipitation becomes runoff.
- Daily potential evaporation was calculated using the Penman-Monteith equation.
- Daily potential evaporation was adjusted (reduced) using the crop coefficients for cattails (bioswale bottom) and Kentucky bluegrass (bioswale side slopes).

According to Appendix C of the *Conceptual Storm Water Management and Floodplain Mitigation Report (Section 10.5, item 6)*, bioswale vegetation will conform to the following recommendation:

> *"6. Vegetation - Vegetate the channel bottom and side slopes to provide solid entrapment and biological nutrient uptake. Cover the channel bottom with loamy soils upon which cattails, sedges, and reeds should be established. Side slopes should be planted with native or irrigated turf grasses."*

Per the recommendation, the channel bottom will be covered with loamy soils to retain water and facilitate vegetative growth. Because the hydraulic conductivity of a loamy soil (0.055 ft/day to 11.5 ft/day, [Leij et. al., 1996]) is significantly lower than the estimated native soil hydraulic conductivity (100 ft/day), recharge to the aquifer in the bioswale area will be reduced.

The effect of the bioswale was investigated by modifying the numerical model to include additional recharge to the aquifer along the length of the bioswale. In order to maximize recharge to the aquifer, it was assumed that the hydraulic conductivity of the loamy soils was the same as the aquifer hydraulic conductivity.

Recharge (Table 1) was applied to the model assuming that cattails, sedges and reeds would be present along the entire length of the bioswale under summer conditions. Additional drain cells were added to represent homes north of the intersection of Kewanee Dr. and Cimmaron Way. Ground water modeling predicts that after development, the total summer sump pumping flow rate will be about 2.0 gpm lower than the simulated pumping rate for current conditions.

Table 1 Bioswale Recharge Estimate

Component	Summer (in)	Winter (in)	Area (acre)
Precipitation	13.1	7.7	2.52
Irrigation			
Cattails	(1)	-	-
KY Bluegrass	16.9	-	1.83
Runoff from Impervious Areas (CN=98)	7.89	4.19	9.6
Runoff Landscaped Areas (CN=69)	0.30	0.03	9.6
Winter Frost Period (Dec, Jan, Feb)	-	2.59 (2)	9.6
Evapotranspiration			
Summer (cattails)	24.3	(3)	0.69
Summer (KY Bluegrass)	19.3	(3)	1.83
Bioswale Recharge	36.0	33.7	2.52

(1) It was assumed that precipitation and runoff are sufficient to sustain cattails and no additional irrigation is required.
(2) It was assumed that the ground will be frozen during the months of December, January, and February and 100% of the precipitation during these months becomes runoff to the bioswale.
(3) It was assumed that no evapotranspiration occurs during the winter season.

1.6 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.

2.0 REFERENCES

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