Soccer Field Drainage Improvement

A Case Study in Guangzhou

Yinuo Zhang
Advisor: Michael Walter

Table of Contents

1. Executive Summary

1.1 Purpose

The purpose of this paper is to provide a design recommendation for proper drainage and improvement of the home pitch of Guangzhou Evergrande Football Club, a Chinese football club located in Guangzhou. Given the fact that as a city in the very South of China, Guangzhou is extremely rainy, poor drainage of any recreational field can cause limited usage of the field as well as increase the potential of athletic injury, not to mention the fact that soccer is an intense game. With excessive water, the soccer ball may not be able to move on the ground smoothly and people are easy to fall on the ground running on a slippery ground.

1.2 Design Options and Conclusions

The major design that was used was piping. Land grading, although a common method to improve soccer field drainage in real world practices as well, is not considered in this case. Based on information from sports news, after preliminary on site evaluation, piping is considered by experts hired by the club (Sina sports, 2013). More importantly, based on past experience, land grading is extremely expensive, most likely 10 to 15 times more expensive compared to piping. From a cost effective perspective, which is most likely the most important perspective if both methods deliver similar results, it is pointless to consider land grading.

2. Introduction/Background Information

2.1 Guangzhou Evergrande – the Most Successful Football Club in China and Asia

Figure 1: Group photo of the team

Barring the poor performance of the China national team, Guangzhou Evergrade, as a football club in China, is no doubt a successful one. The sponsor company Guangzhou Evergrande (abbreviated GZE from here on) itself started as a real estate company while doing business in other areas such as spring water. Ever since GZE acquired the used-to-be Guangzhou Football Club in on March 1, 2010, the club was able to demonstrate an astonishing performance and successfully jumped from secondary League to the Chinese Football Association (CFA) Super League, the top league in China. From season 2011-2012 to season 2014-2015, GZE had won five championships of the CFA Super League in a row and two AFC Champions League. During these years, despite numerous top players, two top coaches who had won the World Cup also joined the team – Lippi (Italy, 2006) and Scolari (Brazil,

2002) (Guangzhou Evergrande, 2016) . Given the fact that soccer became professionalized and commercialized late in 1994 in China, it is quite an accomplishment.

2.2 The Creation of the Soccer Pitch – Guangzhou Tianhe Stadium

Tianhe (天河) in Chinese means “river in the sky” by literal translation, which implicates the Milky Way and the Galaxy. Guangzhou Tianhe Stadium was built in 1987. Besides regular soccer matches in a season, it takes the responsibility of hosting other events as well.

Figure 2: Interior view

Figure 3: Exterior view

3. Problem Analysis/ Design Objectives

3.1 Current Drainage System

Guangzhou is a rainy city, and with extent of rain in Guangzhou, the pitch becomes flooded fairly easily. There were several news years ago reporting the pitch being soaked. Pooling of water could lead to potential injury for the players, as it creates uneven ground after the water evaporates or is drained. For professional football players, sprains and strains are the most common lower extremity injuries. Injuries to the upper extremities usually occur from falling on an outstretched arm or from player-to-player contact (Stop Sports Injuries, n.d.)

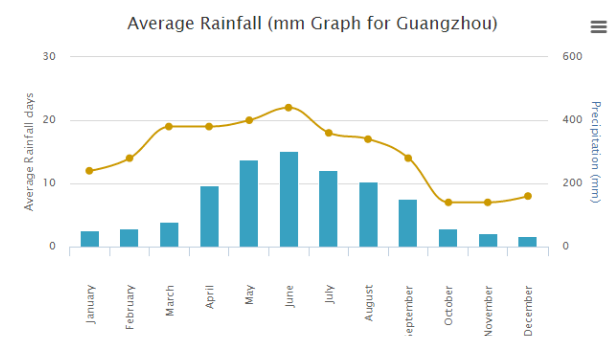

Figure 4: Precipitation scenario in Guangzhou

Figure 5: Soaked soccer field

Figure 5 in this section demonstrates the conditions of the soccer field shortly after a rainy day in Guangzhou. As one can see, the water accumulates so much that the water flies around in the air. This really affects the performance of the players, which then negatively affects the quality of the game, not to mention the risk of being injured. Figure 4 presents the precipitation scenario in Guangzhou. It is pretty clear from the figure that Guangzhou is a very rainy city, which makes drainage design critical, not only to soccer fields, but to the entire city as well.

