MEMORANDUM

ANDERSON CONSULTING ENGINEERS, INC.
Civil • Water Resources • Environmental

DATE: March 11, 2013 **ACE PROJECT NO.:** COBLDR12

TO: Heidi Schum, P.E., Development Review Manager, City of Boulder Public Works

FROM: Scott Parker, P.E., Project Engineer, Anderson Consulting Engineers, Inc. SRP

SUBJECT: Boulder Creek Commons Ground Water Engineering Peer Review

Anderson Consulting Engineers, Inc. (ACE) has completed our review of the report entitled "Boulder Creek Commons Ground Water Recharge Evaluation, Boulder, Colorado", Telesto Solutions, Inc. , June 2012 (2012 Ground Water Recharge Evaluation). The City of Boulder (COB) contracted with ACE to perform this peer review which, for the entire project, includes reviews of related reports, correspondence, web sites, presentations and other materials related to the development review process dating back to 2010. COB staff also requested that ACE address selected comments and concerns of neighbors to the proposed Boulder Creek Commons development (aka the Hogan-Pancost property). Discussion of these items is also included in this report.

A list of the pertinent items reviewed and other materials cited is included in the References section at the end of this memorandum. Many of the items are available publically through the City of Boulder website, which is also listed under References.

General comments and conclusions covering all of the material addressed in this memorandum are in the Conclusions section located prior to References.

Report Summary - 2012 Ground Water Recharge Evaluation

The 2012 Ground Water Recharge Evaluation summarizes the efforts of Telesto Solutions, Inc. (Telesto) to quantify ground water recharge on the Boulder Creek Commons (BCC) site. The report was prepared for BCC, LCC (Applicant). BCC is a proposed residential development in southeast Boulder, Colorado. The site is approximately 20 acres located in the South Boulder Creek watershed. The triangular property is bounded on three sides by irrigation ditches, abuts the Keewaydin Meadows neighborhood on the west, the East Boulder Community Park and Recreation Center on the north and a large private residence (Bodam property) on the south. The site is transected by 55th Street in southeast corner. The small parcel east of 55th Street is not slated for residential development. It is well understood by all parties that groundwater is high in this area of the watershed. Some residents of adjacent neighborhoods, particularly Keewaydin Meadows to the west, experience problems with groundwater flooding in the basement levels of their homes. These residents use sump pumps to control ground water levels. Neighbors to the BCC site have opposed the development, in part, over concerns that it will exacerbate groundwater problems.

The report focuses on estimating pre-development and post-development recharge through a calculation that weighs estimated precipitation, ditch leakage, and irrigation (gains) against evapotranspiration and runoff (losses). The balance is considered recharge to ground water. Each parameter is estimated by methods described the extensive appendices. Two pre-development scenarios are considered, one with historic flood irrigation and one without. The report concludes that the development will reduce recharge to the local ground water table relative to either pre-development scenario and provide a net benefit to neighbors. The bulk of the reduction to recharge following development is attributed to piping the Dry Creek No. 2 irrigation Ditch along the western boundary.

Comments and Recommendations - 2012 Ground Water Recharge Evaluation

Comments and recommendations are offered below, broken out by Report and Appendices.

Report

(1) Page 4 of the report states "*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 minimal changes in the natural hydrologic process.*" This statement discounts the potential affect that changes to the aquifer itself due to development construction may have on ground water flows and thus the hydrologic process. This will be discussed in more detail in the part of this review that addresses questions and concerns of project neighbors.

(2) Page 5 of the report states that the Dry Creek Ditch No. 2 typically flows March though August. This observation may be true, but the report does not specifically state how this period was established. ACE downloaded the Structure Summary Report for the Dry Creek Ditch No. 2 diversion from the Office of the State Engineer (SEO) HydroBase website (See Attachment A). The structure summary contains diversion records from 1950 to 2011 (the most recent year available). The diversion records show historic diversions occurring from April through October, with the bulk of the diversion in the May through August period. Dry Creek Ditch No. 2 traverses a large area in the South Boulder Creek drainage basin so it is possible that it picks up surface drainage and runoff in March or has other sources. It would clear up confusion if the author would discuss the justification for the March through August period.

(3) Page 7 of the report discusses the assumption that there is no infiltration during the "winter frost period". The assumption is that the ground is frozen through this time period so precipitation during this period does not infiltrate and instead "*runs off, evaporates or sublimes*". In our experience, this is a typical assumption along the Colorado front range that is often used in ground water and water rights engineering analyses. The justification is that freezing nighttime temperatures may occur from October to May along the front range. It is possible that under the right conditions surficial layers of the soil may be sufficiently frozen to prevent infiltration anytime during this period. Some parts of the ground may be frozen one day and not the next. During periods where freezing temperatures are more likely in the daytime, December through February, it is more likely that the ground will be frozen. The engineering compromise is that rather than attempting to determine on what specific day the ground may be frozen in the October through May time frame the period is assumed to be during the typically coldest months of December to February. Engineers differ on how much of this period is assumed. The author has assumed the full three months, which is on the upper limit, but is reasonable. We are not troubled by this assumption.

(4) Page 9 of the report discusses assumptions concerning recharge from storm water runoff and states: "*for the purposes of this evaluation it was assumed that 100% of the storm water runoff entering the swales from irrigated, non-irrigated, and impervious areas will percolate downward and provide seepage recharge to ground water.*" As it is stated in the report, from the standpoint of comparing pre-development to post-development recharge this is a conservative assumption. It should be noted that it is not a realistic one. The soils in this swale will have an infiltration capacity that will be

exceeded by the storms of a certain intensity and duration. The infiltration capacity is unknown, but is likely much lower than the native soils. When the infiltration capacity is exceeded there will be runoff from swales and detention ponds.

(5) Page 11 of the report states that "*there are simply no mechanisms associated with the development that could cause the summer pumping rates to increase.*" This is a dispositive statement that might not be entirely justified by the findings of this report. More realistically the author might have stated that there are no mechanisms associated with the development that might cause recharge to increase. The mechanisms that lead to regional ground water problems may be more complicated than recharge alone.

(6) Tables 2, 3, 4a and 4b note a winter frost period runoff of 2.7 inches. If the Boulder area measured rainfall values in Table 1 are added for the December to February time period, and then averaged for the 22 years of data, the total precipitation is about 2.46 inches for this period. Assuming 100% runoff in the winter frost period, as is stated on Page 7, the maximum runoff would be 2.46 inches. This amounts to about a 10% overestimation of winter frost period runoff in both the pre-development and post-development cases and a 5% underestimation of winter recharge. Also, the placement of the winter frost period runoff calculation underneath the runoff heading denoting an SCS curve number (CN) of 61 is confusing. If an SCS calculation was performed for the winter frost period runoff the appropriate CN would have been closer to that determined for impervious surfaces (CN = 98) in Appendix A, Page A-4. The author should clarify the source of the 2.7 inch winter runoff figure in these tables.

(7) Table 4a notes an Irrigation Delivery Efficiency of 77.5%. It is unclear how this efficiency factors into the water balance calculations. The author should clarify whether the amount of summer irrigation water tabulated (11.9 inches) is before or after the irrigation efficiency is applied. Put simply, does this table account for the 22.5% (= 100% - 77.5%) of applied irrigation water that would, by the assumptions of the report, infiltrate?

The methodology described by note (1) and Appendix A, Page A-8 would imply that the irrigation rate of 11.9 inches was arrived at by subtracting the annual effective precipitation (precipitation minus runoff = 18.1 inches) from the annual irrigation rate (Appendix A = 30 inches). See comments and recommendations for Appendix A, Pages A-7 and A-8 for further discussion of irrigation rate.

(8) Table 4c shows runoff and recharge for impervious areas in the post-development scenario. The SCS curve number (CN) shown is incorrect. According to Appendix A, Page A-4 the appropriate CN for impervious areas is 98. The runoff amounts calculated for impervious areas appear to be based on the erroneous CN. This error would lead to the underestimation of post-development recharge. The author should recalculate impervious area runoff with the correct curve number and update dependent calculations.

(9) Tables 4d, 4e and 5 will need to be updated based on corrections to Tables 4a and 4c.

Appendices

(1) Appendix A contains a number of sections addressing the rationale and calculations behind various assumptions and parameters referenced in the report.

(2) Appendix A, Page A-2 contains the table "*Crop Coefficients and Growing Season Dates*". These numbers are used in the computation of evapotranspiration. The crop coefficients (Kc) listed for pasture grasses (0.83 - 1.09) and Kentucky blue grass (0.6 - 0.78) appear to be in error. Based on our experience, Kentucky blue grass generally has a higher Kc than pasture grasses. Attachment B is curve defining Kc for pasture grasses (See References USDA, 1970). The Kc for pasture grasses, based on 25-Mar to 15-Oct growing season varies from about 0.8 to 0.92 on this curve. For comparison purposes, ACE has used Kc values of 0.89 - 1.06 for Kentucky blue grass in previous work based on numbers provided to us by Denver Water. The tabulated pasture grass coefficients list a reference for a Blaney-Criddle method. The Kc values we have listed also are for use in the Blaney-Criddle method. The author has selected the Penman-Monteith method to compute evapotranspiration. There are differences between the Kc values used in each method, but the relative difference noted above should be similar (ASCE, 1990).

Taken alone, the practical effect of the Kc error would be: (1) to underestimate the pre-development recharge reported in Table 2 and Table 3: and, (2) overestimate post-development recharge reported in Table 4a. Predicting the net effect is complicated by the fact that the results of the evapotranspiration calculations play a part in determining the Flood Irrigation Application Rate as presented in Appendix A, Page A-7. The author should verify the Kc values, correct the evapotranspiration calculations as necessary, and update dependent calculations. See comments and recommendations for Appendix A, Pages A-7 and A-8 for further discussion of irrigation rate.

(3) Appendix A, Page A-7 and Appendix A, Page A-8 address irrigation rates for flood irrigation and lawn irrigation respectively. The author references Table 4.14 of Water Requirements for Urban Lawns (Danielson, 1980) as the source for the "*net irrigation water*" figure of 30 inches per irrigation season. On Page A-7 "*net irrigation water*" is defined as "*irrigation plus precipitation*". In practice irrigation and precipitation are two separate considerations in crop water requirement analyses and no term containing irrigation includes precipitation. The recommended average daily irrigation levels presented in the Danielson reference are the amount of irrigation water <u>*in addition to*</u> precipitation recommended for urban lawns. Pages 30 and 31 of Danielson, 1980 explain the methodology behind the construction of Table 4.14. Equation 4.1 presented therein is the equation used to determine daily irrigation levels in the tables. A term the accounts for precipitation is shown on the right hand side (Pages 30 and 31 of Danielson, along with Table 4.14 is included in Attachment C).

In Table 4a the quantity of summer irrigation (11.9 inches) appears to have been determined by subtracting effective precipitation (annual precipitation minus runoff 18.1 inches) from the annual irrigation rate for lawns of (30 inches). The 30 inch irrigation quantity should have been used without adjustment for rainfall, since average effective rainfall was already taken into consideration by Danielson in computing the irrigation recommendation. The author should adjust the irrigation value in Table 4a and dependent calculations. This error could result in a significant underestimation of post-development recharge.

(4) Appendix B contains a report detailing the use of an analytical element model to determine the leakage rate from Dry Creek Ditch No. 2.

(5) Appendix B, Page B-2 discusses the modeling approach. It is stated that monitoring well B-1 is likely to be more affected by neighborhood sump pumping than monitoring well B-3. These two monitoring wells are both on the east side of the Dry Creek Ditch No. 2 and roughly equivalent distances from the ditch and neighboring sumps. The author should explain more clearly the justification for focusing solely on monitoring well B-3 for the analysis.

(6) Appendix B, Page B-3 states that the hydraulic conductivity used in the model was set at 100 ft/day based on other work that the author has completed in the area. Average hydraulic conductivities for fluvial deposits, unconsolidated sediments, mixtures of clay, silt, sand, gravel and cobble laid down by river systems, typically range over 8 orders of magnitude from around 1 ft/day to 10,000 ft/day depending in the particular size of sediment that dominates a given area (Hiscock, 2005). Concentrations of the individual components can exhibit hydraulic conductivities much higher and much lower (Fetter, 2001). The Colorado Ground Water Atlas reports reported hydraulic conductivity values for the South Platte Valley-Fill Aquifer, of which South Boulder Creek is a part, of 44 to 3,200 ft/day (CWGA, 2000). The most recent geotechnical engineering report (EEC, 2012) notes that dominant water bearing strata at the BCC site is composed of sand, gravel, some cobble and occasional silt. A hydraulic conductivity of 100 ft/day seems reasonable for this material.

(7) Appendix B, Page B-4 states that a value of 0.2 is assumed for Specific Yield. This value comports with typical engineering practice in alluvial unconfined aquifers in Colorado.

(8) Appendix B, Page B-4 under the heading "*Uniform Flow*" the estimated saturated thickness is 11.5 feet. On Page B-2 the total aquifer thickness is 10.67 feet. The author should explain how the saturated thickness can exceed the aquifer thickness.

(9) Appendix B, Page B-6 states "*There was no precipitation during the observation period. Therefore the change (increase) in water level at the monitoring well B-3, which is located near Dry Creek Ditch No. 2, is directly attributable to leakage from Dry Creek Ditch No. 2.*" This observation has merit, based on the data tabulated in Table B-1; however, the data also indicates some background increase in the water levels at this location. Changes to the ground water levels pursuant evident in the measured data will be discussed in greater detail in the comments and recommendations for Table B-1.

(10) Appendix B, Page B-7 under the heading "*Transient Validation*" The transient validation is the effort to show that the calibrated model will match historic recorded events with sufficient accuracy to give confidence to the predictive ability of the model. It is stated that "*Dry Creek No. 2 Ditch was assumed to start flowing on May 6, 2011*." Diversion records (Attachment A) show that the first day of use for the Dry Creek No. 2 Ditch in 2011 was May 2nd. It is reasonable that the ditch may have begun flowing on or around May 6th at BCC site. Given the importance of the validation for the model, the author should provide more justification for this assumption.

(11) Appendix B, Page B-7 under the heading "*Discussion and Conclusions*". In a comparative analysis the following is stated: "*When using the ditch company's leakage rate of 20%, and a flow rate equal to the piped ditch design capacity of (28 gpm), the average leakage rate across the project area is calculated to be approximately 51.5 gpm.*" It is not clear how a leakage rate of 51.5 gpm is calculated based on a ditch flow rate of 28 gpm in the ditch, which indicates that either the flow rate is in error or there is missing information. The author should clarify how this calculation was made and give a source or justification for the reported ditch flow rate.

(12) Table B-1 lists water table elevation data measured over several different periods from 2006 to 2012. Of particular interest are the periods immediately preceding and following the study period (25-Apr to 27-Apr) used to model ditch leakage. In the approximately one month period prior to the study period (22-Mar to 25-Apr) the trends in the water table elevation are mixed, half of the monitoring wells show rising elevations the other half show declining elevations. The variations have significantly different magnitudes in this period. The Dry Creek No. 2 Ditch and the lateral start flowing on 26-Apr. From 25-Apr to 27-Apr five out of six monitoring wells demonstrated an increase in the water table elevation. Three of the six (B-3, B-4, PVC-SE) showed an increase on the order of six to seven inches in three days. Between 28-Apr and 9-May, the 12 days following the study period, the same three monitoring wells demonstrated roughly the same increase as during the study period. An indication that the water table elevation was increasing, but at a slower rate. Table B-1 is included as Attachment D. Table B-1 demonstrates a clear response of the water table to the flows beginning in Dry Creek Ditch No. 2. The extent to which this increase is solely attributable to leakage from the ditch as it crosses the BCC site is debatable. Some of the rise may be attributable to background rise in the aquifer, due to South Boulder Creek rising, off-site ditch seepage and irrigation above (south or west of) the site.

The unanswered question is to what extent on-site ditch seepage is contributing to the increase. The most recent geotechnical report (EEC, 2012) reports a percolation rate for site soils of less than 5 minutes per inch, and a suggested design percolation rate of 10 to 15 minutes per inch. In relative terms, these percolation rates are high, the values expected in medium to coarse sands (Davis, 1998). The ditch is well entrenched to similar soils. The response of the water table to the ditch running water was also quite rapid. This information lends credence to idea that a significant portion of the local increase in water table is due to local recharge on the order of 70.9 gpm (64.7 gpm plus 6.2 gpm, see Table B-2), perhaps mostly due to ditch seepage. Additional discussion of the potential impact of other sources of local recharge is included under Discussion and Comments - Questions and Concerns of Project Neighbors. There are concerns expressed that the author should address.

Also, the author should include a better description of how the water table elevations in Table B-1 were established i.e.: were monitoring wells surveyed?; who did the survey?; where is the benchmark or temporary benchmarks?; what is the datum?, etc.

<u>Discussion and Comment - Questions and Concerns of Project Neighbors</u>

Boulder staff asked ACE to address selected comments and concerns of neighbors to the proposed BCC development (aka the Hogan-Pancost property). The included questions and concerns are those specifically identified by the staff and are taken from communications to the staff. Questions and concerns, which have been paraphrased, are italicized.