3.2 Soil

The exact soil composition of Tianhe soccer field was not found successfully. Under current circumstance, it is unrealistic to actually be on site and conduct relevant experiments. Given the fact that Rugby football and soccer are similar (both are intense, speedy, and involve body interaction), it is very likely safe to assume that the soil composition of a Rugby field resembles that of a soccer field. The reason a Rugby field is chosen as a resemblance over other choices is because there is a Rugby pitch in Ithaca. With a comparable item in Ithaca (210 – 318 Pine tree Rd.), a preliminary onsite evaluation is possible, and relevant soil data is very easy to obtain from a website called "Web Soil Survey".

Figure 6: The rugby pitch in Ithaca

The soil in the rugby pitch is split 52.6% silt loam and 47.4% silty clay loam in this area (Web Soil Survey, 2016). It is known that silt and clay based soils are more likely to be compacted (Cornell Cooperative Extension, 1988), potentially leading to conditions for the pooling and flooding on the soccer pitch.

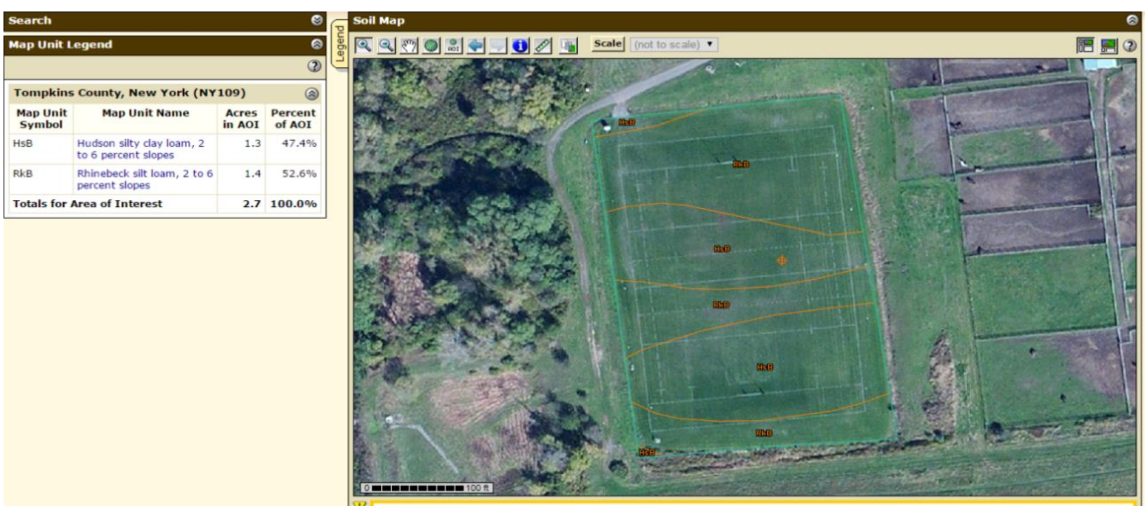

Figure 7: Soil data

According to our assumption, these soil data are assumed to be true for the Tianhe soccer field, too, except Tianhe has a different dimension (96m × 68m).

4. Methodology/ Design Approach

4.1 Overview

As mentioned earlier, the option being considered is piping. This recommendation comes from engineers hired by the club who have already conducted a preliminary on-site evaluation. It is both cheap and effective.

In this project, only the average daily precipitation in June, the rainiest month in Guangzhou, will be used for calculation, since pipes do not expand and contract themselves under the ground, and it is necessary to take the "worst case scenario" under consideration and not necessary to consider less rainy months once considered June. Daily average precipitation in June is approximately 11 mm (China Weather, 2016).

4.2 Piping

Subsurface drainage systems are long-lasting and reliable solutions to many types of drainage problems. The materials and structures used may vary for each circumstance. In the case of this soccer pitch, plastic pipes are most ideal because they are lighter than concrete or clay, which makes them easier and cheaper to transport and install. In addition, corrugated plastic pipes are more preferable than smooth plastic pipes because they have greater resistance to outside pressure and greater flexibility for installation (Ritzema, 1994). Therefore, corrugated plastic pipes will be used.