(1) Question or Concern:

Jeff McWhirter, a project neighbor, sent an email to Telesto and COB staff on 7-Feb pointing out an apparent error in Appendix A of the "Ground Water Hydrology and Monitoring Report" prepared by Western Ecological Resource, Inc. and dated May 5, 2010. The error was associated with the conversion of flow rate over weirs in the Bodham Lateral. The email also outlined Mr. McWhirter's concern that the 2012 Ground Water Recharge Evaluation underestimates recharge due to the Bodam Lateral by taking into account only direct recharge from seepage occurring due to overflow from the liner and not addressing indirect recharge due to the uses of the Bodam Lateral water on the Bodam property immediately south of the BCC site. Mr. McWhirter lays out the case that there is on the order of 900 gpm of water diverted onto the Bodam property, but the 2012 Ground Water Recharge Evaluation only attributes 6.2 gpm recharge to the Bodam Lateral. Mr. McWhirter's email is included as Attachment E.

Discussion:

There is a conversion error in Appendix A of the May 2010 Ground Water Hydrology and Wetland report. As noted by Mr. McWhirter the conversion from cubic feet to gallons was incorrectly applied. The correct conversion and resulting numbers are as noted in his email. The flow in the lateral at that particular time was just over 1 cfs (453 gpm).

The Dry Creek Ditch No. 2 recharge estimate in the 2012 Ground water Recharge Evaluation is based on measured data from monitoring wells on the BCC site. The modeling was calibrated and validated specifically to measured changes in water table elevation over time. This data driven analysis makes the findings in this report distinct from the previous studies completed for this effort. Based on the reasoning outlined in Appendices Comment 12, Appendix B of the Recharge Evaluation makes a compelling case that ditch seepage is a significant contributor to raising ground water levels at the site. Mr. McWhirter is suggesting that the use of water on the Bodam property is itself a significant contributor to local recharge. If this is the case then perhaps some portion of the 64.7 gpm of recharge attributed to the Dry Creek No. 2 Ditch may be coming from ponds/wells/irrigation on the Bodam property. The Recharge Evaluation does not address what water uses were occurring on the Bodham property during the 25-Apr to 27-Apr study period, i.e.: was there irrigation?; were the ponds or sumps full or being filled over the time period? Telesto may have notes, observations, records or data associated with water use on the Bodam property during study period that would be useful in addressing this concern.

During the study period, the most responsive monitoring wells in Table B-1, Appendix B of the report are B-3, B-4 and, PVC-SE which are closest to Dry Creek Ditch No. 2, the "Unnamed Ditch" crossing the east parcel of the Hogan-Pancost property, and the Bodam Lateral/property, respectively. Other than indicating all three features as possible sources of recharge, the data in Table B-1 is not particularly instructive as the relative magnitude of the potential sources of recharge. The practical effect of recharge on the Bodam property influencing the measured data would be to reduce (but not eliminate) the amount of recharge attributable to Dry Creek Ditch No. 2 to something less than 64.7 gpm, thus reducing the magnitude of the potential benefit of piping the ditch.

(2) Question or Concern:

The developer is proposing to install an underdrain system for the homes immediately adjacent to the Bodam Lateral. In a general construction practice sense, why would underdrains be pursued at a location where the homes are on fill up to 5 feet thick without any basements?

Discussion:

According to the latest geotechnical report (EEC, 2012), earthwork plans call for cut on the order of zero (0) feet to (2) feet and fill on the order of zero (0) feet to five (5) feet. Consequently, the amount of fill at any given point in the development could be significantly less than 5 feet depending on the final grading plan. In addition, frost free foundations need to be placed to depth of 30 inches below the ground surface. The EEC report and previous geotechnical report (Western, 2010) recommended installation of underdrain systems to control the moisture content of soils below foundations/slabs and protect any below grade space. This is a typical recommendation for homes that border an irrigation ditch or drainage conveyance since these feature come with a risk of surface flooding in addition to ground water that can saturate soils around foundations.

COB staff inquired about proposed underdrain plans with the Applicant and they responded as follows:

"We have discussed an underdrain system for the homes immediately adjacent to the Bodam Lateral. The foundations of these homes are above the historical high ground water elevation but are down gradient from the lateral. We have looked at a few design alternatives to confirm that an underdrain system, should it be needed to serve these specific homes, would have a viable outfall the system either to a pond via storm drain or to the wetland mitigation area in the SW corner of the property. The remaining homes are graded such that the bottom of the foundations (assuming spread footing at 36" below FF elev) will generally be above the historical high ground water elevation. In addition, these remaining homes back to detention pond areas or drainage swales which provide an opportunity to outfall a home specific underdrain should a home or homes require one. Design details of any underdrain system serving more than one home would be provided at Technical Document Review as is typical for City of Boulder project."

(3) Question or Concern:

Will moving ground water to the north of the site exacerbate the sump pumping problems for the adjacent homes?

Discussion:

Pursuant to eventual outfall location(s) of the proposed underdrain discussed in Question or Concern 1 there does not appear to be any other proposed mechanism that intentionally "moves" ground water to the north part of the site. It is our interpretation that the proposed underdrains would affect relatively few homes. Judging by the drawings included with the latest Site Review Package (December 21, 2012 - see project website) potential areal recharge from drainage swales and detention ponds is distributed relatively evenly across the site. Surface drainage certainly moves north and west, but that is the status quo. Some possibility of utility trenches carrying water from north to south exists, as discussed below, and appropriate ground water barriers should be installed to prevent this.

(4) Question or Concern:

There is a large amount of water brought into the area by the Bodam ditch lateral. This water is specifically intended to recharge ground water levels. Perhaps 5-10 acre-feet/day is brought into the area by this ditch. In the 2 ground water reports this feature is not mentioned. Why is that? The 2010 Ground water report is based on an estimated recharge rate that may underestimate the actual recharge by a factor of 100 or more. 0.05 acre-ft/day versus 5 acre-ft/day. The 2012 report is based on the 2010 report. Does the 2012 report mischaracterize the irrigation hydrology and its recharge estimate is in error by a further factor of 2.5 - perhaps a factor of 250 to 500?

Discussion:

This concern been discussed under Question or Concern (1) above. The 2012 Ground water Recharge Evaluation does not specifically address the potential effect of recharge from the Bodam property on the modeling effort completed for the evaluation. This review has asked that the author address this concern.

(5) Question or Concern:

Staff has claimed that in their experience developments tend to reduce ground water levels. Considering that much of the ground water on the site originates off-site and consists of lateral flow through the area what is the mechanism that will lower the ground water levels?

Discussion:

There is no single answer to whether development in general will raise or lower ground water levels. The affect of development on ground water is dependent on the specific details of the site under consideration. The experience of engineers with ground water issues will vary based on the projects they have worked on. The 2012 Ground water Recharge Evaluation specifically states on Page 1 that the Applicant "*can only control changes within the Project area as part of its development.*" It is within the power of the Applicant to affect recharge within the confines of the development. Piping Dry Creek No. 2 Ditch will reduce recharge to some degree, which is very likely to benefit neighbors closest to the ditch, regardless of other changes. More efficient lawn/landscape irrigation may also reduce recharge to some degree as compared to prior uses. There are errors in the evaluation pointed out in this review that the author must correct in order to better estimate whether and to what extent areal recharge will change pre-development to post-development.

(6) Question or Concern:

How will ground water levels be affected in a "wet" year? The developer has only measured ground water levels in years that have received either an average amount of precipitation (approximately 17 inches per year) or a less than average amount of precipitation.

Discussion:

A reasonable definition for a "wet year" is a year with above average precipitation. Assuming that this condition occurs over the South Boulder Creek basin it may cause the water table elevation in the entire alluvial aquifer to rise to an above average level. Regional hydrologic conditions are, of course, beyond the Applicant's control. Looking specifically at the proposed BCC development it is clear that, regardless of the hydrologic condition, piping Dry Creek Ditch No. 2 will reduce local recharge. Local recharge due to precipitation will always be relative to the hydrologic condition and will increase in a "wet year". Recharge due to irrigation may or may not decrease in a "wet year", but is unlikely to increase. With respect to recharge the presence of the development is unlikely to affect water table elevations relatively more in a "wet year" than in a normal year. How earthworks related to the development may affect ground water flow is discussed in response to Question or Concern 9 below.

(7) Question or Concern:

How much leakage can be expected from the Dry Creek Ditch #2 and is this leakage the cause of the sump pumping problems? In the 2nd report they come up with a leakage rate along the ditch of 64 GPM. They derive this number from the ground water model. Is the estimated leakage rate accurate?

Discussion:

Irrigation canals, like the Dry Creek No. 2 Ditch, are typically constructed so that they run roughly parallel to the source stream some distance uphill in the valley. This allows the canals to carry water that is then used to irrigate ground between the ditch and the stream with return flows, both surface and subsurface, make their way back to the source stream. The upland position of irrigation canals insures that they are nearly always contributors to ground water, especially earthen canals through porous materials. Ditch companies that operate canals factor in these losses in order to make deliveries to users. The ratio of the total water delivered to the total water diverted is called the conveyance efficiency (ASABE, 2007). The remainder is the transmission loss. Appendix B, Page B-7, of the 2012 Ground water Recharge Evaluation reports a "*ditch company's leakage rate of 20%".* Thus, the expected transmission loss in the Dry Creek Ditch No. 2 is 20%, in aggregate. Some of the transmission loss is evaporation but it is generally accepted in the industry that seepage to ground water dominates transmission losses, in the absence of large numbers of phreatophytic plants. ACE has conducted seepage studies on canal systems. In our experience, losses on the order of 20% or greater are reasonable for earthen ditches in alluvial soils.

A recharge of 64.7 gpm or more from the Dry Creek No. 2 Ditch as it crosses the site is certainly possible. The modeling method used changes in measured water table elevation data over a small area with well established boundary conditions. In our opinion the model should capable of reasonably estimating recharge from the ditch. The Applicant must address questions on the relative impact that water uses on the Bodam property may have had on the determination of recharge during the study period outlined in the evaluation.

(8) Question or Concern:

Do the reports submitted to date accurately describe the source of ground water, its depth, how much it flows and its direction of flow?

Discussion:

The ground water reports submitted by the Applicant do a reasonable job of describing the sources, quantities and direction of ground water flow at the BCC site.

ACE reviewed both the 2010 Ground Water Evaluation and the 2012 Ground Water Recharge Evaluation among many other associated reviews, documents and correspondence related to the project (See References). The 2010 evaluation has been well reviewed and discussed previously so we have focused on the 2012 evaluation, which addressed many of the valid criticisms of the earlier report. To the extent that many of the neighbors comments and concerns are more general and apply to both evaluations they have been addressed in this review.

(9) Question or Concern:

The following questions have been grouped together because they ask about possible effects of earthworks on ground water flows:

The site plan shows some roads at the current grades. How will the road bed excavation, fill and compaction affect the ground water flows? Conversely, how will the high ground water levels affect the structural stability of the road way?

How will utility trenches impact ground water?

How will the extensive fill dirt that will be brought onto the property affect ground water flow? There will be approximately 60,000 cubic yards of fill dirt brought onto the site. There will be up to 5 feet placed in some areas.

Will the extensive site preparation, fill compaction, foundation wall construction, road construction and utility trench construction affect the later ground water flows on the property?

Discussion:

Project neighbors have expressed significant concern over how earthwork on the site along with the construction of roads, foundations and utilities will ultimately affect ground water flows. The focus seems to be how construction might affect permeability (hydraulic conductivity) of the site and a fear that construction on the site might create a groudwater "dam" that restricts flow and raises the water table elevation on adjacent properties.

A project neighbor maintains a website (www.hoganpancost.org) on which the following research paper is referenced and made available for download: "The Impacts of Urbanization on Groundwater Systems and Recharge" by John M. Sharp, Jr. A copy of this research paper is included as Attachment F it is very instructive on the affects of urbanization on hydrogeology. On page 53 Dr. Sharp discusses the affects of urban infrastructure on the "permeability field" which is basically the average hydraulic conductivity of a given area. It is noted that: (1) urban soils tend to become less permeable due to compaction; and (2) that utility trenches and fill around buildings tend to be more permeable than the surrounding soil. Each point will be discussed in turn with respect to the BCC site.

It is reasonable that the increased loading (earthfill, structures) and compactive effort on native soils would tend to make them less permeable; however, the composition of the soils makes a significant difference in the magnitude of this affect. Dr. Sharp does not address the relative impact on different soil types. According to the most recent geotechnical report (EEC, 2012) the fine grained cover soils at the site are composed of silty, sandy, clayey soils with some combination of the following classifications SC, SM, ML and CL. These soils are shallow and vary from nearly absent to 5 feet deep (less according to the boring logs). Soils in these classifications are nearly impermeable when compacted (Budhu, 2000). Below the cover soils are granular soils classified as SP-GP that extend to bedrock 7 to 14 feet down. These soils are generally permeable to very permeable when compacted (Budhu, 2000). During the May 2012 subsurface investigation the water table was encountered in the granular soils. The cover soils may indeed compact under construction loading and become less permeable. In-situ granular soils tend to be dense and it is unlikely that construction loading will change their permeability though further consolidation. Where compaction of granular soils is recommended it is because disturbing these soils through excavation loosens their structure. It should also be noted that the soils report recommends that the cover soils be removed from areas of structural concern and replaced with granular structural fill. Cover soils in structural areas left in place or used for fill must be above the water table and well drained. Given the specific characteristics of the soils at the site, and the recommended soil modifications in the geotechnical report, significant changes to the permeability field due to compaction is not considered likely.

Utility trenches tend to be more permeable than the native soils into which they are excavated. There are two primary reasons for this: (1) pipe are usually bedded in very stable coarse grained granular materials; and (2) it is usually difficult to compact soil materials back to the level of compaction they had originally. The same logic holds true in other types of excavations, such as those around buildings. Utility trenches tend to become conduits for ground water rather than dams, which is why building regulations often require the use of ground water barriers. Attachment G is a ground water barrier detail taken from the City of Boulder Design and Construction Standards, Technical Drawing Details, Drawing No. 4.08. Table B-1 in Appendix B of the 2012 Ground water Recharge Evaluation shows measured water table elevations from the BCC site. There is a significant gradient in the water table from north to south across the property that is consistently 6 to 8 feet between monitoring wells B-3 (high) and B-1 (low). The introduction of utility trenches in the proposed streets without ground water barriers could lead to the water table "leveling" across the site. Ground water barriers force water to move through undisturbed soils and would maintain a water table similar to pre-development.

Other concerns expressed by neighbors are the effect of concrete foundations and the placement of "flowfill" flowable fill backfill material in utility trenches may have on ground water flows.

Three things should be kept in mind when considering the possible effects of concrete foundations on ground water flow: (1) foundations in the proposed development will be shallow (30-36 inches below ground surface); (2) most foundations will be placed on some amount of fill that elevates them above existing grades; and (3) both the 2010 and 2012 geotechnical reports spell out requirements for stabilization of soils supporting structures. All three of these items would tend to mitigate the effects. ACE examined the boring data from the most recent geotechnical report (EEC, 2012) to identify which boreholes encountered ground water at the shallowest depths. Depth to ground water averaged about 5 feet (maximum = 8', minimum = 2.5', median = 5', mode = 5'). The borings with the shallowest depth to ground water were B-8, B-10, B-11, and B-13. These borings are located in proposed lot numbers 46, 14, 25, and 3, respectively. Sheet C3, the proposed Preliminary Grading Plan, in the Applicant's Site Review Package includes existing contours and proposed finished floor elevations for each lot in the development. Subtracting four feet from the finished floor elevation is a good proxy for the bottom of footing elevation. In the cases of lots 3, 14, 25, 46 the bottom of the footing was at, or a few inches below, the existing ground surface. In May 2012, the water table was 2.5 to 4 feet below the ground surface at these lots. Elsewhere, the water table was five to eight feet below the ground surface. Water table fluctuations visible in Table B.1 (Attachment D) show the water table reaching elevations up to two feet higher than those measured in May 2012. A cursory examination of other lots indicates that most of the proposed foundations will not extend to water table depth given the combination of shallow depth and fill placement. Final grading plans may vary, so foundations or other structures that that do risk encountering ground water either have to bear on granular subsoils, have cover soils removed and replaced with granular materials, or have an underdrain system that lowers the water table and keeps fine grained cover soils at an appropriate moisture content (Western, 2010 and EEC, 2012). It should also be pointed out that excavations around foundations tend to be more permeable than native soils, and provide a pathway around the structure. Another consideration is that the proposed ground modifications at the BCC site will bring lot elevations on the western side of the BCC site to levels on par with adjacent lots on Cimarron Drive. The Cimarron Drive homes have basements. BCC lots will have shallow foundations. Groundwater will intersect the basements in Cimarron Drive before it intersects adjacent shallow foundations in BCC. The preponderance of the specific preliminary design details indicates that foundations will not significantly impede ground water flow across the site.

The placement of impermeable flowfill in utility trenches could potentially impede ground water flow, depending on the depth and length of the trench in question. The Applicant has suggested that utility trenches on the order of 6 feet deep would be necessary. The average depth to bedrock based on 15 boreholes is about 11 feet (maximum = 15', minimum = 1.5', median = 11.5', mode = 13.5'). A little over half of the total aquifer depth would be affected by a 6 foot trench. The impact to upgradient water surfaces would depend on the linear extent of the flowfill at that depth. A longer installation would have a greater effect. The placement of flowfill in utility trenches is governed by Boulder Revised Code, Section 8-5-12, "Standards for Repairs and Restoration of Pavement or Sidewalks". This section of the code governs utility trenches placed into existing pavements, but not new construction. Section 8-5-12 also allows for the use of rock fill in trenches deeper than 5 feet. Since the proposed development is new construction, and therefore not subject to repair and restoration rules, backfill will probably fall under the requirements of the "City of Boulder Design and Construction Standards", Chapter 9-C-10, which outlines backfilling requirements for utility trenches using "approved backfill material" which could be suitable native soil or imported structural fill. It is unlikely that flowfill materials intended for placement in shallow trenches for repairs, will ever make up a significant portion of trench length in the proposed development to any great depth. Consequently, it is also unlikely that flowfill trenches will impede ground water flow in any measurable way.

(10) Question or Concern:

The developer is proposing to pipe the Dry Creek Ditch #2 and also develop a flood conveyance channel along the west side of the property. This will require extensive excavation along the ditch corridor. Will excavation in this area and construction of the ditch pipe negatively affect ground water flows?

Discussion:

Considering the information presented in the response to Question or Comment 9 above it is not expected that piping the Dry Creek Ditch No. 2 will result in an impediment to ground water flow. Given that utility trenches and bedding become preferential flow paths for ground water, consideration should be given to installing ground water barriers along the proposed pipe. Placing

Dry Creek Ditch No. 2 in a pipe will reduce recharge from the ditch, which will be of some benefit to neighbors.

(11) Question or Concern:

The following questions have been grouped together because they ask about industry standards for ground water hydrology investigation and analysis for development:

The ground water reports and conclusions are just based on simulations of the ground water. What other techniques make up industry standard best practices that allow one to understand ground water hydrology in a development of this size? For example, dye tests to determine flow directions, pump tests to determine hydraulic conductivity, actual measurements of ditch flows to determine leakage rates.

To date the developer has presented the results from just 2 model-based evaluations of the ground water hydrology. These models are based on a single parameterization of recharge rates and hydraulic conductivity. They do not provide error estimates, confidence intervals or any sensitivity analysis. Does this level of analysis follow normal industry standards for understanding ground water hydrology and the impacts that development may bring to it?

Discussion:

The individual steps taken to understand and quantify ground water hydrology for land development are dependent on the experience and judgment of the consultant, usually a professional engineer or geologist. The first and most important step is subsurface exploration by a geotechnical engineer. Geotechnical testing establishes the subsurface profile, the subsurface materials and the presence, depth and gradient of ground water. Monitoring of ground water may be done to study variations of the water table over time. This allows the owner/planner/civil designer team to decide what type of construction may be appropriate, i.e. basements, crawlspaces, slab-on-grade. Depending on that decision they may decide that ground water mitigation is necessary. At this point a consultant in ground water may be brought in to discuss mitigation measures. This consultant may do further subsurface exploration, further monitoring of existing wells, hydraulic conductivity tests, identification of possible sources through field surveys and analysis of water table elevation data, identification of feasible underdrain discharge points, and ground water modeling. Typically if the owner/planner/civil designer team elect to avoid ground water through ground modification and shallow foundations a ground water consultant is not hired. In this instance it seems that neighborhood involvement was the driving force behind the efforts made to understand ground water.

The performance of specific tests is also up to the discretion of the ground water consultant. The election in this case to use a hydraulic conductivity established at a similar site instead of performing site specific test is not at odds with typical practice. Another consultant may have elected to use a tabulated value. The consistent profile of soils across the site justifies using a uniform hydraulic conductivity in modeling. The direction of ground water flow is typically established by mapping the water table surface. Dye tests are usually the province of contaminant investigations and tracing specific sources for specific problems, as was done for the telecommunications trench on Cimarron

Way. Studies to quantify ditch seepage are notoriously difficult and unreliable, that the consultant in this case decided to model seepage based on water table elevation measurements is reasonable.

Like testing, specific decisions regarding modeling are at the discretion of the consultant. The necessary refinement of ground water models for answering specific questions is subjective. In some instances a consultant may choose to forego modeling entirely based in what the geotechnical data reveals. In other cases they may build a model and perform all manner of statistical analyses on the data. There is no universal standard. A licensed professional engineer or geologist is expected to do the level of analysis they feel is necessary to justify their conclusions.

In our experience, the efforts to understand and quantify ground water for the proposed BCC development have met or exceeded the efforts typically expended for land development along the front range of Colorado.

Conclusions

The 2012 Ground Water Recharge Evaluation takes a workmanlike approach in determining the potential changes to ground water recharge as a result of BCC development and the effects on neighbors. The water balance approach is straightforward and persuasive. There are instances where the methodology for determining parameters used in the water balance are not well explained. There are also errors in the determination of parameters. The errors in the runoff calculation for impervious areas (Report, Comment 8), the crop coefficients (Appendices, Comment 2), the determination of pre-development irrigation quantities (Appendices, Comment 2), and the determination of post-development irrigation quantities (Appendices, Comment 3) increase the magnitude of the expected recharge difference. It is our belief that correcting these errors by themselves will not change the conclusion of the report that pre-development recharge will exceed post-development recharge. The Applicant should make these corrections to demonstrate the net effect.

The single most important number in the recharge evaluation is the estimated Dry Creek Ditch No. 2 leakage of 64.7 gpm. It is this number that in all cases results in pre-development recharge exceeding post-development recharge. Although it is our belief that Dry Creek Ditch No. 2 does recharge the regional aquifer, project neighbors have brought up a valid point that the analysis presented in Appendix B does not address how possible recharge from the aquifer due to water uses on the Bodam property may have influenced the determination of ditch leakage (Questions and Concerns of Project Neighbors, Question or Concern 1). There is no information given in the report that would support an estimate of how this number may change. The applicant must address this concern in order to justify the conclusion of the evaluation.

Regardless of the outcome of the concerns expressed above the piping of Dry Creek Ditch No. 2 though the BCC property is very likely to benefit those project neighbors adjacent to the ditch along Cimarron Way. Basement flooding in properties adjacent to irrigation ditches is a well known problem along the front range of Colorado. While it may not eliminate sump pumping it is likely to reduce the amount of water contributing to the problem at certain times of the year.

Based on our review of the available documentation we do not share the concern of project neighbors that the development, as described in the preliminary documents submitted to Boulder, will significantly affect groundwater flow through the area, provided precautions are taken (Questions and Concerns of Project Neighbors, Question or Concern 9). The Applicant and Boulder should be cognizant that groundwater barriers should be installed in utility trenches on this site. The applicant and Boulder should also be aware that flowfill backfill in deep utility trenches can impede the flow of groundwater; however, it is our belief that it is unlikely that flowfill backfill will ever be placed over a sufficient length to a sufficient depth to impede groundwater flow at this site.

The larger concerns of project neighbors as to what causes high groundwater are beyond the scope of this memorandum; however, the review has lead ACE to a pair of observations that should inform the thinking on this subject.

1. Table B.1 (Attachment D) shows a steep gradient in the water table from south (high) to north (low). Without a larger field of data it is not possible to tell what all the influences on this gradient may be, but it is not indicative of a water table that is being controlled by down gradient processes, like impeded flow to the north. The tendency is consistent throughout the 2006 to 2012 time period captured in the data.
2. COB staff have discovered that a original Street and Utility Plans for Keewaydin Meadows Subdivision included a 6" drain tile installed below the sanitary sewer in the same trench. This indicates that the possibility of high ground water was known to the original developer. The condition of this drain tile may have bearing on the problems experienced by the homeowners on Cimarron Drive. Drain tiles of this type can have service lives of over 100 years if protected, but they are subject to damage from overhead construction and tree roots. If the existence of the tile was unknown to later utility crews it may have been damaged inadvertently. The location and condition of the outlet for the drain tile is also of interest. Attachment H contains a copy of the Street and Utility Plans and a blow up of the relevant notes.

References

ASABE. Design and Operation of Farm Irrigation Systems. American Society of Agricultural and Biological Engineers. 2007.

ASCE. ASCE-Manuals and Reports on Engineering Practice-No. 70, Evapotranspiration and Irrigation Water Requirements. American Society of Civil Engineers. 1990.

BCC, LLC. Site Review Package, Boulder Creek Commons. December 21, 2012.

Boulder Revised Code, 1981.

Budhu, Muni. Soil Mechanics and Foundations. John Wiley & Sons. 2000.

CH2MHill. Letter to Katie Knapp, P.E., CFM, City of Boulder Planning and Development Services. December 8, 2010.

City of Boulder Design and Construction Standards. Chapter 9. Effective: November 16, 2000.

Colorado Ground-Water Association. Colorado Ground-Water Atlas. CGWA. 2000.

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

Davis, Mackenzie Leo. Introduction to Environmental Engineering. WCB/McGraw Hill. 1998.

Earth Engineering Consultants, Inc. Preliminary Geotechnical Subsurface Exploration, Boulder Creek Commons, Boulder, Colorado, EEC Project No. 1122042. June 15, 2012.

Fetter, Charles Willard. Applied Hydrogeology, Prentice-Hall Inc. 2001.

Hiscock, Kevin M. Hydrogeology: Principles and Practice. Blackwell Science Ltd. 2005.

McCurry Hydrology, LLC. Memorandum to Steve Meyer, President South East Boulder Neighborhoods Association, RE: Review and Assessment of Ground Water Issues Related to Development of the Hogan Pancost Property, Boulder, Colorado, Revision 4, prepared by Telesto Solutions, Inc., dated November 2010. February 3, 2012.

Sharp, John M. The Impacts of Urbanization on Groundwater Systems and Recharge. Scribo 2010. June 30, 2010.

Telesto Solutions, Inc. Boulder Creek Commons Ground Water Recharge Evaluation, Boulder, Colorado. June 2012.

Telesto Solutions, Inc. Ground Water Evaluation for the Hogan-Pancost Property, Boulder, Colorado, Revision 4. November 2010.

Telesto Solutions, Inc. Letter to Heidi Schum, Engineering Review Manager, Planning and Development Services. RE: Hogan-Pancost Property: Response to Public Comments from Planning Board Meeting on January 19th, 2012. February 14, 2012.

Telesto Solutions, Inc. Letter to Jeff Arthur, Engineering Review Manager, Planning and Development Services. RE: Hogan-Pancost Property: Neighborhood Event Timeline and Response to Specific Questions Raised by Adjacent Neighbors. September 27, 2011.

Telesto Solutions, Inc. Letter to Katie Knapp, PE, CFM, City of Boulder Planning and Development Services. RE: Groundwater Hydrology and the Hogan-Pancost Property. November 8, 2010.

The Sanitas Group. Letter to Heidi Schum, P.E., City of Boulder Planning and Development Services, RE: Response to Public Comments, Boulder Creek Commons, 01/19/12 Planning Board Hearing. February 14, 2012.

The Sanitas Group. Preliminary Storm Water Report for Boulder Creek Commons Subdivision, 5399 Kewanee Drive and 5697 S. Boulder Road, Unincorporated Boulder County, Colorado. June 2012.
Western Ecological Resource, Inc., Groundwater Hydrology Monitoring & Wetland Delineation Report, Hogan Pancost Property, Boulder County, Colorado., May 5, 2010.

USDA, SCS, Engineering Division. Technical Release No. 21, Irrigation Water Requirements. United States Department of Agriculture. April 1967, Revised September 1970.

Western Ecological Resource, Inc. Wetland Mitigation Plan, Boulder Creek Commons Property, Boulder County, Colorado. June 2012.

Western Soils, Inc. Preliminary Subsurface Investigation, Boulder Creek Commons on 55th Street, Within Section 4, T.1S., R.70W., Boulder County, Colorado. April 8, 2010.

Websites

http://www.bouldercolorado.gov/index.php?option=com_content&view=article&id=7148&Itemid=4715

http://www.hoganpancost.org

http://water.state.co.us/DataMaps/DataSearch/Pages/DataSearch.aspx

Attachment A

SEO Structure Summary Report for Dry Creek No. 2 Ditch

Structure Name: **DRY CREEK NO 2 DITCH** **Water District: 6** **Structure ID Number: 570**

Source: SOUTH BOULDER CREEK

Location:	Q10	Q40	Q160	Section	Twnshp	Range	PM
	NE	NW	NW	21	1S	70W	S

Distance From Section Lines: From N/S Line: From E/W Line:

UTM Coordinates (NAD 83): Northing (UTM y): 4422926 Easting (UTM x): 479689.7 Spotted from PLSS distances from section lines

Latitude/Longitude (decimal degrees): 39.956227 -105.237785

Water Rights Summary:							
	Total Decreed Rate(s) (CFS):	Absolute:	19.5000	Conditional:	0.0000	AP/EX:	114.2111
	Total Decreed Volume(s) (AF):	Absolute:	0.0000	Conditional:	0.0000	AP/EX:	0.0000

Water Rights -- Transactions

Case Number	Adjudication Date	Appropriation Date	Administration Number	Order Number	Priority Number	Decreed Amount	Adjudication Type	Uses	Action Comment
90CW0108	1882-06-02	1859-10-01	3561.00000	0		0.9760 C	O,AP	1234568AW	ALT PT TO LOWER BOULDER D
97CW0195	1882-06-02	1859-10-01	3561.00000	0		0.7490 C	O,AP	1234568AW	ALT PT TO LOWER BOULDER DITCH
W8346	1882-06-02	1860-04-01	3744.00000	0		0 C	O,AP	12Q	ALT PT TO LAFAYETTE PL
W8347	1882-06-02	1862-05-25	4528.00000	0		0 C	O,AP	12Q	ALT PT TO S BOULDER BEAR CR D
80CW0468	1882-06-02	1863-05-01	4869.00000	0		0 C	O,AP	1234568Q	ALT PT TO L BOULDER D 90CW108
90CW0108	1882-06-02	1863-05-01	4869.00000	0		0.0430 C	O,AP	1234568AW	ALT PT TO LOWER BOULDER D
84CW0204	1882-06-02	1864-05-01	5235.00000	0		21.1900 C	O,AB	1	ABAN 02/03/1988
85CW0133	1882-06-02	1864-05-01	5235.00000	0		1.6900 C	O,TF	1	TFR TO E BLDR D 12/28/1988 PUBLIC SERVICE TFR
85CW0133	1882-06-02	1864-05-01	5235.00000	0		4.4800 C	O,AB	1	ABAN 12/28/1988 PUBLIC SERVICE TFR
99CW0230	1882-06-02	1864-05-01	5235.00000	0		0.3300 C	O,TF	1	TFR TO COMMUNITY D 08/17/04 LOUISVILLE CHNG USE
99CW0230	1882-06-02	1864-05-01	5235.00000	0		0.8800 C	O,AB	1	ABAN 08/17/04 LOUISVILLE CHNG USE
CA1280	1882-06-02	1864-05-01	5235.00000	0		69.0000 C	O	1	138,356 CA 21299,W-8346
CA21299	1882-06-02	1864-05-01	5235.00000	0		0.9890 C	O,TF	1	E1009 TFR TO LOUIVILLE PL 9-10-70
CA21299	1882-06-02	1864-05-01	5235.00000	0		0.7910 C	O,AB	1	E1009 ABAN 9-10-70
W8346	1882-06-02	1864-05-01	5235.00000	0		10.0300 C	O,AB	1	ABAN 08/28/1979 LAFAYETTE CHNG DCR
W8346	1882-06-02	1864-05-01	5235.00000	0		4.0000 C	O,TF	2Q	CHNG USE TO MUN-LAYFETTE 82CW293
W8346	1882-06-02	1864-05-01	5235.00000	0		4.0000 C	O,TT	12Q	CHNG USE TO MUN FM AG-LAFAYETTE 82CW293
W8500	1882-06-02	1864-05-01	5235.00000	0		0.5300 C	O,TF	1	TFR TO LOUISVILLE PL 04/21/1987
W8500	1882-06-02	1864-05-01	5235.00000	0		8.5900 C	O,AB	1	ABAN 04/21/1987 LOUISVILLE TFR
80CW0468	1882-06-02	1865-02-01	5511.00000	0		0 C	O,AP	1234568Q	ALT PT TO L BOULDER D 90CW108
90CW0108	1882-06-02	1865-02-01	5511.00000	0		0.0640 C	O,AP	1234568AW	ALT PT TO LOWER BOULDER D
80CW0468	1882-06-02	1865-04-01	5570.00000	0		2.2160 C	O,AP	1234568Q	ALT PT TO COTTONWOOD D 90CW108
85CW0119	1882-06-02	1865-04-01	5570.00000	0		1.1655 C	O,AP	12568W	ALT PT TO COTTONWOOD NO 1 D LAFAYETTE TFR
80CW0468	1882-06-02	1866-04-01	5935.00000	0		1.1510 C	O,AP	1234568Q	ALT PT TO COTTONWOOD D 90CW108
85CW0119	1882-06-02	1866-04-01	5935.00000	0		0.6048 C	O,AP	12568W	ALT PT TO COTTONWOOD NO 1 D
80CW0468	1882-06-02	1866-05-15	5979.00000	0		0 C	O,AP	1234568Q	ALT PT TO L BOULDER D 90CW108
90CW0108	1882-06-02	1866-05-15	5979.00000	0		0.0440 C	O,AP	1234568AW	ALT PT TO LOWER BOULDER D
80CW0468	1882-06-02	1866-06-01	5996.00000	0		0 C	O,AP	1234568Q	ALT PT TO L BOULDER D 90CW108
90CW0108	1882-06-02	1866-06-01	5996.00000	0		0.0170 C	O,AP	1234568AW	ALT PT TO LOWER BOULDER D
90CW0108	1882-06-02	1870-06-01	7457.00000	0		1.4360 C	O,AP	1234568AW	ALT PT TO LOWER BOULDER D
97CW0195	1882-06-02	1870-06-01	7457.00000	0		1.6960 C	O,AP	1234568AW	ALT PT TO LOWER BOULDER DITCH
80CW0468	1882-06-02	1870-10-01	7579.00000	0		1.5620 C	O,AP	1234568Q	ALT PT TO COTTONWOOD D 90CW108
85CW0119	1882-06-02	1870-10-01	7579.00000	0		0.8208 C	O,AP	12568W	ALT PT TO COTTONWOOD NO 1 D LAFAYETTE TFR
80CW0469	1882-06-02	1872-04-15	8141.00000	0		0.8600 C	O,AP	123458Q	ALT PT TO DAVIDSON D
85CW0119	1882-06-02	1872-04-15	8141.00000	0		1.2330 C	O,AP	12568W	ALT PT TO DAVIDSON D LAFAYETTE TFR LTD 79AF
W8348	1882-06-02	1872-04-15	8141.00000	0		0 C	O	12Q	W-8347 ALT PT TO DAVIDSON D
80CW0469	1882-06-02	1873-06-01	8553.00000	0		0.8600 C	O,AP	123458Q	ALT PT TO DAVIDSON D
85CW0119	1882-06-02	1873-06-01	8553.00000	0		4.8330 C	O,AP	12568W	ALT PT TO GOODHUE D LAFAYETTE TFR LTD 250AF
W8348	1882-06-02	1873-06-01	8553.00000	0		0 C	O,AP	12Q	ALT PT TO GOODHUE D
85CW0119	1907-03-13	1881-09-01	11567.00000	0		15.0000 C	O,AP	12568W	ALT PT TO HENRY WANEKA R LAFAYETTE TFR LTD
85CW0119	1907-03-13	1884-11-01	12724.00000	0		15.0000 C	O,AP	12568W	ALT PT TO HENRY WANEKA R LAFAYETTE TFR LTD
85CW0119	1907-03-13	1892-02-15	15386.00000	0		17.3800 C	O,AP	12568W	ALT PT TO LAFAYETTE R 1 & 2 LAFAYETTE TFR LTD
85CW0119	1907-03-13	1897-10-01	17441.00000	0		15.0000 C	O,AP	12568W	ALT PT TO HENRY WANEKA R LAFAYETTE TFR LTD
85CW0119	1907-11-03	1906-06-20	20890.20624	0		15.0000 C	S,AP	12568W	ALT PT TO HENRY WANEKA R LAFAYETTE TFR LTD
85CW0119	1953-09-28	1915-08-29	27930.23981	0		16.5000 C	S,AP	12568W	ALT PT TO HECLA RES LAFAYETTE TFR LTD 25AF
90CW0108	1990-12-31	1990-05-15	51269.00000	0		8.0000 C	S,C,EX	1234568AW	LAFAYETTE SEWER EXCH
97CW0195	1997-12-31	1997-06-30	53872.00000	0		8.0000 C	S,C,EX	1234568AW	EXCH FM LAFAYETT SEWER