To determine the subsurface drain spacing (L), the Hooghoudt equation is used:

$$L^2 = \frac{4KH^2}{R} + \frac{8KDh}{R}$$

K is the saturated hydraulic conductivity. In the areas where there is silty clay loam, K is 0.665 m/d, and where the soil is silt loam, K is 0.233 m/d. 30 cm depth is used as the depth of the impermeable layer for the design calculations to ensure proper drainage since typical soil layers above the impermeable layer are around 25 to 30 cm for sports grounds (ACT Government, 2013). For the permeable area, because the two types of soil approximately take a half and half portion of the entire soil body, the overall K value to be used is the average of the two, which is 0.449 m/day.

R is the recharge rate which can be found using the precipitation and evapotranspiration data in Guangzhou and the Thornthwaite-Mather procedure. The recharge constant is 1.58 cm/day (see Appendix for detail).

h is the vertical distance between the highest point of the water table and the pipe. We want to keep the peak of the water table below the surface, so that water does not seep out (technically, h is the general distance between the water table and the pipe, not necessarily the highest point, but in our case, since we are only worrying about the peak, we will define h a little bit differently).

D is the distance between the pipe and the impermeable layer. D and h should sum into 30 cm (D = 30-h).

Since we are dealing with pipes as drains, instead of trenches that penetrate all the way down to the impermeable layer, some flows therefore become radial instead of being all horizontal, and some modifications are needed to be made for the Hooghoudt equation. In this case, D needs to be replaced by de, equivalent depth, and de can be expressed as:

$$de = \frac{\pi L/8}{\ln\left(\frac{L}{\pi r_0}\right) + F(x)}$$

The original equation therefore becomes:

$$L^2 = \frac{4Kh^2}{R} + \frac{\pi KLh}{R[\ln\left(\frac{L}{\pi r_0}\right) + F(x)]}$$

Since $F(x) = 2\pi D/L$ the above equation becomes:

$$L^2 = \frac{4Kh^2}{R} + \frac{\pi KLh}{R[\ln\left(\frac{L}{\pi r_0}\right) + \frac{\pi L}{8D} + \ln\left(\frac{D}{L}\right))]}$$

To determine L, the separation between pipes, we need to determine D, h, and r_0. As mentioned before, D and h should sum into 30 cm, so D = 30 - h, which further modifies the equation to:

$$L^2 = \frac{4Kh^2}{R} + \frac{\pi KLh}{R[\ln\left(\frac{L}{\pi r_0}\right) + \frac{\pi L}{8(30-h)} + \ln\left(\frac{30-h}{L}\right))]}$$

To minimize the cost of this project, a larger pipe length L is desired since less piping will be needed in this case. r_0 is independent of L and h here. In other words, ignoring the fact that too big an r_0 would make h values impossible (e.g. when r_0 = 10cm, h cannot be 25 cm, otherwise the pipe will "bite" into the impermeable layer), the h value that generates biggest L possibly does not change with r_0. Thus, we decided to first assume a r_0 value of 5 cm to determine h where maximum L happens, and then use those values to determine necessary r_0 we need. If the "too big an r_0" problem happens, we will therefore move h to a smaller value.

The equation is too complicated to calculate analytically, so a numerical approach is utilized. We calculated L at every 1 cm of h (from h = 1 to h = 29). It is observed that L increases while h increases. L values for h < 15 are small enough so that it is not necessary to consider them. We listed all L values corresponding to each h larger than and equal to 15.

Table 1: h vs. L

h(cm)	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
L(cm)	277.59	284.2	290.18	295.54	300.31	304.5	308.15	311.25	313.84	315.93	317.54	318.69	319.44	319.81	319.9

The next step is to determine length and size of pipes we need. To do that, the following formula will be used:

$$d = 1.548\,(n\,Q)^{0.3745}\,s^{-0.1875}$$

where **d** is diameter, **n** is Manning's friction coefficient (0.017 is used in our case), **Q** is flow in cubic meter per second, and **s** is the slope (assumed to be 0.0025 if pipes line up along the longer edge, and 0.003 if pipes line up along the shorter edge).