Water Rights -- Net Amounts

Adjudication Date	Appropriation Date	Administration Number	Order Number	Priority/Case Number	Rate (CFS) Absolute	Rate (CFS) Conditional	Rate (CFS) AP/EX	Volume (Acre-Feet) Absolute	Volume (Acre-Feet) Conditional	Volume (Acre-Feet) AP/EX
1882-06-02	1859-10-01	3561.00000	0	97CW0195	0	0	1.7250			
1882-06-02	1863-05-01	4869.00000	0	90CW0108	0	0	0.0430			
1882-06-02	1864-05-01	5235.00000	0	99CW0230	19.5000	0	0			
1882-06-02	1865-02-01	5511.00000	0	90CW0108	0	0	0.0640			
1882-06-02	1865-04-01	5570.00000	0	85CW0119	0	0	3.3815			
1882-06-02	1866-04-01	5935.00000	0	85CW0119	0	0	1.7558			
1882-06-02	1866-05-15	5979.00000	0	90CW0108	0	0	0.0440			
1882-06-02	1866-06-01	5996.00000	0	90CW0108	0	0	0.0170			
1882-06-02	1870-06-01	7457.00000	0	97CW0195	0	0	3.1320			
1882-06-02	1870-10-01	7579.00000	0	85CW0119	0	0	2.3828			
1882-06-02	1872-04-15	8141.00000	0	85CW0119	0	0	2.0930			
1882-06-02	1873-06-01	8553.00000	0	85CW0119	0	0	5.6930			
1907-03-13	1881-09-01	11567.00000	0	85CW0119	0	0	15.0000			
1907-03-13	1884-11-01	12724.00000	0	85CW0119	0	0	15.0000			
1907-03-13	1892-02-15	15386.00000	0	85CW0119	0	0	17.3800			
1907-03-13	1897-10-01	17441.00000	0	85CW0119	0	0	15.0000			
1907-11-03	1906-06-20	20890.20624	0	85CW0119	0	0	15.0000			
1953-09-28	1915-08-29	27930.23981	0	85CW0119	0	0	16.5000			
1990-12-31	1990-05-15	51269.00000	0	90CW0108	0	0	8.0000			
1997-12-31	1997-06-30	53872.00000	0	97CW0195	0	0	8.0000			

Irrigated Acres Summary -- Totals From Various Sources

GIS Total (Acres):	261.7085	Reported:	2010
Diversion Comments Total (Acres):	0	Reported:	2007
Structure Total (Acres):		Reported:	

Irrigated Acres From GIS Data

Year	Land Use	Acres Flood	Acres Furrow	Acres Sprinkler	Acres Drip	Acres Groundwater	Acres Total
1956	***Year Total***	308.26	0	0	0	0	308.26
1956	GRASS_PASTURE	188.34	0	0	0	0	188.34
1956	SUGAR_BEETS	119.92	0	0	0	0	119.92
1976	***Year Total***	307.69	0	0	0	0	307.69
1976	GRASS_PASTURE	187.99	0	0	0	0	187.99
1976	SUGAR_BEETS	119.69	0	0	0	0	119.69
1987	***Year Total***	278.42	0	0	0	0	278.42
1987	ALFALFA	44.36	0	0	0	0	44.36
1987	SMALL_GRAINS	234.06	0	0	0	0	234.06
2001	***Year Total***	358.56	0	0	0	0	358.56
2001	GRASS_PASTURE	358.56	0	0	0	0	358.56
2005	***Year Total***	282.37	0	0	0	0	282.37
2005	GRASS_PASTURE	282.37	0	0	0	0	282.37
2010	***Year Total***	261.71	0	0	0	0	261.71
2010	GRASS_PASTURE	261.71	0	0	0	0	261.71

Diversion Summary in Acre-Feet - Total Water Through Structure

Year	FDU	LDU	DWC	Maxq & Day	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Total
1950	1950-04-13	1950-07-16	95	29 05-22	0	0	0	0	0	218	393	615	496	0	0	0	1722
1951	1951-05-09	1951-09-10	112	14 07-18	0	0	0	0	0	0	220	323	659	169	44	0	1414
1952	1952-06-04	1952-08-17	75	25 06-08	0	0	0	0	0	0	0	1150	845	198	0	0	2194
1953	1953-05-12	1953-08-08	86	22 05-28	0	0	0	0	0	0	450	837	797	103	0	0	2188
1954	1954-04-26	1954-07-17	27	20 05-18	0	0	0	0	0	8	712	0	75	0	0	0	795
1955	1955-05-03	1955-08-31	51	30 05-17	0	0	0	0	0	0	349	522	71	399	0	0	1341
1956	1956-05-08	1956-08-26	71	35 06-13	0	0	0	0	0	0	514	827	101	313	0	0	1755
1957	1957-06-19	1957-09-04	78	20 07-01	0	0	0	0	0	0	0	357	1200	996	119	0	2672
1958	1958-06-04	1958-07-20	47	30 06-20	0	0	0	0	0	0	0	734	278	0	0	0	1012
1959	1959-05-18	1959-08-10	71	15 05-19	0	0	0	0	0	0	85	597	736	139	0	0	1557
1960	1960-04-21	1960-07-27	98	20 06-18	0	0	0	0	0	56	238	853	738	0	0	0	1884
1961	1961-05-31	1961-08-07	62	27 06-22	0	0	0	0	0	0	38	772	861	99	0	0	1769
1962	1962-05-04	1962-08-02	91	25 05-09	0	0	0	0	0	0	998	742	647	36	0	0	2422
1963	1963-05-13	1963-09-29	82	18 05-31	0	0	0	0	0	0	504	678	14	20	363	0	1579
1964	1964-05-02	1964-07-20	70	27 05-21	0	0	0	0	0	0	613	561	605	0	0	0	1779
1965	1965-05-02	1965-09-12	96	24 07-06	0	0	0	0	0	0	327	776	593	87	180	0	1964
1966	1966-05-10	1966-07-04	56	15 05-12	0	0	0	0	0	0	532	748	97	0	0	0	1377
1967	1967-04-10	1967-09-17	109	22 04-12	0	0	0	0	0	387	369	99	56	0	284	0	1194
1968	1968-05-22	1968-08-19	76	18 05-23	0	0	0	0	0	0	274	659	307	179	0	0	1418
1969	1969-06-02	1969-10-06	63	16 06-06	0	0	0	0	0	0	0	214	492	40	69	60	875
1970	1970-05-05	1970-08-02	88	18 05-28	0	0	0	0	0	0	647	764	405	8	0	0	1823
1971	1971-05-03	1971-08-06	96	18 06-27	0	0	0	0	0	0	401	805	583	32	0	0	1821
1972	1972-05-03	1972-08-07	90	15 06-05	0	0	0	0	0	0	601	718	317	63	0	0	1700
1973	1973-06-07	1973-08-19	74	8 06-25	0	0	0	0	0	0	0	282	419	210	0	0	910
1974	1974-05-10	1974-08-07	90	12 06-17	0	0	0	0	0	0	361	508	672	127	0	0	1668
1975	1975-05-22	1975-08-25	95	14 07-30	0	0	0	0	0	0	103	415	708	506	0	0	1732
1976	1976-05-06	1976-10-13	133	10 05-16	0	0	0	0	0	0	401	545	516	371	36	61	1930
1977	1977-05-12	1977-09-01	91	14 06-01	0	0	0	0	0	0	488	740	133	305	6	0	1672
1978	1978-04-24	1978-08-13	86	11 06-14	0	0	0	0	0	50	30	460	599	186	0	0	1325
1979	1979-06-07	1979-09-03	79	12 08-17	0	0	0	0	0	0	0	301	611	428	42	0	1383
1980	1980-06-01	1980-08-11	72	16 06-22	0	0	0	0	0	0	0	635	823	147	0	0	1605
1981	1981-06-10	1981-06-18	9	10 06-10	0	0	0	0	0	0	0	115	0	0	0	0	115
1982	1982-05-20	1982-08-13	86	10 07-14	0	0	0	0	0	0	101	278	470	175	0	0	1023
1983	1983-05-11	1983-09-08	102	7 06-09	0	0	0	0	0	0	63	327	276	244	10	0	920
1984	1984-04-19	1984-08-15	119	18 06-29	0	0	0	0	0	26	222	579	823	220	0	0	1870
1985	1985-04-13	1985-08-07	114	20 05-12	0	0	0	0	0	93	329	504	424	93	0	0	1444
1986	1986-04-26	1986-07-27	90	7 07-21	0	0	0	0	0	58	307	300	242	0	0	0	906
1987	1987-05-20	1987-07-24	66	5 05-20	0	0	0	0	0	0	112	253	163	0	0	0	528
1988	1988-05-05	1988-07-24	81	34	0	0	0	0	0	0	75	347	137	0	0	0	560
1989	1989-04-26	1989-09-26	134	5 05-25	0	0	0	0	0	26	232	216	120	24	35	0	652
1990	1990-04-01	1990-07-28	118	8 06-25	0	0	0	0	0	46	88	369	282	0	0	0	785
1991	1991-05-13	1991-08-14	88	10 06-17	0	0	0	0	0	0	80	506	312	184	0	0	1082
1992	1992-04-24	1992-07-29	97	12 05-17	0	0	0	0	0	35	314	230	229	0	0	0	808
1993	1993-05-10	1993-08-07	86	7 06-01	0	0	0	0	0	0	102	318	244	49	0	0	712
1994	1994-05-09	1994-07-05	58	18 05-25	0	0	0	0	0	0	166	312	43	0	0	0	521
1995	1995-06-16	1995-08-30	76	7 08-11	0	0	0	0	0	0	0	72	249	350	0	0	671
1996	1996-04-19	1996-08-14	118	14 05-25	0	0	0	0	0	51	361	337	251	85	0	0	1086
1997	1997-04-01	1997-08-28	150	11 07-02	0	0	0	0	0	57	123	278	240	164	0	0	862
1998	1998-05-19	1998-08-21	93	10 06-10	0	0	0	0	0	0	109	520	208	251	0	0	1088
1999	1999-04-01	1999-09-13	159	13 06-11	0	0	0	0	0	60	61	626	561	312	74	0	1694
2000	2000-04-01	2000-07-23	113	6 06-28	0	0	0	0	0	69	163	312	168	0	0	0	712
2001	2001-04-08	2001-08-19	108	7 06-01	0	0	0	0	0	23	228	308	91	32	0	0	682
2002	2002-04-02	2002-06-19	79	4 05-24	0	0	0	0	0	54	135	145	0	0	0	0	333

2003	2003-04-01	2003-10-01	129	8	06-18	0	0	0	0	0	64	88	340	188	0	81	4	766
2004	2004-05-05	2004-08-15	102	7	06-16	0	0	0	0	0	0	146	328	87	81	0	0	643
2005	2005-05-04	2005-07-19	77	14	05-26	0	0	0	0	0	0	246	413	161	0	0	0	820
2006	2006-05-16	2006-07-22	68	11	06-09	0	0	0	0	0	0	152	386	383	0	0	0	921
2007	2007-05-22	2007-07-19	59	7	05-24	0	0	0	0	0	0	131	372	238	0	0	0	740
2008	2008-05-20	2008-07-31	73	10	05-25	0	0	0	0	0	0	162	382	318	0	0	0	862
2009	2009-05-10	2009-07-24	76	7	07-02	0	0	0	0	0	0	178	235	259	0	0	0	672
2010	2010-05-05	2010-08-08	78	14	06-10	0	0	0	0	0	0	166	280	144	45	0	0	636
2011	2011-05-02	2011-09-12	112	8	05-16	0	0	0	0	0	0	287	344	225	110	25	0	991
			Minimum:	4		0	0	0	0	0	0	0	0	0	0	0	0	115
			Maximum:	35		0	0	0	0	0	387	998	1150	1200	996	363	61	2672
			Average:	15		0	0	0	0	0	22	235	461	371	122	22	2	1235

62.00 years with diversion records

Notes: The average considers all years with diversion records, even if no water is diverted.
The above summary lists total monthly diversions.
* = Infrequent Diversion Record. All other values are derived from daily records.
Average values include infrequent data if infrequent data are the only data for the year.

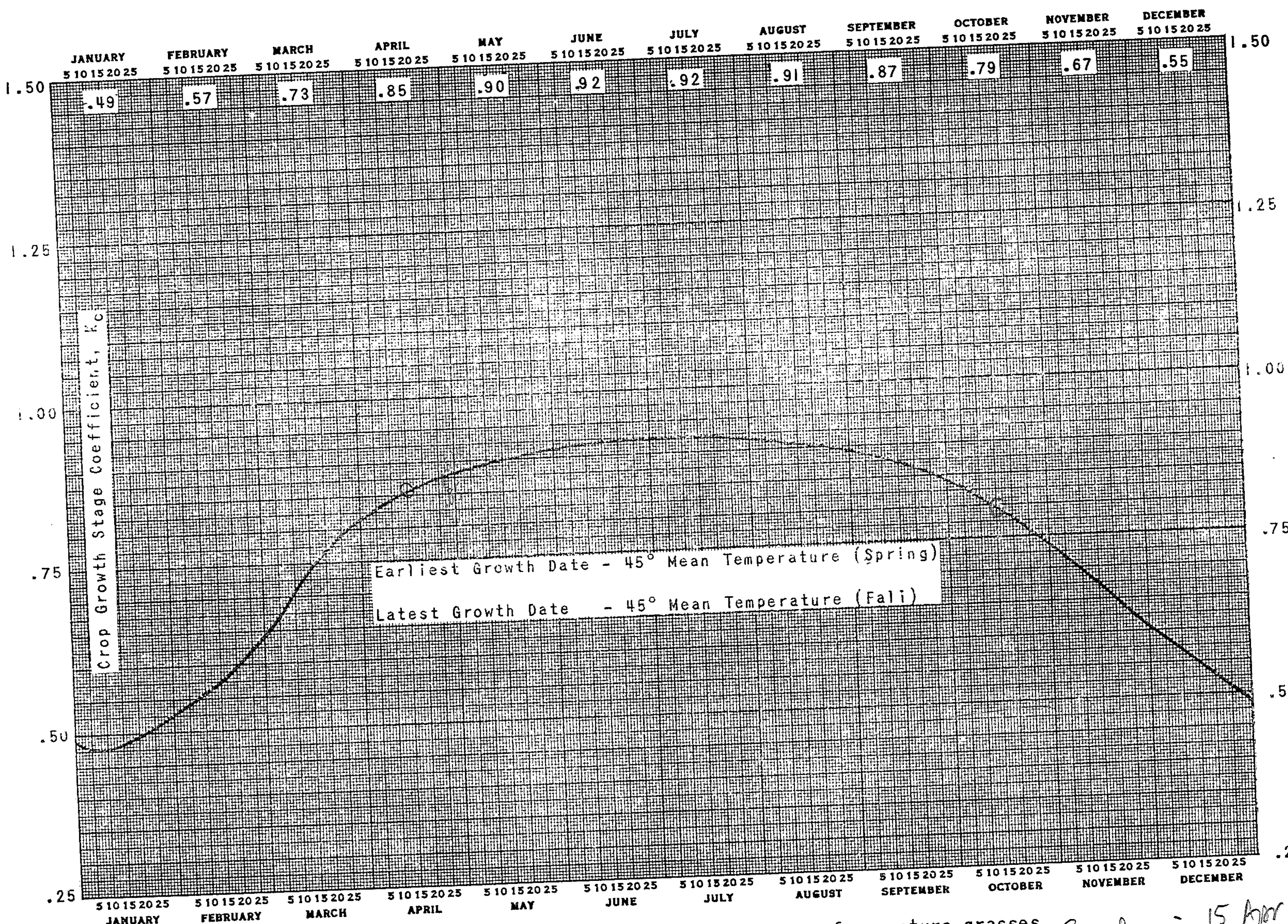
Diversion Comments

IYR	NUC Code	Acres Irrigated	Comment
1950		2500	
1951		2500	
1952		2500	
1953		2375	
1954		2375	
1955		2375	
1956		2375	8/1 RAIN
1957		2375	
1958		2375	
1959		2375	
1960		2375	
1961		2375	
1962		2375	
1963		2375	
1964		2375	
1965		2375	7/24 RAIN
1966		2375	
1967		2375	NO WATER AVAILABLE IN AUGUST
1968		2375	8/14 RAIN
1969		2375	
1970		2375	
1971		2375	
1972		2375	
1973		2375	
1974		2375	
1975		2375	
1976		2375	
1977		2375	
1978		2375	
1980		2375	
1981		2375	
1982		2375	
2000		0	<1CFS DIVERTED NOV-MAR FOR STOCK WATER
2001		0	<1CFS DIVERTED NOV-MAR FOR STOCK WATER
2002		0	<1CFS DIVERTED NOV-MAR FOR STOCK WATER
2003		0	HISTORICAL USES INCLUDE STOCKWATER.
2004		0	HISTORICAL USES INCLUDE STOCKWATER.
2005		0	HISTORICAL USES INCLUDE STOCKWATER.
2006		0	HISTORICAL USES INCLUDE STOCKWATER.
2007		0	HISTORICAL USES INCLUDE STOCKWATER.

Note: Diversion comments and reservoir comments may be shown for a structure, if both are available.

Attachment B

Chart of Crop Coefficient Values for Pasture Grasses



Crop growth stage coefficient curve for pasture grasses

Curve No. 17

: 15 Apr 45° mean
15 Oct 45° mean

Attachment C

Pages 30, 31 and Table 4.14 of “Water Requirements for Urban Lawns”

Chapter 4

LAWN WATERING GUIDELINES

Unlike agricultural irrigation, which is justified on the basis of crop yield, urban lawn irrigation is required to help maintain cooler summer temperatures, to reduce the amount of airborne dust, and to provide an aesthetically pleasing environment. It is difficult to quantify the "proper" amount of irrigation for urban lawns because yield is not important and the irrigation requirement is only related to plant appearance - a subjective value.

Lawn Quality

In this project lawn appearance was summarized by a lawn quality rating (Q), which varied from zero (lowest quality) to ten (highest quality). Values for the lawn quality ratings, averaged over two seasons, were 6.5 for Northglenn and 7.5 for Fort Collins. Thus, in neither city was a significant number of residents demanding the highest possible lawn quality and apparently, the sampled residents of Northglenn did not demand as high a quality lawn as did those of Fort Collins. Part of this difference was undoubtedly a result of the different water pricing policies of the two cities. In Northglenn, residents pay for the amount of water used; in Fort Collins, they pay a flat rate based upon lot size and other factors related to the residence.

For the guidelines established, three lawn quality ratings will be considered; namely, high (Q=8), medium (Q=6), and low (Q=4). The water requirements to maintain a lawn at a specific quality rating will be estimated for various cities in Colorado.

Lawn Water Requirements

It is assumed that lawn quality is related to the amount of water available to the grass and that other management practices are constant or, at least, consistent with the watering practices. One way of quantifying water application (irrigation plus rainfall) for a given period is to relate it to the potential evapotranspiration. Thus, the application ratio (L_m) can be defined as,

$$L_m = \frac{d}{E_{tm}}$$

where d is the total applied water and E_{tm} is the measured evapotranspiration by the lawn under conditions of soil moisture non-limiting (i.e., with the bucket lysimeters). The averaged observed values of Q versus irrigation water applied at Fort Collins and Northglenn are provided in figure 3.2 for 1977 and in figure 3.3 for 1978. The average daily irrigation needed to meet E_{tm} requirements is shown on the figures as arrows. The value depends upon seasonal rainfall as well as E_{tm}. The arrow for Fort Collins in 1977 (figure 3.3) represents an irrigation rate where the rainfall was adjusted due to an exceptionally large storm on 24 and 25 of July. Much of that rain was lost either to runoff or to deep percolation. The lawn quality rating, when the amount of irrigation indicated by the arrows was applied, was about 7 in 1977 and about 7.5 in 1978 for both cities. These values were representive of the highest average quality obtained regardless of the amount of irrigation provided. The scatter in the points is, of course, due to differences in timing and distribution of the irrigation between the various cooperators and to their management practices including fertilizer use. Evapotranspiration of the lawn cannot exceed E_{tm}; but since the residents irrigate inefficiently in terms of how often and how evenly the water is applied, application rates exceeding the theoretical minimum to meet E_{tm} are generally required to maintain as entire lawn of high quality. Assuming reasonably good management practices, it may be concluded from figures 3.2 and 3.3 that a total water application rate (irrigation plus rainfall) equal to E_{tm} (L_m=1.00) will result in an average seasonal quality rating of 8 and that quality ratings of 6 and 4 could result when L_m values are 0.78 and 0.36 respectively. If E_{tm} and rainfall values are known, it is possible to calculate the irrigation requirements needed to provide these lawn quality ratings for any location. The measurements of E_{tm} using lysimeters is expensive, however, and would be impractical for large numbers of locations.

Use of Evapotranspiration Estimating Equations

In order to avoid the high cost of measuring E_{tm}, it is desireable to predict it from climatic data at a specific location. Various equations have been developed for this purpose depending upon the type of climatic information available. The recommendations presented here are based upon the use of the Jensen-Haise equation. It has been shown to be quite accurate and requires a minimum of weather data.

The expected evapotranspiration of a crop can be estimated as follows.

$$E_{tj} = c\ E_{tpj}$$

where E_{tpj} is the potential evapotranspiration as calculated by the Jensen-Haise equation, E_{tj} is the expected evapotranspiration of the crop under the existing growing conditions, and c is a coefficient which takes into consideration the crop, the moisture stress in the soil, and how recently the crop was irrigated or received rainfall. Haw (1977) estimated c using information in the literature for agricultural crops and the assumption that urban lawns have a growth response to water similar to that of pasture grass under full cover. His calculations yielded a value of c equal to 0.89 and a plot of the 1977 data indicated that by using his c value

$$E_{tj} \approx E_{tm}$$

A subsequent evaluation of the data obtained in this study at Fort Collins and Northglenn indicates that the ratio of cumulative seasonal E_{tm} to E_{tpj} is about 0.92. A value of c equal to 0.90 (the mean of 0.89 and 0.92) is used to prepare the guidelines. Thus,

$$L_m = \frac{d}{0.9\ E_{tpj}}$$

and

$$di = 0.9\ E_{tpj}\ L_m - dr \qquad (4.1)$$

where di is the required daily irrigation to provide the desired lawn quality rating, L_m is the necessary application ratio for that quality rating, and dr is the average daily long-term rainfall value.

Application

The techniques described above were applied to 17 Colorado cities (figure 4.1). Historical precipitation, temperature, and solar radiation were obtained from appropriate sources (Jensen, 1973; U.S. Dept. Commerce; Siemer, 1977). The results are presented in tables 4.1 through 4.17. In those tables, temperature is the mean for each month,

Table 4.14 Average climatic data and recommended average daily irrigation levels for urban lawns to provide lawn quality ratings of 40, 60 and 80 percent of maximum.

City Longmont, Colorado

Elevation (meters) 1,509

Latitude 40° 10' N

Longitude 105° 04' W

Month	Ave. Temp. °C	Ave. ppt. mm/day	Pot. E_t mm/day	Irrigation mm/day 40%	60%	80%
May	13.67	2.07	5.49	--	1.8	2.9
June	18.33	1.60	7.47	0.8	3.6	5.1
July	22.00	0.99	8.10	1.6	4.7	6.3
August	21.06	0.84	7.01	1.4	4.1	5.5
September	16.11	0.83	5.06	0.8	2.7	3.7
October	10.22	0.86	2.94	0.1	1.2	1.8

Attachment D

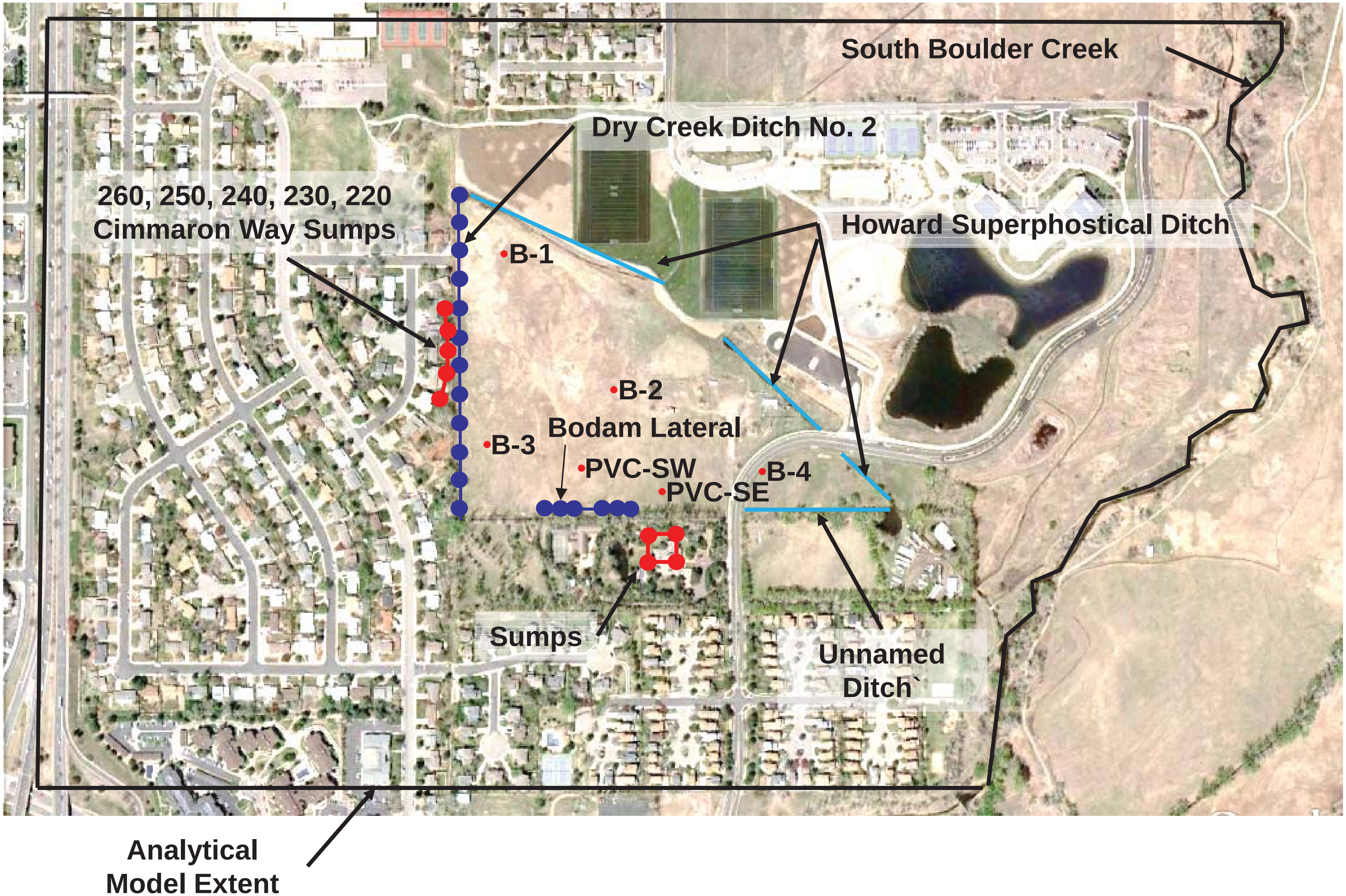
Table B-1, Appendix B, 2012 Groundwater Recharge Evaluation

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



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

FIGURE B-1
ANALYTICAL ELEMENT MODEL EXTENT & FEATURES

PREPARED FOR:
BOULDER CREEK COMMONS, LLC.

Attachment E

Email from Jeff McWhirter to COB Staff, Feb 7, 2013

Scott Parker

From: Schum, Heidi [SchumH@bouldercolorado.gov]
Sent: Tuesday, February 12, 2013 5:00 PM
To: Scott Parker
Subject: FW: Errors in Hogan-Pancost report
Attachments: hplaterals.pdf

Hi Scott,

I just received some additional information on one of the questions I sent to you late last week. Please keep the below information in mind when you look through the question I sent you.

Thanks, and let me know if you have any questions.

Heidi

Heidi Schum, P.E.
City of Boulder
Public Works
Development Review Manager
303-441-4276
schumh@bouldercolorado.gov

From: Knapp, Katie
Sent: Tuesday, February 12, 2013 4:51 PM
To: Schum, Heidi; Kuhna, Scott
Subject: FW: Errors in Hogan-Pancost report

From: Leslie Ewy [mailto:lewy@thesanitasgroup.com]
Sent: Tuesday, February 12, 2013 4:16 PM
To: Knapp, Katie
Cc: David Johnson; Terry Fairbanks; wniccoli@telesto-inc.com; mike@mboyers.com
Subject: FW: Errors in Hogan-Pancost report

Katie,

We received the following email chain from Jeff McWhirter. The initial email, on which you were included, was not received by Terry Fairbanks as he is an independent contractor and is no longer employed by Telesto.

The Annexation/Initial Zoning and Site Review applications currently under consideration for approval by the City are based on the **October 2011** "*City of Boulder Wetland Delineation Report for the Boulder Creek Commons Property*" prepared by Western Ecological Resource, Inc. The 2011 study presents the delineation of the wetlands as of 2011 and is based on site information monitored or observed in 2011.

Mr. McWhirter cites an old and outdated report which was based on observations made nearly 5 years ago. For the record, the conversion error noted by Mr. McWhirter for the flows of the adjacent irrigation laterals do not change the wetland delineations presented in the older report. The irrigation flows were provided as supplemental information documenting that the irrigation lateral was flowing during the field observations made on the Boulder Creek Commons property.

Sincerely,
Leslie

Leslie R. Ewy, PE
Principal | General Manager
Civil Engineer
LEED AP ND *and* BD+C

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From: Jeff McWhirter [mailto:jeff.mcwhirter@gmail.com]
Sent: Tuesday, February 12, 2013 5:56 AM
To: David@westerneco.com; Rea@westerneco.com; Heather@westerneco.com; Kyle@westerneco.com; jeff rifkin
Subject: Errors in Hogan-Pancost report

Dear Sirs,

I am writing in regards to a number of serious errors you have published in the May 2010 Hogan-Pancost Groundwater Hydrology Monitoring & Wetland Delineation Report. My apologies, I sent the below message to Terry Fairbanks at Telesto last week but did not include your firm, the authors of the report.

As you can see in the below message there are a number of errors including a gross miscalculation of the irrigation ditch flows in the area and a lack of understanding of the irrigation hydrology. Your report has been part of the public record for almost 3 years and will be used as part of the upcoming City of Boulder Site and Annexation review.

Seeing orders of magnitude errors in such an important report cause myself and my neighbors who have had numerous basement flooding problems a great deal of concern. These errors may have given the developer, and the City of Boulder staff, Planning Board and Council an incorrect understanding of the area irrigation hydrology and of the scope and extent of possible groundwater problems. Furthermore, these errors may have led your firm to incorrect conclusions regarding the nature of the wetlands on the site.

These errors need to be corrected before the upcoming Site Review. Given the tight time frame on this our group would appreciate a prompt response.

Thank you for your time,
Jeff McWhirter
President, Southeast Boulder Neighborhoods Association (SEBNA)

---------- Forwarded message ----------
From: **Jeff McWhirter** <jeff.mcwhirter@gmail.com>
Date: Thu, Feb 7, 2013 at 4:56 AM
Subject: ditch flow calculation errors
To: tfairbanks@telesto-inc.com, "Knapp, Katie" <KnappK@bouldercolorado.gov>

Mr Fairbanks,

I am one of the Hogan-Pancost neighbors. I'm not sure if we have met in the past and I didn't get a chance to meet with you at the community meeting last week.