5. Results and Discussions

In this case, the soccer field has a dimension of 96 meters long and 68 meters wide. As briefly mentioned before, there are two ways to lay the pipes. One way is to do it along the longer edge, and the other way is to do is along the shorter edge. Number of pipes needed are rounded up (e.g. if calculation indicates that we need 20.2 pipes, then we will go with 21 to guarantee a big enough safety factor). Relevant calculation is performed in a spreadsheet and results are presented in the Appendix. The results indicate that constructing pipes along the shorter edge at a depth of 24 cm with pipe diameter of 2.24 centimeters require the least plastic.

However, in reality, an arbitrary pipe size is usually not possible and unrealistic to construct. Under most circumstances, pipe sizes are standardized, and a size of "2.24 cm in diameter" may not exist. In addition, it is always a good thing to take into account a factor of safety by using larger pipes than calculation indicates. Calculation error might be one source of error, since a lot of numbers (such as Manning's friction coefficient) are based on estimations and approximations. Their accuracy can hardly guaranteed. This is much less significant, though, compared to the potential influence brought by uncertainties in precipitation quantity. Precipitation does not happen evenly over the year. There can be one day in which precipitation exceeds 100 mm, and no rain happens at all for the next week. On that "unlucky" day, the field can be flooded and water will drain slowly if we simply use a pipe as thin as the calculation suggests. With all these uncertainties, we think it is reasonable to assume a safety factor regarding the diameter – we will use pipes that have diameter of approximately 7.5 cm (which increases the cross section area by 11 times). Since we are constructing pipes at 24 cm deep, this is fine since the pipes will only extend to 28 cm deep and will not "bite" into the impermeable layer.

6. Cost Estimation

One type of 75-mm pipe fits our need perfectly. This kind of pipe works perfectly fine from -5 to 60 degrees Celsius, which makes sense since Guangzhou never went below -5. The historical lowest temperature was 0 degree Calsius in 1999 (China Weather, 2016). It also resists both high and low pH. The longest pipe available is 30 m per portion, which is sold at 124 Chinese Yuan per portion. Going with our optimal plan, 115 30m pipes are needed, which leads to a cost of ¥14260 (Taobao, 2016).

Figure 8: Pipe being considered

In addition to paying for the pipes, labor and equipment to excavate the field also incur cost. In a big city like Guangzhou in China, the average hourly pay of a field worker is 4,000 Chinese Yuan per month (615 USD based on current exchange ratio). Assuming 50 people are needed for two month to upgrade the piping system, one could easily calculate the labor cost to be 400,000. Leasing an excavator costs 35,000 Yuan per month (21-rent, 2016), which leads to an equipment cost of 70,000. Assume that all other trivial costs except pipes, labor, and equipment is 20,000. The total cost then would be 504,260, approximately 500,000 Yuan.

It is worth noting that the cost is simply an estimation. It is highly recommended that further analysis of the pitch be conducted for more accurate results and that the contracting company be contacted for a direct quote.

7. Conclusion

The daily precipitation data for June in Guangzhou was collected, and the daily recharge R is 1.58 cm based on calculation using the precipitation data. With this value, the spacing of pipes was then calculated, which leads to the possibility of calculating total pipes needed to complete this drainage improvement project. Constructing a piping system with diameter of the pipes being 7.5 cm at 24 cm deep from the soil surface is the optimal plan, based on the assumptions and calculations presented previously in this report. The cost of completing this project is estimated to be 500,000 Yuan (75,000 US dollar).

9. Appendix

A.1 Estimating Evapotranspiration

To estimate evapotranspiration (ET_0) in Guangzhou, a software called ET_0 calculator was employed (FAO, 2009). This software calculates ET_0 based on the data input (mainly temperature, relative humidity, wind speed, and solar radiation), and makes reasonable assumptions and approximations when information is missing. In this case, the solar radiation data of Guangzhou was not successfully gathered.