I am writing to inform you that I have recently discovered a very large error in the groundwater reports that needs to be addressed. In Appendix A of the May 2010 Groundwater Hydrology Monitoring & Wetland Delineation Report ditch flow measurements are reported for the west and east laterals. Unfortunately when converting from cubic feet/second to gallons/minute a conversion error occurred.

The conversion factor of 0.13368 is applied incorrectly. Instead of dividing by the conversion factor the CFS is multiplied by the conversion factor. In other words there are 7.5 gallons per cubic foot, not 1/7.5 gallons.

The following incorrect calculations are given in the Appendix:

	East wier	West wier
CFS:	1.6786	1.0081
G/second:	0.2244	0.1348
G/day:	19388.16	11646.72

The correct values should be:

G/second:	12.55	7.54
G/day:	1084912	651554

The correct value is 56 times greater than the given value.

Also, in the above report as well as in the 2 groundwater reports an important feature of the irrigation hydrology on the Bodam property is not noted. As seen in the attached PDF there is a junction box on the lateral at the southeast corner of the property. A 15 inch pipe diverts considerable flow to the northwest to feed the decorative pond. This flow is not noted in any of the reports and is at least the same amount of flow that was measured along the west lateral. In the wetlands report the pond is described as being fed by the lateral from the north. This is incorrect. The pond is fed by the lateral branch from the south and the pond's outlet runs north.

Furthermore, as seen in the PDF, the intent of the Bodam irrigation is to recharge the groundwater. As noted in the wetlands report the water is diverted into a storage well on the west side of the property specifically for recharge purposes. While there may be a small amount of water that "spills over a portion of the ditch lining and recharges the ground water system" the majority of the lateral flow is diverted into the storage well and pond for recharge purposes by design.

With the conversion error corrected and taking into account the pond lateral there is at least 900 GPM of irrigation water being brought onto the property. This value is probably on the low side as the irrigation has changed and the east lateral no longer flows. This is more than 2 orders of magnitude difference from the 6.2 GPM that is given in the 2012 GW report.

Dr McCurry is doing a thorough review of these new findings as well as of the 2012 groundwater report. But, I wanted to give you a heads up so you don't get blindsided by these errors. The errors need to be corrected before the upcoming Site Review.

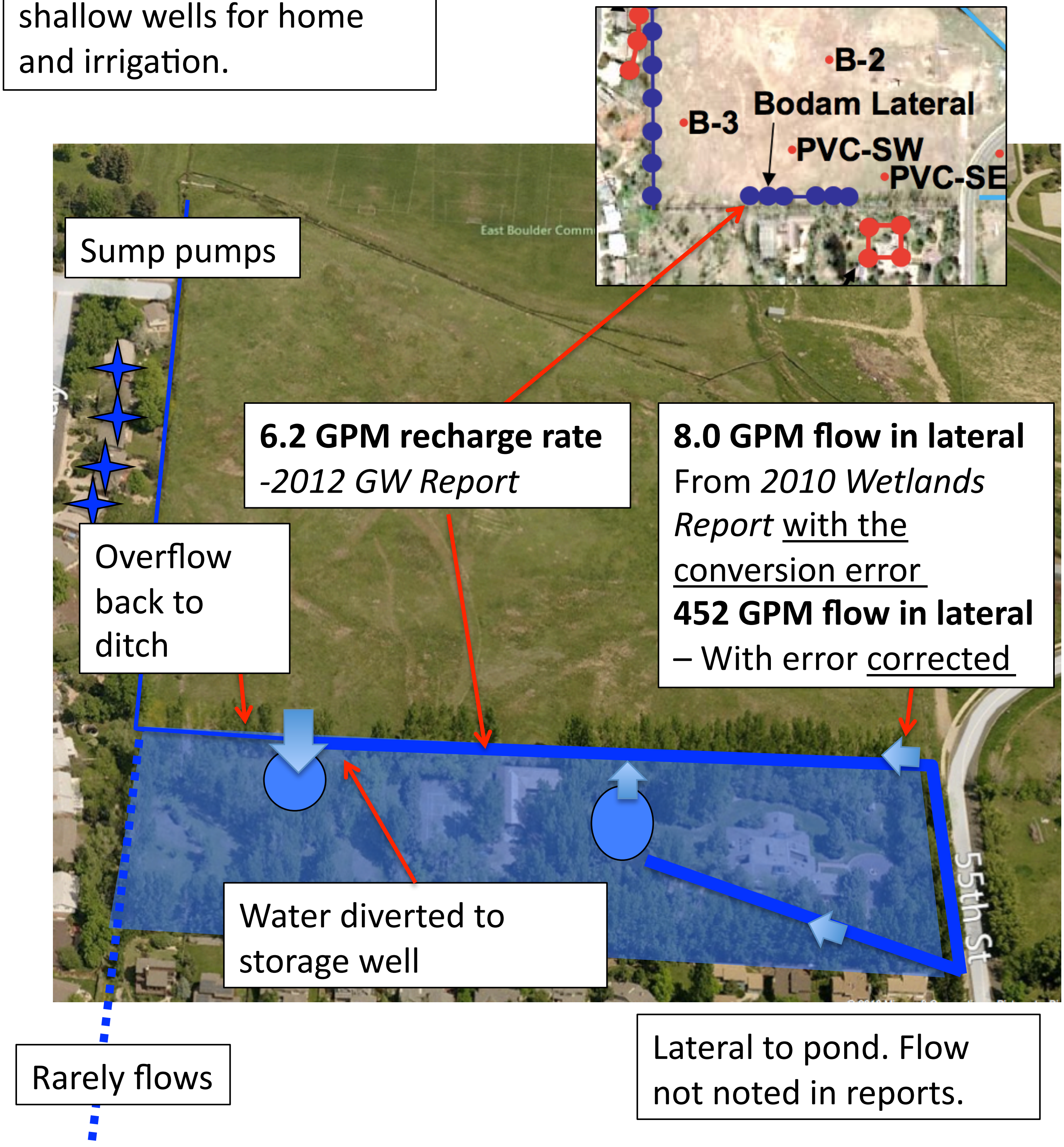
If you have any questions please feel free to contact myself or Dr McCurry mccurry@comcast.net

Ms Knapp - could you please forward this information to the Andersen 4th party reviewer.

-Jeff

Irrigation water is brought in specifically to recharge the groundwater through the pond and storage well. The property owner has shallow wells for home and irrigation.

"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".
-2012 Groundwater Report



Attachment F

“The Impacts of Urbanization on Groundwater Systems and Recharge” by John M. Sharp, Jr.

The impacts of urbanization on groundwater systems and recharge

John M. SHARP, Jr.

Abstract: Urbanization is a major geomorphic process affecting both surface and groundwater systems. The development of cities inevitably increases paved surfaces and roofs (termed impervious cover) and storm drains. Installation of a network of subsurface structures, including utility systems, is another necessary aspect of modern cities. Urbanization alters topography and natural vegetation, stream flows and flooding characteristics, temperatures both above and below the land surface, and water quality of surface streams and groundwater. Major physical changes to the groundwater system include changes in water table elevation; a dramatically altered permeability field created by construction and utility system emplacement; and altered groundwater recharge. Subsurface permeabilities may increase by orders of magnitude in certain preferred zones, which makes prediction and remediation of subsurface contaminants difficult. Groundwater recharge commonly increases because of: 1) leakage from water distributions systems, sewer lines, detention ponds, and storm drains; 2) over irrigation of lawns, gardens, and parks; 3) artificial recharge; 4) reduced evapotranspiration and 5) infiltration through "impervious" cover. This, coupled with pumping of shallow groundwater, controls water table fluctuations. The impacts of urbanization on groundwater systems are predictable and should be considered in urban planning from geotechnical, environmental, and water resources perspectives.

Keywords: urbanization, groundwater, recharge, permeability.

Riassunto: *L'urbanizzazione è il maggiore processo geomorfico che interessa sia il sistema delle acque superficiali che quello delle acque sotterranee. Lo sviluppo delle città aumenta inevitabilmente le aree impermeabili come le superfici pavimentate, i tetti (definiti una copertura impermeabile) ed i canali di deflusso. L'installazione di una rete di strutture al di sotto della superficie, incluso i sistemi di servizio pubblico (distribuzione e canalizzazione dei reflui) è un altro aspetto delle città moderne. L'urbanizzazione altera la topografia e la vegetazione naturale, il flusso delle acque superficiali e il comportamento degli eventi di piena, le temperature sia sopra e sotto la superficie del terreno, e la qualità delle acque dei fiumi e delle acque di falda.*
I principali cambiamenti fisici nel sistema delle acque sotterranee includono le variazioni di quota della superficie freatica; la drammatica alterazione della permeabilità creata dalla costruzione e dal collocamento del sistema delle infrastrutture; l'alterazione della ricarica della falda. La permeabilità sotterranea può aumentare di ordini di grandezza in certe zone preferite, ciò rende difficile la previsione e la bonifica dei contaminanti nel sottosuolo. La ricarica della falda generalmente si incrementa a causa di 1) perdite dai sistemi di distribuzione dell'acqua, delle reti fognarie, dei bacini di immagazzinamento, e dai canali di deflusso; 2) eccessiva irrigazione dei prati, giardini e parchi; 3) ricarica artificiale; 4) riduzione di evapotraspirazione e 5) infiltrazione attraverso le coperture "impermeabili". Questo, associato al pompaggio delle acque sotterranee poco profonde, controlla le fluttuazioni della superficie freatica. Gli impatti dell'urbanizzazione sul sistema delle acque sotterranee sono prevedibili e dovrebbero essere considerati nella pianificazione urbana dal punto di vista geotecnico, ambientale e delle risorse idriche.

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Received: 23 may 2010 / Accepted: 07 june 2010
Published online: 30 june 2010

Introduction

Mankind is the major geomorphic agent that affects the Earth's land surfaces (Sherlock, 1922; Underwood, 2001) and, perhaps second only to agriculture, urbanization is the major process now affecting the land. Over 50% of the Earth's population now lives in cities and it is estimated that by 2025 this will increase to over 67% (Ramsey, 2003). Megacities and urban sprawl cover large areas of all continents except Antarctica. The conversion of natural, agricultural, and other low-population density lands to cities or urban areas changes to the hydrology of the area. Below I consider these changes as they affect the groundwater systems and, in particular, their physical aspects and water resources implications. The effects of urbanization on flooding have been well documented for over 40 years (Leopold, 1968). This is attributed to increasing impervious cover and storm drains that channel precipitation off roads, roofs, and parking lots to streams. "Impervious" cover is a major index or urbanization areas and is considered the most pervasive, relevant characteristic leading to hydrologic impacts (e.g., Arnold and Gibbons 1996). Urban hydrologic analysis and design has commonly only consisted of quantifying and planning for the larger peak flows associated with floods in an urban setting. Higher flood peaks, stream flashiness, and, in some cases,

 DOI 10.4409/Am-004-10-0008

runoff volumes are the results of urbanization, but other hydrologic consequences include changes in baseflow (often mistakenly assumed to decrease); increased stream loads of nutrients, salts, heavy metals, and sediments; and changes to urban stream temperature patterns (Moglen, 2009). In addition, it has been documented that urbanization can alter the local and, perhaps, the regional climate.

However, groundwater systems in urban areas are also impacted significantly, and these impacts can have important consequences for human activities and the environment. Because usually groundwater is out of sight, it is sometimes out of mind, but the impacts of urbanization on groundwater systems must be considered in land-use planning, construction, or in regards to water resources to make future urban areas sustainable. Urban groundwater systems remain an under-appreciated and under-underutilized urban resource (Sharp, 1997).

General hydrogeological effects of urbanization include altered topography and vegetation, increasing shallow groundwater temperatures, changes to water table elevations, and a multitude of changes associated with construction and pumping, and pollution of groundwaters and surface waters. The last topic has an extensive literature, but is not the subject of this study, but the physical alterations to the hydrogeological system need to be considered in remediation and water management. This paper focuses primarily on the imposition and effects of a highly altered shallow permeability field and on altered, generally increasing groundwater recharge. However, these effects are all interrelated.

General hydrogeologic effects

Altered topography

Urbanization tends to level off the landscape for ease of construction and for roadway design. Over time, low-lying areas are filled in and elevated areas lowered. In very old cities, younger construction cover successively older city structures. This commonly leads to burial of surface streams, which may be covered, filled-in, converted into storm sewers, or just forgotten. Case histories include London, UK (Barton, 1962), Washington D.C., USA (Williams, 1977), and Minneapolis-St. Paul, Minnesota, USA (Brick, 2009). However, the high-permeability alluvial strata often remain buried beneath streets and buildings. These will often be in the form of lenses or channels that make accurate predictions of groundwater flow and solute transport difficult.

Altered vegetation

Changes in the rates and distribution of evapotranspiration can alter recharge and groundwater flow directions. Clearly, impervious cover will decrease and may even eliminate transpiration by native vegetation. Alternatively, especially in desert cities, irrigation of lawns and gardens may increase transpiration, as can the introduction of non-native vegetation that may include phreatophytes, such as tamarisk and eucalyptus. Finally, over-watering of lawns, playing fields, and gardens may lead to irrigation return flows that increase groundwater recharge as, for example, in Lethbridge, Canada (Berg et al., 1996) and Austin, Texas, USA (Garcia-Fresca, 2004; Garcia-Fresca and Sharp, 2005).

Groundwater temperatures

The urban heat island effect is well documented. Urban areas are hotter than adjoining rural areas. The annual mean air temperature of a city with 1 million people can average (1–3°C warmer than its surroundings and in the evenings this difference can be even greater. The U.S Environmental Protection Agency maintains a website on the Heat Island Effect. Groundwater is also affected; shallow groundwater temperatures increases, which can affect water quality and groundwater dependent ecosystems. Examples include Tokyo, Japan (Taniguchi et al., 1999; 2001) and Minneapolis/St.Paul, Minnesota, USA (Taylor and Stefan, 2009).

Changing water table elevations

Water tables can either fall or rise (Simpson, 1994; George, 1992; Whitesides et al., 1983) with urbanization. Groundwater extraction in the urban area can either increase or decrease with time as imported waters are introduced, as surface water systems replace local groundwater resources, as surface water systems decline as in droughts, with reservoir-induced changes in river stages, or with the implementation of new technologies, such as desalination or ASR (aquifer storage and recovery). Except in the case of areas with relatively deep water tables, ASR effects can be significant but are presumably temporary with the possible exception of where water tables may rise until the fluctuating nature of a functional ASR commences.

Conversion from using local aquifer systems to large surface water systems or imported water can cause rising water tables, which can, in turn, can cause engineering problems (flooding of basements, tunnels, and utility systems; mass wasting, etc.) and new boggy areas. Wet soils as in Wagga Wagga, Australia, can cause foundations problems (Cooke et al., 2001; Young, 2008), especially when the groundwater is brackish or saline. On the other hand, continued use of groundwater can cause falling water tables, which can, in turn, cause saltwater intrusion, subsidence, or the decline of groundwater dependent ecosystems, including springs.

Construction and pumping effects

Various construction activities and designs affect groundwater. If the water-table is close to the surface or if deep tunnels or subways are being built, dewatering or depressurization may be required that can lower water tables for considerable periods of time (Powers et al., 2007). In some construction the dewatering must be essentially permanent. For instance, sump pumps may be required and this may depress water tables, induce leakage from utility lines, change groundwater flow patterns, and lower natural baseflows to streams and wetland areas, although the water being pumped must be disposed and typically to some stream. If construction occurred in an historical period of low water tables (e.g., in a time when groundwater supplied the city and was eventually replaced by imported surface waters or in a time of extended drought), then the dewatering occur post-construction.

Pumping for production of groundwater or for remediation of subsurface contamination can create similar effects. In certain cases, the construction may form subsurface dams that can locally alter the groundwater flow field, such as in Hong Kong, China (Jiao et al., 2006). If subsidence is the result of pumping, this can cause alteration of surface stream gradients and flood zones, breakage of underground utility systems, and inundation near coastal areas. Examples (e.g., Johnson, 1991) where these effects have been significant include Houston, Texas, USA; Venice, Italy; and Calcutta, India.

Altered permeability field

The network (or reticulation) of water mains, sewer lines, electrical and telephone conduits, storm drains/sewers, subways, and other subsurface systems is one of the major alterations to the hydrogeology of an urban area. Although urban soils tend to be come less permeable because of compaction (Pitt et al., 2002), fill near buildings and over utility trenches (Figure 1) is more permeable. In the latter case, permeability commonly increases by several orders of magnitude.

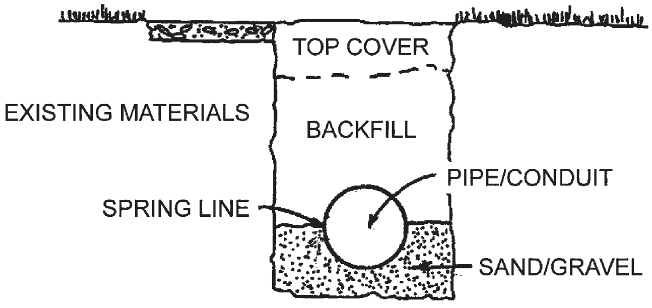


Fig. 1: *Elements of a utility trench. Typically well-sorted, high permeability sand or gravel is emplaced up to the spring line. Back fill is then placed and sometimes tamped or compacted. In some cases, there may be a top cover of soil, gravel, or other materials. Figure 2 shows one data set of how permeabilities compare in the backfill/top cover to the natural existing soils.*

Figure 2 shows data on hydraulic conductivities of utility trench fill compared to undisturbed soils developed on alluvium and terrace deposits. Similar trends are found where the trenches are excavated in carbonate rock materials in Austin, Texas, USA (Sharp et al., 2003). Further, if the conduit or pipe is breached as commonly happens in storm drains, sewers, and electrical/telephone conduits, permeabilities can be much greater in these pipes/conduits than in the fill. In older cities, abandoned utility lines and pipes, old trench fills, remnants of older structures and construction, and buried alluvial strata remain after new construction to create a very complicated secondary permeability field.

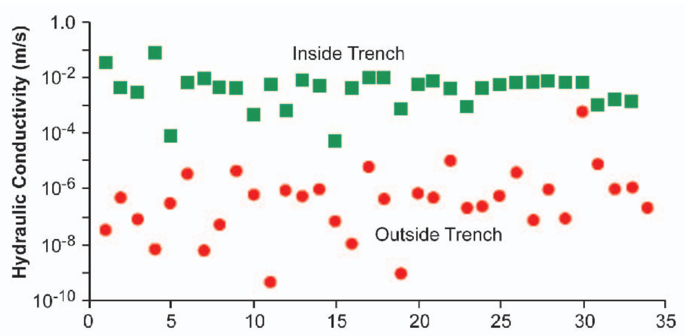


Fig. 2: *Hydraulic conductivities of soils developed in Quaternary terrace and alluvial deposits and fill materials in utility trenches in the same soils in Austin, Texas, USA. Modified from Sharp et al. (2003).*

This double- or triple-permeability system has been considered analogous to a karstic system (Sharp and Garcia-Fresca, 2003). In fact, the secondary porosity of the urban underground is roughly equivalent to that of a karstic aquifer. For instance, secondary porosity under Quebec City, Canada in a crystalline bedrock environment is essentially that estimated for the rocks of Mammoth Cave National Park, Kentucky, USA (Garcia-Fresca, 2004; Worthington, 2003; Boivin, 1990). The rate of increase of this urban secondary porosity and permeability, however, occurs in a span of only decades or perhaps a few centuries. Whereas the natural development of secondary porosity and permeability normally occurs over much longer time spans of millennia to millions of years.

This highly altered permeability field can lead to the following:

- Altered groundwater flow systems.
- Maintenance of stream baseflows and spring flows during times of limited rainfall or, alternatively.
- Reduced increased spring flows, if flow is diverted from spring orifices.
- Diversion of groundwater to different streams or catchments.
- Artificial recharge caused by leakage of water, sewage, and storm waters along the utility lines.
- Difficulty in predicting, modeling, and remediating subsurface contamination.
- Creation of multiple contaminant plumes that can migrate in different directions than might be predicted from standard analyses.
- Utility trenches and mains/sewers serving as "French drains" to limit rising water tables.

Krothe (2002) and Sharp et al. (2003) demonstrate that utility trench systems with 2-4 orders of magnitude greater permeability deflect groundwater flow patterns and that multiple contaminant plumes can arise from a single point source. Clearly, prediction of contaminant migration pathways becomes problematic under such conditions. In addition, in these high permeability zones can serve as drain pathways. For instance, storm drains in Austin, USA, are observed to flow in periods of no precipitation. If the utility trench systems are above the water table, they can serve as recharge line sources, which is discussed below.

The assessment of how urban development changes the groundwater flow system and permeability fields is site specific. It depends upon the hydrogeology of strata underlying the city, the details of urban development, the use of local aquifers for water supply, and alterations to the rates and distribution of recharge.

Groundwater recharge

Although it is commonly stated, that groundwater recharge is reduced with urbanization because of the increase in impervious cover, the reverse is the more common condition – urbanization increases ground water recharge. In some cases, groundwater dependent ecosystems are augmented by increased urban recharge (Sharp et al., 2009). Asquith and Roussel (2007), Drouin-Brisebois (2002), and Scheuler (1994) all indicate little difference in stream baseflows between urbanized and undeveloped watersheds. Figure 3 shows a compilation of data from cities around the Earth showing comparing recharge before and after urbanization. In all cases, except Birmingham, UK, increases are estimated. The increases in groundwater recharge are most notable in more arid zones and cities with that may not be able to maintain their utility system and roadway infrastructure. Of course, it should be noted that the recharge and changes to recharge in a city also vary spatially. It may be decreased in one portion of an urban area because of increases in impervious cover and soil compaction and increased in other areas because of a number of other factors. These include leakage from water mains, sewer lines, and storm drain systems; the effects of storm water detention ponds and artificial recharge; irrigation return flow from lawns, gardens, and parks; losing streams; and the fact that impervious cover is not all impervious.

Leakage from water mains estimated to range from lows approaching 5% to over 60 % of water pumped from the surface reservoirs or groundwater (Garcia-Fresca and Sharp, 2005). The lowest rates are for special low-pressure, newly constructed water delivery systems, but rates under 10% can be achieved with good, continual

DOI 10.4409/Am-004-10-0008

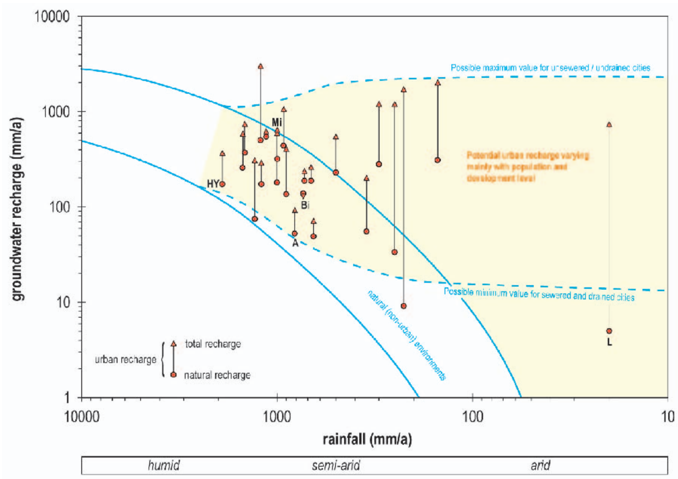


Fig. 3: *Estimates of groundwater recharge in cities prior to (circle) and after urbanization (triangle) (modified from Garcia-Fresca and Sharp, 2005, and Foster, 1996). In all estimates, only Birmingham, UK (Bi in the figure shows a decrease as documented by Knipe et al., 1993). Added to Garcia-Fresca and Sharp (2005) are Austin, USA (A) and Milan, Italy (Mi). Hat Yai, Thailand (HY) and Lima, Peru (L) are from Foster (1996).*

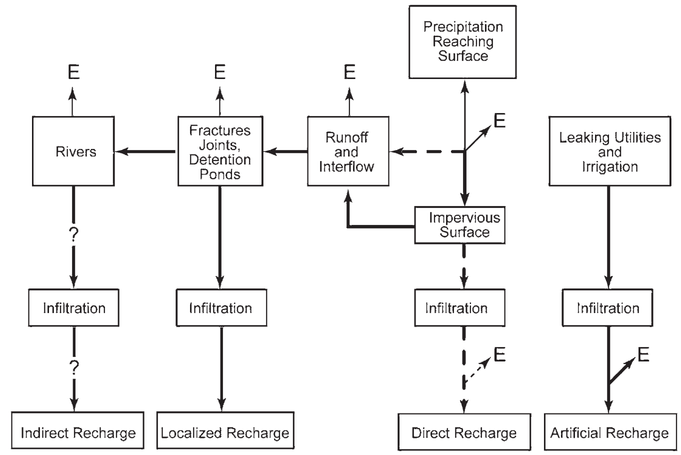


Fig. 4: *Sources of recharge in an urban area. Modified from Wiles and Sharp, (2008).*

maintenance. However, general rates in developed countries are in the range of 16 to 25% (Lerner, 1997b; Thornton, 2002). In the absence of field data, leakage rates of water from sewer lines in the USA is estimated very conservatively at 6% and from storm drains at 5% for high flow rates and 10% at low flows rates (Rieckermann et al., 2003; Thornton, 2002; Wurbs and James, 2002). In many urban areas, storm water retention/detention ponds are installed to alleviate the effects of floods after heavy rains and for water quality protection. These ponds are shown to be significant point sources of recharge and, as stated by Milczarek et al. (2004), "If maximizing GW recharge…is desired, the design and siting of stormwater basins …merits…consideration". Artificial recharge basins have been to increase recharge significantly and lower overall evapotranspiration on Long Island New York, USA (Scorca, 1996). Stormwater retention/detention ponds can be designed to serve in this capacity.

While the effects of overwatering of lawns, gardens, and parks are relatively well understood and accepted, the competing effects of "impervious cover" are not. Figure 4 shows sources of recharge in an urban area. There are 4 styles of recharge (Wiles and Sharp, 2008; Lerner, 1997a) – direct, indirect, artificial, and localized.

Direct recharge occurs from precipitation reaching the land surface. In urban areas this is expected to decrease because of runoff from roofs and paved surfaces diverting precipitation. This also occurs if the soils are less permeable because of compaction. The diverted water generally flows onto streets and storm drains where present. The net effect of impervious cover and storm drain is increasing flood peaks and decreasing flood lag times as has been demonstrated repeatedly since Leopold (1968). However, the impervious cover also reduces evapotranspiration losses and, as is indicated below, not all precipitation reaching roadways and parking lots becomes surface runoff.

Indirect recharge includes water that flows over the land surface or in streams that recharges through a mappable recharge feature. The most notable example is that of losing streams in karstic areas. For example, over 50% of the water recharging the Edwards Aquifer in Austin, Texas, USA is indirect recharge (Hauwert, 2009). If urbanization increases stream flows to losing streams, this can increase recharge.

Artificial recharge includes leakage from water mains, sewers, storm drains, and detention ponds as discussed above. It also includes irrigation return flows from overwatering and other means of artificial recharge, such as soakways, injection wells, drain fields, diversion of surface waters into sinkholes, etc. If the shallow groundwater system is not being utilized, artificial recharge is expected to raise the water table. Austin, Texas, uses water from the Colorado River, which has different chemical and isotopic signatures than groundwater that has recharged through the Cretaceous carbonates that underlie the city. As streams become more urbanized as indexed by impervious cover percentages, the chemical and Sr-isotopic signatures evolve match those of the River rather than those of the Cretaceous bedrock (Figure 5). During low flow conditions in completely urbanized reaches of the stream, it appears that nearly all stream flow originated from treated water that once flowed through the city's water distribution system (Sharp et al., 2006; Christian et al., in preparation).

Localized recharge occurs where water runs a short distance from the point of precipitation impact to where it intersects fractures or

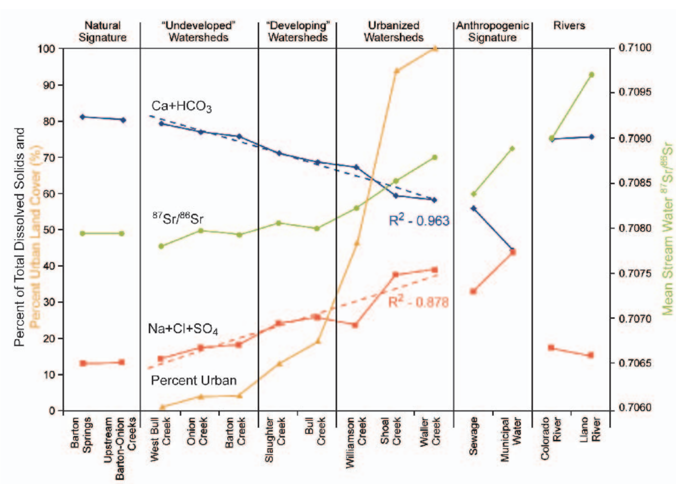


Fig. 5: *Chemical and Sr-isotopic data for streams in the Austin, Texas, USA (Christian et al., in preparation). As streams become more urbanized, their chemical and isotopic signatures approach those found in Austin tap water. Leakage (artificial recharge) from municipal water (water main leakage and over irrigation of lawns, gardens, and parks) and from sewage lines can account for this trend.*

joints in the paved surfaces, which are secondary permeability features (Wiles and Sharp, 2008). Localized recharge can also be significant and DeVries and Simmers (2002) infer that it may be the dominant recharge component in arid or semi-arid zones. Wiles and Sharp report the measurement of permeability of these secondary features in Austin, Texas, USA. They conclude by upscaling over pavement area that approximately 20% of the mean annual precipitation could become localized recharge (through "impervious" cover). This number is consistent with estimates of recharge obtained from empirical studies of sewer systems and roadway design (Wiles and Sharp, 2008, Figure 2 therein).

Although recharge rates vary spatially and temporally so that it may decrease in some areas and increase in other areas of a city because of the varying intensity of factors discussed above, recharge generally is expected to increase with urbanization for the urban area as a whole.

Conclusions

Urbanization causes changes to the land surface by altering topography and vegetation, increasing shallow groundwater temperatures, raising or lowering water tables, and extraction of groundwater during or after construction and as a water resource that can cause subsidence and its accompanying effect. These all affect the shallow groundwater systems.

Two general and important effects are:

1) The alteration of the permeability field by construction, particularly high permeability utility systems and the trenches dug to accommodate their emplacement. This alters groundwater flow paths and makes contaminant remediation difficult.

2) Changes to groundwater recharge. Recharge rates may vary spatially and temporally but recharge generally increases within urban areas.

Alterations to urban hydrogeology should be considered in planning urban design, future water resources needs, and protection of groundwater dependent ecosystems.

Acknowledgements: This research was partially supported by the Geology Foundation of the John A. and Katherine G. Jackson School of Geosciences at The University of Texas through the Dave P. Carlton Professorship and by the Geological Society of America. Earlier funding by the National Science Foundation (2000) and the AT&T Foundation (2000-2003) supported the pilot studies for this research. I appreciate Lance Christian, Jay Banner, and Larry Mack for providing Figure 5 from their forthcoming paper, which was funded by NSF Hydrologic Sciences grant EAR-0711339 to Banner and the Geology Foundation of The University of Texas.

References

Arnold, C.L., Jr., and Gibbons, C.J., 1996, Impervious surface coverage: The emergence of a key environmental indicator: Journal of the American Planning Association., v. 62(2), p. 243–258.

Asquith, W.H., and Roussel, M.C., 2007, An initial-abstraction constant-loss model for unit hydrograph modeling for applicable watersheds in Texas: U.S Geological Survey Scientific Investigations Report 2007-5243, 82p.

Barton, N.J., 1962, The Lost Rivers of London: Historical Publishers. Ltd., New Barnet, Herts., United Kingdom, 148p.

Berg, A.A., Bryne, J.M. and Rogerson, R., 1996, An urban water balance study, Lethbridge, Alberta: Estimation of urban lawn overwatering and potential effects on local water tables: Canadian Water Resources Journal, v. 21(2), p. 355-366.

Boivin, D.J., 1990, Underground space use and planning in the Quebec City area: Tunnelling and Underground Space Technology, v. 5, no 1-2, p, 69-83.

Brick, G., 2009, Subterranean Twin Cities: University of Minnesota Press, Minneapolis, MN, 223p.

Christian, L.N., Banner, J.L., and Mack, L.E., in preparation, Sr isotopes as tracers of anthropogenic influences on stream water in the Austin, Texas, area.

Cook, P.G., Stauffacher, M., Therrien, R., Halihan, T., Richardson, P., Williams, R.M., and Bradford, A., 2001, Groundwater recharge and discharge in a saline, urban catchment; Wagga Wagga, New South Wales: CSIRO Land and Water Online Report 01/39.

De Vries, J.J., and Simmers, I., 2002, Groundwater recharge: An overview of processes and challenges: Hydrogeology Journal, v. 10. p. 5-17.

Drouin-Brisebois, I.A., 2002, Predicting Local and Regional Effects of Urbanisation on the Subsurface Water Balance of North Pickering Agricultural Lands: unpublished M.S. thesis, Univ. Toronto, Toronto, Ontario, Canada, 90p.

Foster, S.S.D., 1996, Groundwater quality concerns in rapidly developing countries: in Hydrology and Hydrogeology of Urbanizing Areas (Guswa, J.H., et al., eds.), American institute of Hydrology, St. Paul, M, p. MIU12, MIU26.

Garcia-Fresca, Beatriz, 2004, Urban Effects on Groundwater Recharge in Austin, Texas: unpublished M.S thesis, University of Texas, Austin, TX, 173p

Garcia-Fresca, B., and Sharp, J.M., Jr., 2005, Hydrogeologic considerations of urban development – Urban-induced recharge: in Humans as Geologic Agents (Ehlen, J., Haneberg, W.C., and Larson, R.A., eds.) Geol. Soc. America, Reviews in Engineering Geology, v. XVI, p. 123-136.

George, D J. 1992, Rising Groundwater: A Problem of Development in Some Urban Areas of the Middle East: in Geohazards - Natural and Man-made (eds., McCall, G.J.H., Laming, D.J.C., and Scott, S.C.), Chapman and Hall, London, p. 171-182,

Hauwert, N.M., 2009, Groundwater Flow and Recharge Within the Barton Springs Segment of the Edwards Aquifer, Southern Travis and Northern Hays Counties, Texas: unpublished Ph.D. dissertation, University of Texas, Austin, TX, 328p.

Jiao, J., Wang, X.-S., and Nandy, S., 2006, Preliminary assessment of the impacts of deep foundations and land reclamation on groundwater flow in a coastal area in Hong Kong, China: Hydrogeology Journal, v. 14(1-2), p.100-114.