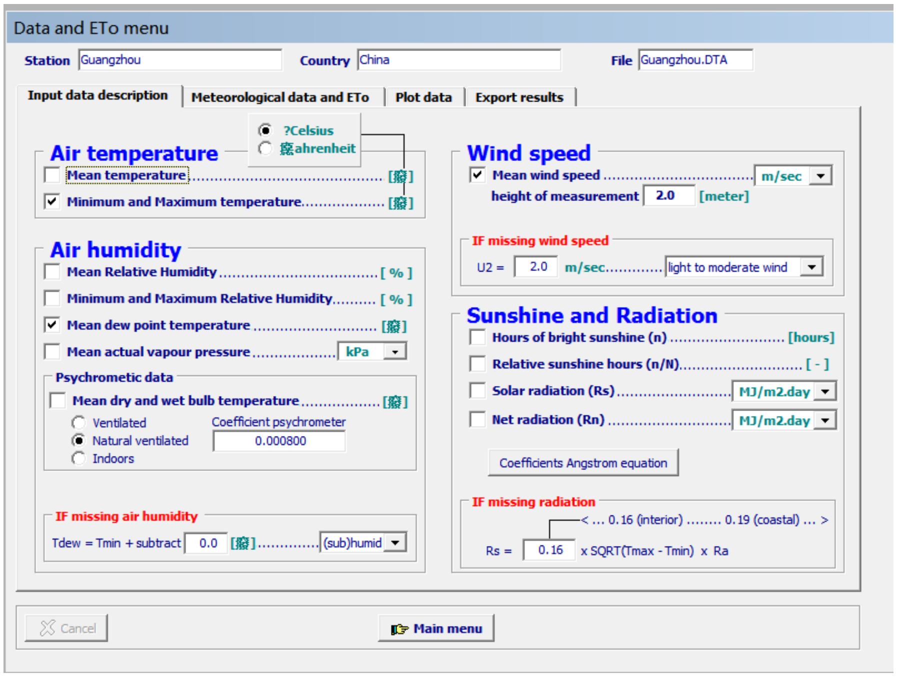

Figure A1: Software interface (since this software was developed in 2009 when many people were still using Windows XP, there are Unicode issues and some symbols cannot be displayed on Windows 10, the author's OS)

With the software and monthly weather data from wunderground.com, the following results were able to be obtained:

Table A1: Monthly ET_0

Month	T_{max}(℉)	T_{min}(℉)	T_{dew}(℉)	Wind speed (m/s)	ET_0 (mm/day)
Jan	75	43	46	2.24	3.4
Feb	82	42	52	2.24	4.1
Mar	86	51	61	2.24	4.8
Apr	91	51	64	2.69	5.8
May	96	67	75	2.24	6.4
Jun	98	74	78	2.24	6.5
Jul	98	74	78	2.24	6.5
Aug	98	73	76	2.24	5.8
Sept	96	72	74	2.24	5.8
Oct	93	61	66	2.24	5.2
Nov	87	49	63	2.69	3.8
Dec	79	41	52	3.14	3.5

With monthly ET_0, we can now use the T-M procedure and calculate the recharge coefficient R.

A.2 Calculating Recharge Rate (R) Using the T-M Procedure

Steenhuis and Van der Molen were able to formulate a pretty concise and accurate description of the T-M procedure (Steenhuis and Van der Molen, 1986):

$$\mathrm{APWL}_t = \mathrm{APWL}_{t-\Delta t} + (\Sigma\,\mathrm{PET} - \Sigma\,\mathrm{P}) \quad (1)$$

where: APWL_t = the accumulated potential water loss at time t (cm); $\mathrm{APWL}_{t-\Delta t}$ = the accumulated potential water loss at time $t - \Delta t$ (i.e., previous month; cm); $\Sigma\,\mathrm{PET}$ = cumulative evaporation over time period Δt (cm); and $\Sigma\,\mathrm{P}$ = cumulative precipitation over time period Δt (cm).

In this method, the relationship between APWL and the amount of water stored in the root zone is expressed as:

$$\mathrm{ST}_t = \mathrm{ST}_f\,[\exp(-\mathrm{APWL}_t/\mathrm{ST}_f)] \quad (2)$$

where: ST_t = the available water stored in the root zone at time t (cm); and ST_f = the available water stored at field capacity in the root zone (cm).

For months that the potential evaporation is less than the precipitation (i.e. moisture content increases and/or percolation occurs) the storage in the soil is incremented by the difference between the potential evaporation and precipitation, viz:

$$\mathrm{ST}_t = \mathrm{ST}_{t-\Delta t} + \Sigma\,\mathrm{P} - \Sigma\,\mathrm{PET} \quad (3)$$

If the storage ST_t at time t is higher than field capacity then the percolation (Rech_t) is simply calculated as:

$$\mathrm{Rech}_t = \mathrm{ST}_f - \mathrm{ST}_{t-\Delta t} + \Sigma\,\mathrm{P} - \Sigma\,\mathrm{PET}$$

There has to be a starting point, so take $\mathrm{APWL}_0 = 0$. The average precipitation of each month was chosen to perform the calculation. By taking the weighted average of the field capacity of silt loam (0.31) and silty clay loam (0.38), (Decagon Devices, 2015), the field capacity of the land is calculated as $0.526 \times 0.31 + 0.474 \times 0.38 = 0.343$.

The water storage at field capacity in cm can then be calculated this way:

$96 \times 68 \times 0.3 \times 0.343 = 671.7\,m^3$ → this is the volume of water at field capacity

$671.7 / (96 \times 68) = 0.1029\,m = 10.29$ cm → "height" of water at field capacity

The rest of the calculation can be performed repetitively in an Excel spreadsheet following the T-M procedure. The following result was able to be obtained:

Table A2: Recharge rate R (darker rows from May to September indicate existence of recharge; negative numbers are labeled zero)

Jan	PET_1	0.34	P_1	0.0508	$APWL_1$	0.2892	ST_1	10.005	R_1	0 (starting point)
Feb	PET_2	0.41	P_2	0.127	$APWL_2$	0.5722	ST_2	9.7334	R_2	0
Mar	PET_3	0.48	P_3	0.0508	$APWL_3$	1.0014	ST_3	9.3358	R_3	0
Apr	PET_4	0.58	P_4	0.305	$APWL_4$	1.2764	ST_4	9.0896	R_4	0
May	PET_5	0.64	P_5	2.032	$APWL_5$	-0.116	ST_5	10.482	R_5	1.584
Jun	PET_6	0.65	P_6	0.711	$APWL_6$	-0.177	ST_6	10.543	R_6	0.314
Jul	PET_7	0.65	P_7	1.245	$APWL_7$	-0.772	ST_7	11.138	R_7	1.443
Aug	PET_8	0.58	P_8	0.737	$APWL_8$	-0.929	ST_8	11.295	R_8	1.162
Sept	PET_9	0.58	P_9	0.279	$APWL_9$	-0.628	ST_9	10.937	R_9	0.346
Oct	PET_{10}	0.52	P_{10}	0.178	$APWL_{10}$	-0.286	ST_{10}	10.58	R_{10}	0
Nov	PET_{11}	0.38	P_{11}	0.102	$APWL_{11}$	-0.008	ST_{11}	10.298	R_{11}	0
Dec	PET_{12}	0.35	P_{12}	0.203	$APWL_{12}$	0.1394	ST_{12}	10.152	R_{12}	0

As we can see from the above table, the biggest recharge rate calculated based on historical climate data is 1.58 cm/day. This is the R used in the Hooghhout Equation.

The following table presents the results we obtained regarding the least (optimal) “area” of pipes needed. Lighter cells correspond to results if pipes line up with the short edge, and darker cells correspond to results in case of pipes lining up with the long edge. Highlighted in black and white is the solution requiring the least amount of plastic.