Johnson A.I. (ed.), 1991, Land Subsidence: International Association of Hydrological Sciences, Publication 200, Proceedings of the Fourth International Symposium on Land Subsidence, 690 p.

Knipe, C.V., Lloyd, J.W., Lerner, D.N., and Greswell, R., 1993, Rising groundwater levels in Birmingham and the engineering implications: CIRIA Special Pub, No. 92, 114p.

Krothe, J.N., 2002, Role of Utility Trenches in Redirecting Groundwater Flow: unpublished M.S. thesis, University of Texas, Austin, Texas, 190p.

Leopold, L.B., 1968, Hydrology for urban land planning: a guidebook on the hydrologic effects of urban land use: U.S. Geological Survey Circular 554, 18p.

Lerner, D.N., 1997a, Groundwater recharge: in Geochemical processes, Weathering and Groundwater Recharge in Catchments (Saethe, O.M., and de Caritat, P., eds.), Balkema, Rotterdam, p. 109-150.

 DOI 10.4409/Am-004-10-0008

Lerner, D.N., 1997b, Too much or too little: Recharge in urban areas: in Groundwater in the Urban Environment: Problems, Processes and Management (Chilton, J., ed.), Proceedings of the 27th Congress, International Association of Hydrogeologists, Balkema, Rotterdam, p. 41-47.

Milczarek, M., Harding, J., Goodrich, D., and Levick, L., 2004, Predicting groundwater recharge rates in small urbanized watersheds: Southwest Hydrology, July/August, p. 6-7.

Moglen, G.E., 2009, Hydrology and impervious areas: Journal of Hydrologic Engineering, v. 14, p. 303-304.

Pitt, R., Chen, S.-E., Clark, S., and Ong, C.K., 2002, Urbanization factors affecting infiltration: in Ground Water/Surface Water Interactions, Am. Water Resources Assoc., Summer Specialty Conference, p. 181-186.

Powers, J.P., Corwin, A.B., Schmall, P.C., and Kaeck, W.E., 2007, Construction Dewatering and Groundwater Control (3rd ed.): John Wiley & Sons, Hoboken, NJ, 638p.

Ramsey, M.S., 2003,Mapping the City Landscape From Space: The Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) Urban Environmental Monitoring Program: in Earth Sciences in the City (Heiken, G., Fakundiny, R., and Sutter, J., eds.), Am. Geophysical Union, Washington, DC, Ch. 9, p.337-376.

Rieckermann, J., Kracht, O., and Gujer, W., 2003, How "tight" is our sewer system? Swiss Federal Institute for Environmental Science and Technology: EAWAG News, no. 57, p. 29-31.

Schueler, T.J., 1994, Importance of imperviousness: Watershed Protection Techniques, v.1, p. 100-111.

Scorca, M.P., 1996, Urbanization and recharge in the vicinity of East Meadow Brook, Nassau County, New York: U.S. Geol. Survey Water-Resources Inv. Rpt. 96-4187, 39p.

Sharp, J.M., Jr., 1997, Ground-water supply issues in urban and urbanizing areas: in Groundwater in the Urban Environment: Problems, Processes and Management (Chilton, J., ed.), Proceedings of the 27th Congress, International Association of Hydrogeologists, Balkema, Rotterdam, v. 1, p. 67-74.

Sharp, J.M., Jr., Christian, L.N., Garcia-Fresca, B., Pierce, S.A., and Wiles, T.J., 2006, Changing recharge and hydrogeology in an urbanizing area – example of Austin, Texas, USA: Geo. Soc. America, Abs. with Programs (Ann. Mtg.), v. 38(7), p. 289.

Sharp, J.M., Jr., and Garcia-Fresca, B., 2003, Effects of urbanization of groundwater resources, recharge rates, and flow patterns: Geol. Soc. America, Abs. with Programs (Ann. Mtg.), v. 35(6), p. 158.

Sharp, J.M., Jr., Krothe, J.N, Mather, J. D., Garcia-Fresca, B., and Stewart, C. A., 2003, Effects of Urbanization on Groundwater Systems: in Earth Sciences in the City (Heiken, G., Fakundiny, R., and Sutter, J., eds.), Am. Geophysical Union, Washington, DC, Ch. 9, p.257-278.

Sharp, J.M., Jr., Llado, L.E., and Budge, T.J., 2009, Urbanization-induced trends in spring discharge from a karstic aquifer – Barton Springs, Austin, Texas, USA: in Proceedings, 15th International Congress of Speleology (White, W.B., ed.), Kerrville, TX, v. 2, p. 1211-1216.

Sherlock, R.L., 1922, Man as a Geological Agent: H.F. & G. Witherby, London, 372p.

Simpson, R.W., 1994, Keynote paper. Quantification of processes: in Groundwater Problems in Urban Areas (Wilkinson, W.B., ed.), Thomas Telford, London p. 105-120.

Taniguchi, M., Sakura, Y., and Uchida, Y., 2001, Effects of urbanization, landcover changes and groundwater flow on subsurface temperatures in Japan: in Impact of Human Activity on Groundwater Dynamics (Gehrels, H., et al., eds.), International Association of Hydrological Sciences, Publication 269, p. 143-153.

Taniguchi, M., J. Shimada, T. Tanaka, I. Kayane, Y. Sakura, Y. Shimano, S. Dapaah-Siakwan, and S. Kawashima, 1999, Disturbances of temperature depth profiles due to surface climate change and subsurface water flow: 1. An effect of linear increase in surface temperature caused by global warming and urbanization in the Tokyo Metropolitan Area, Japan: Water Resources Research, v. 35(5), p. 1507-1517.

Taylor, C.A., and Stefan, H.G., 2009, Shallow groundwater temperature response to climate change and urbanization: Journal of Hydrology, v. 375 (3-4), p. 601-612.

Thornton, J., 2002, Water Loss Control Manual: McGraw-Hill, New York, 526 p.

Underwood, J. R., Jr., 2001, Anthropic rocks as a fourth basic class: Environmental and Engineering Geoscience, v. 7, p. 104-110.

Whitesides, D.V., Faust, R.J., and Zettwoch, D.D., 1983, Problems of rising ground-water levels in urban areas with special reference to the Louisville, Kentucky, area: U.S. Geological Survey Water-Resources Investigations Report 83-4233, 26p.

Wiles, T.J., and Sharp, J.M., Jr., 2008, The secondary permeability of impervious cover: Environmental and Engineering Geoscience, v. 14(4), p. 251-265.

Worthington, S.R.H. 2003, A comprehensive strategy for understanding flow in carbonate aquifers: in Speleogenesis and Evolution of Karst Aquifers (Palmer, A.N., Palmer, M.V., and Sasowsky, I.D., eds.), Karst Modeling Special Publication 5, The Karst Waters Institute, Charleston, West Virginia, p. 30-37.

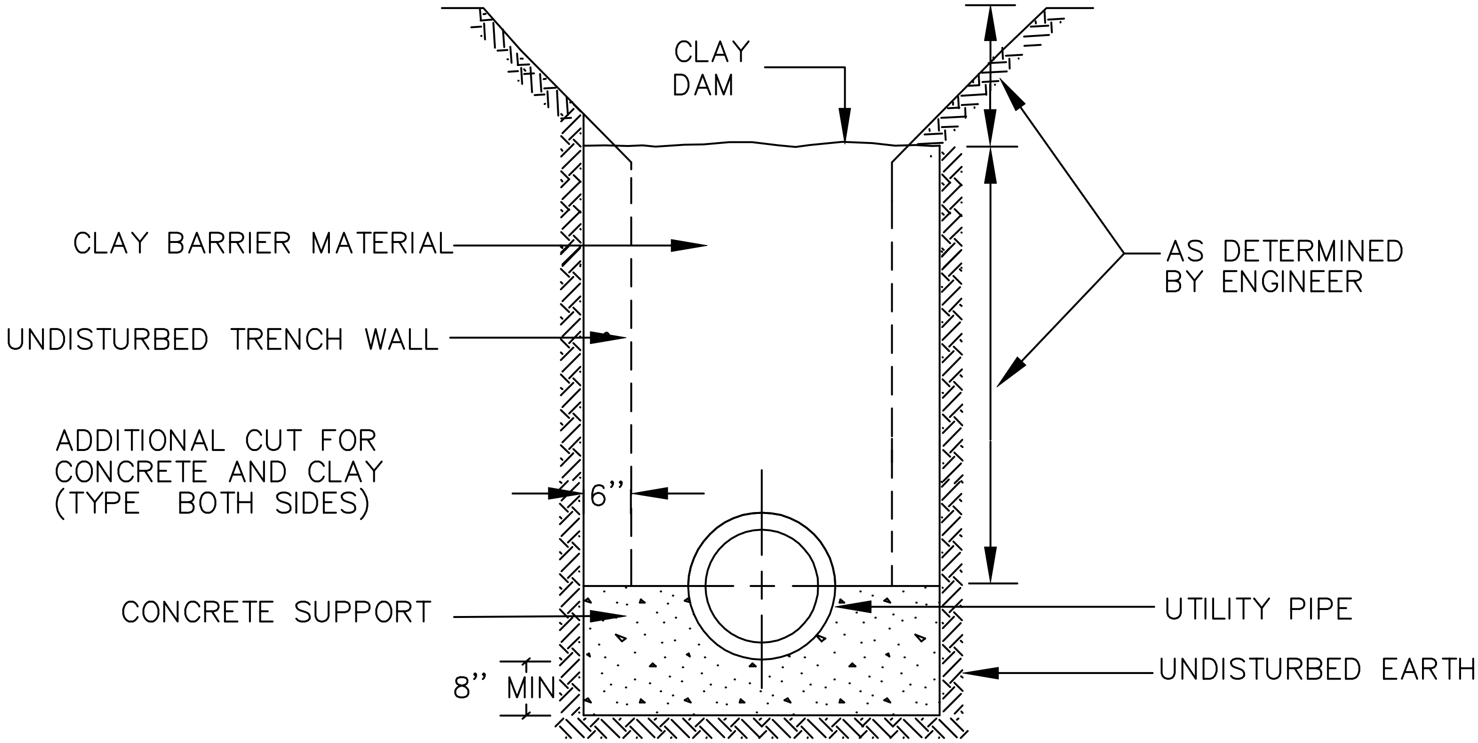
Williams, G.P., 1977, Washington, D.C.'s vanishing springs and waterways: U.S. Geological Survey Circular 752, 19p.

Wurbs, R.A., and James, W.P., 2002, Water Resources Engineering: Prentice Hall, Upper Saddle River, NJ, 828p.

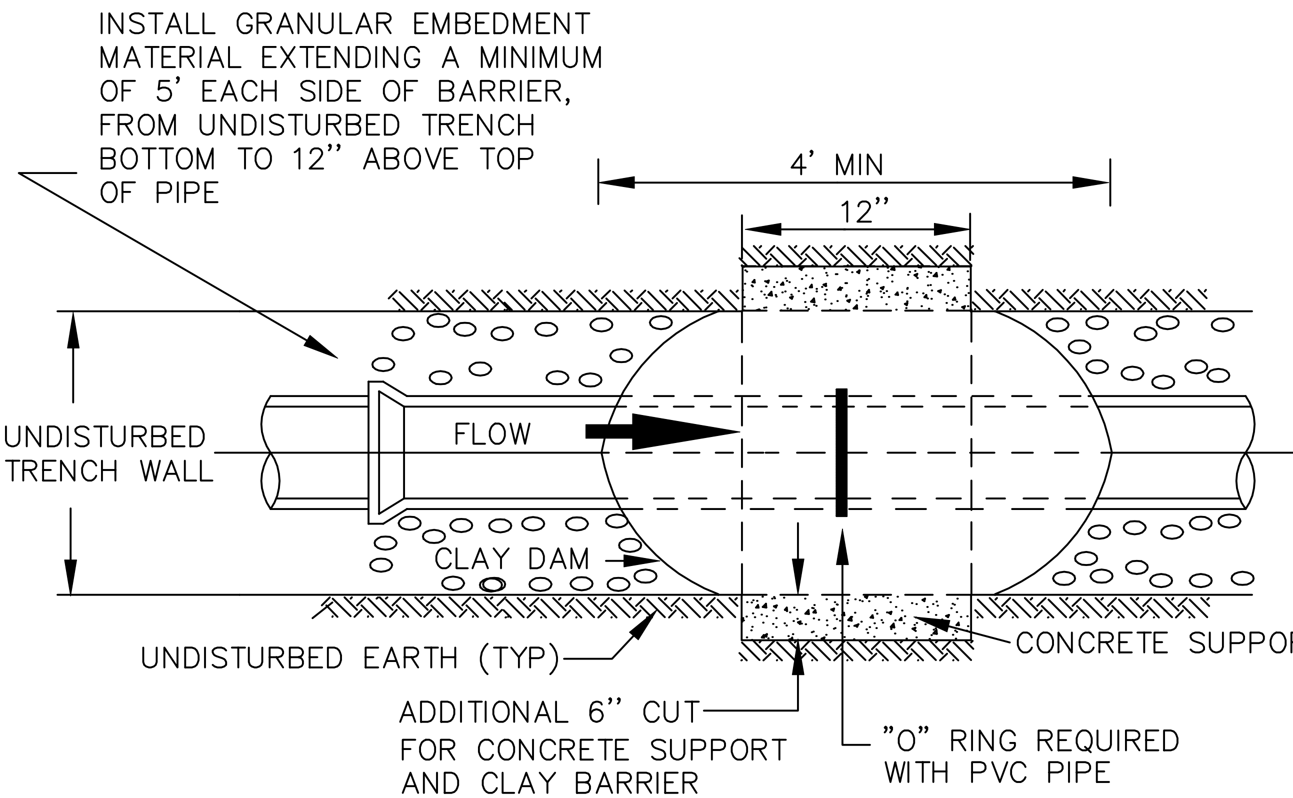
Young, D., 2008, Salt Attack and Rising Damp: A Guide to Salt Damp in Historic and Older Buildings (2nd ed.): Heritage Council of New South Wales, Australia, 79p.

Attachment G

Ground Water Barrier, COB Design and Construction Standards, Drawing No. 4.08



SECTION



PLAN

DRAWN BY: JSH

CHECKED BY: RJH

APPROVED BY:
DIRECTOR OF PUBLIC WORKS

CITY OF BOULDER, COLORADO

GROUND WATER BARRIER

ISSUED: JULY 2, 1998

REVISED: OCT. 17, 2000

DRAWING NO.

4.08

Attachment H

Keewaydin Meadows Street and Utility Plans


KEEWAYDIN MEADOWS
A SUBDIVISION OF A PART OF THE CITY OF BOULDER
COUNTY OF BOULDER, STATE OF COLORADO
AND BEING A PART OF THE W1/2 SE1/4 SECTION 4
TOWNSHIP 1 SOUTH, RANGE 70 WEST, 6TH P.M.
DEDICATION
STREET AND UTILITY PLANS
PREPARED
R. J. GALLAGHER & ASSOCIATES
CONSULTING ENGINEERS
BOULDER, COLORADO
APRIL 1, 1963
SCALE 1"=100'
OUTLOT "A"
TRANSITIONAL ZONING
NOTES
MANHATTAN DRIVE
CIMARRON WAY
IROQUOIS DRIVE
SEMINOLE DRIVE
CHEROKEE WAY
THUNDERBIRD ROAD
CENTERLINE CURVE DATA
SURVEYORS' CERTIFICATE
CLERK AND RECORDERS' CERTIFICATE
PLANNING BOARD CERTIFICATE
MAYORS CERTIFICATE
CLEARED FOR EASEMENTS
MY COMMISSION EXPIRES JANUARY 25, 1966
06798

...ITIONAL ZONING

NOTES

ALL STREET WIDTHS ARE 36' WIDE WITH 18' EACH SIDE OF CENTERLINE EXCEPT FOR 40' BETWEEN CURBS ON MANHATTAN DRIVE FROM ILLINI WAY TO SOUTH BOULDER ROAD

ALL CURB AND GUTTERS AND CURBWALKS ARE TO BE ACCORDING TO CITY OF BOULDER STANDARDS.

ALL SEWER LINES AND MANHOLES ARE 5' SOUTH AND EAST OF STREET CENTERLINES EXCEPT SHOSHONE COURT AND EXCEPT WHEN ENTERING OR ROUNDING CURVED STREETS.

ALL SEWER LINES ON THIS PLAT ARE PROPOSED 8" VITRIFIED CLAY PIPE WITH THE EXCEPTION OF THAT 10" DIAM. SECTION ON SIOUX DR. AND THAT NOTED AS EXISTING.

6" DRAIN TILE IS PROPOSED WITH ALL SANITARY SEWER LINES.

ALL WATER MAINS ARE 10' NORTH AND WEST OF STREET CENTERLINES EXCEPT THAT ON SIOUX DRIVE AND SHOSHONE COURT.

ALL WATER MAINS ON THIS PLAT ARE PROPOSED

ALL WATER MAINS ARE 8" DIAM. ON SIOUX DRIVE, CHEROKEE WAY AND ILLINI WAY.

WATER MAINS ARE 4" DIAM ON SHOSHONE COURT AND BOTH CUL-DE-SACS. THE REMAINING ARE 6" DIAM.

FIRE HYDRANTS = ✣

WATER VALVES = —●—

CONC. VALLEY GUTTERS =