Table A3: optimal quantity of pipes needed

h(cm)	L(cm)	Q (m^3/s)	d (cm)	Q' (m^3/s)	d' (cm)	Length of pipes needed (m)		"Area" of pipe needed (m^2)	
15	277.59	3.452E-05	2.134	4.87E-05	2.512	3892	3959	26087	31248
16	284.2	3.534E-05	2.153	4.99E-05	2.534	3811	3827	25769	30474
17	290.18	3.608E-05	2.169	5.09E-05	2.554	3730	3695	25419	29654
18	295.54	3.675E-05	2.184	5.19E-05	2.572	3649	3695	25037	29858
19	300.31	3.734E-05	2.197	5.27E-05	2.587	3568	3563	24628	28965
20	304.5	3.787E-05	2.209	5.35E-05	2.601	3568	3563	24756	29115
21	308.15	3.832E-05	2.219	5.41E-05	2.612	3486	3563	24302	29245
22	311.25	3.870E-05	2.227	5.46E-05	2.622	3486	3563	24393	29355
23	313.84	3.903E-05	2.234	5.51E-05	2.630	3486	3431	24469	28356
24	315.93	3.929E-05	2.240	5.55E-05	2.637	3405	3431	**23959**	28426
25	317.54	3.949E-05	2.244	5.57E-05	2.642	3405	3431	24005	28481
26	318.69	3.963E-05	2.247	5.59E-05	2.645	3405	3431	24037	28519
27	319.44	3.972E-05	2.249	5.61E-05	2.648	3405	3431	24059	28544
28	319.81	3.977E-05	2.250	5.61E-05	2.649	3405	3431	24069	28557
29	319.9	3.978E-05	2.250	5.62E-05	2.649	3405	3431	24071	28560

8. References

ACT Government. (2013) *Sportsground Design*. Design Standards for Urban Infrastructure. Canberra, Australia.

China Weather. (2016) Climate in Guangzhou. Retrieved Apr. 2016 from <http://www.weather.com.cn/weather/101280101.shtml>

Cornell Cooperative Extension. (1988) *Athletic Field Maintence: A Guide for Sports Turf Managers*. Cornell University College of Agriculture and Life Sciences. Information Bulletin 213.

FAO Water. (2009) ETo Calculator. Retrieved Apr. 2016 from <http://www.fao.org/nr/water/eto.html>

Google Picture. (2016) Retrieved Apr. 2016 from <https://www.google.com/maps/uv?hl=en&pb=!1s0x3402fefce39a9cf5%3A0x4dd1f5f21f3b54cd!2m5!2m2!1i80!2i80!3m1!2i100!3m1!7e1!4s%2F%2Fplus.google.com%2Fphotos%2Fphoto%2F117699332171101765917%2F6240588416564408786!5s%20-%20Google%20Search&imagekey=!1e3!2s-Kvo34zmYXgs%2FUiG_IT-kSUI%2FAAAAAAAAAA0%2FrLbQMpQwxUo>

Guangzhou Evergrande Official Website. (2016) *Team information*. Retrieved Apr. 2016 from <http://www.gzevergrandefc.com/about.aspx?ftid=298>

Ritzema, H.P. (1994). *Drainage Principles and Applications*. International Institute for Land Reclamation and Improvement/ILRI. Wageningen, The Netherlands.

Sina Sports. (2013) *Guangzhou Evergrande Decided to Upgrade the Drainage System*. Retrieved Apr. 2016 from <http://sports.sina.com.cn/j/2013-01-29/08146400981.shtml>

Steenhuis, T.S., Van der Molen W.H., 1986 The Thornthwaite-Mather Procedure as a Simple Engineering Method to Predict Recharge. *Journal of Hydrology*, 84 221-229.

Taobao. (2012) Retrieved Apr. 2016 from <https://item.taobao.com/item.htm?id=20807888163&ali_refid=a3_420630_1006:1104342807:N:%E6%8E%92%E6%B0%B4%E7%AE%A1:e661aa5ad338ff1f6b7c13b0714a8f11&ali_trackid=1_e661aa5ad338ff1f6b7c13b0714a8f11&spm=a231k.7623930.1998287352.122.Wxqe37>

Tecent Sports. (2015) Awful Drainage System in Tianhe Stadium. Retrieved Apr. 2016 from <http://sports.qq.com/a/20150505/064566.htm>

Web Soil Survey. (2016) Soil Composition of Ithaca Rugby Pitch. Retrieved Apr. 2016 from <http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx>

World Weather Online. (2016) Retrieved Apr. 2016 from <http://www.worldweatheronline.com/Guangzhou-weather-averages/Guangdong/CN.aspx>