



University of Wisconsin - Madison

Department of Geography

GIS Application(Geog578)- Final Project Paper

**Wellhead Protection and the Future Water Demands from
Public Wells in the City of Madison**

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Introduction and Background:

Ultimately, chemicals and other contaminants washed on the ground will make their way to reach the groundwater or aquifer and that way these pollutants will make the ground water unsafe for drinking. Where all these uncertainty about groundwater came from. Groundwater pollution most often results from inappropriate disposal of wastes and the Landuse management. It can also accrue naturally due the presence of chemical elements in the aquifer layers. But the majority of groundwater contamination come from human activities. There might be several reasons such as population growth, urbanization, rainfall, Landuse management and etc. that has impact on the groundwater quantity and quality across the nation, but having good quality, safe drinking water at a reasonable cost is something that most people want it, especially if their water comes from a public water supply system.

in this paper, we are mainly focusing on a few components that might affect the quantity and quality of groundwater in the city of Madison Wisconsin if they aren't considered seriously.

Madison is relatively a rapidly growing city and as of July 1, 2016, Madison's estimated population of 252,551 (*Madison City Population .2018*) made it the second largest city in Wisconsin. According to the Demographic Service Center of Wisconsin "City of Madison is estimated to have the fastest proportional growth of (7.23%) from 2010 - 2017".

Potential consequences of rapid population growth include groundwater depletion and contamination, to make sure the groundwater quantity and quality is safe from human activities, our goal in this project is to estimate the Wellhead Protection Area, Well Recharge Area and the future water demands from Madison wells in the next 50 years

1. Wellhead Protection Area:

Wellhead Protection Area means protecting the area surrounding public drinking water supply wells from contamination. As all the 22 wells are and will continue to be the sources of drinking water for many year and for most of the people in the city of Madison, so protection of these dynamic resources from rapid population growth, agricultural practices and building chemical factories around them is crucial!

For example, building chemical factories nearby the public water supply well may bring with potential sources of contamination. Rapid growing of population around a well may stress the quantity of water, and agricultural practices around a well may contaminate the groundwater with Nitrate.

Some advantage of Wellhead Protection Program:

- Avoid cleaning up contaminated groundwater
- Less spending on water treatment
- Having long lasting of clean water supply to public
- Having a positive climate for commercial growth

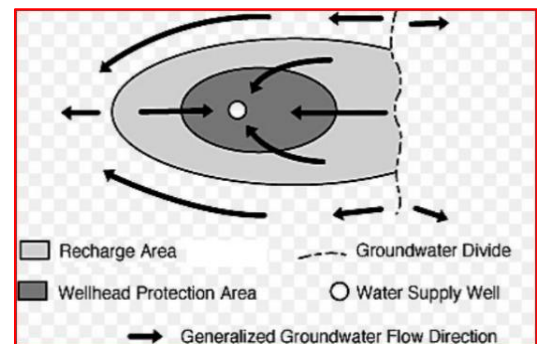


Figure 1.
Wellhead Protection Area and Recharge Area

2. Well Recharge Area:

The surface from which water is added to the zone of saturation is called Well Recharge Area.

Sometime the recharging area of a well is bigger than the wellhead protection area, but mostly it depends to the Time of Travel, while the Well Recharge Area is regardless of Time of Travel.

There are more details information about the Wellhead Protection and Well Recharge area in the implementation part. Most of the groundwater recharge came from natural infiltration (snow, rainfall, sleet, hail), when the precipitation occurs, a portion of it infiltrated to the ground and

making the groundwater. To protect the recharging areas for all 22 wells in the city of Madison, we need to avoid paving more surfaces and reducing open area where the wells get their recharges from.

3. Population Growth and Future Water Demands:

As stated previously, Madison is relatively one of the rapid growing city in Wisconsin and according to the Demographic Services Center of Wisconsin “Madison city population is projected to be 281,150 at 2040” and it may go above than this in 2068. Considering the population growth in the city, determining the amount of water needed in the future is one of the key concepts of our project. We used *Minor Civil Division* formula to estimate the annual population growth for the city of Madison and based on the daily water consumption rate, we will estimate the total water demands for estimated population now and in 2068. For more information about the water demands now and in 2068, please see the implementation part of our paper.

Below tables shows the largest municipalities projected population from 2010 – 2040, (*Wisconsin Future Population, Robertson 24*).

Largest Municipalities (by Size at 2040), 2010-2040						
Municipality	Estimate 2013	Projection 2040	Numeric Change	Percent Change	Rank 2013	Rank 2040
C Milwaukee	596,500	627,400	30,900	5.2%	1	1
C Madison	238,000	281,150	43,150	18.1%	2	2
C Kenosha	99,700	123,250	23,550	23.6%	4	3
C Green Bay	104,300	113,500	9,200	8.8%	3	4
C Waukesha	70,900	81,350	10,450	14.7%	7	5
C Appleton	73,150	80,605	7,455	10.2%	6	6
C Racine	78,700	76,650	-2,050	-2.6%	5	7
C Janesville	63,600	74,000	10,400	16.4%	10	8
C Oshkosh	66,300	73,800	7,500	11.3%	9	9
C Eau Claire	66,480	73,770	7,290	11.0%	8	10
C West Allis	60,300	61,850	1,550	2.6%	11	11
C La Crosse	51,600	51,850	250	0.5%	12	12

Table 1

From the table above, we can see that city of Madison is #1 in numeric change, while Kenosha is #1 for percent changes.

Conceptualization:

There are three significant key concepts in our project: wellhead protection area, well recharge area and the future water demand in the next 50 years. Wellhead protection area and recharge area could take the charge for the quality and quantity of groundwater. For conceptualizing wellhead protection and well recharge areas, we need to find wells and aquifer attributes, and for that we need to contact with city of Madison Water Utility, Wisconsin Department of Natural Resources, Dane County Planning and Development department and other organization.

In the meantime, we are doing a regression analysis of the city population for the past three decades, its projected population in the next 50 years, number of wells, water consumption and the future water demands.

Currently there are 22 public wells in the city of Madison that provide drinking water to the residents, we will contact the Water Utility if they could provide us with the number of people each well is serving, otherwise we are going to divide the city in to 22 polygons using *Theisen Polygon* method in ArcMap to analyze the dense of population around each well. Theisen Polygon is an interpolation method that define individual areas of influence around each of a set of points.

After we completed our analysis, we may or may not recommend more investment on the technologies to keep the quality of drinking water safe and to construct a new public well(s), if we figure out that the existing 22 public wells won't meet the projected population water demands in 2068.

Conceptualization Diagram

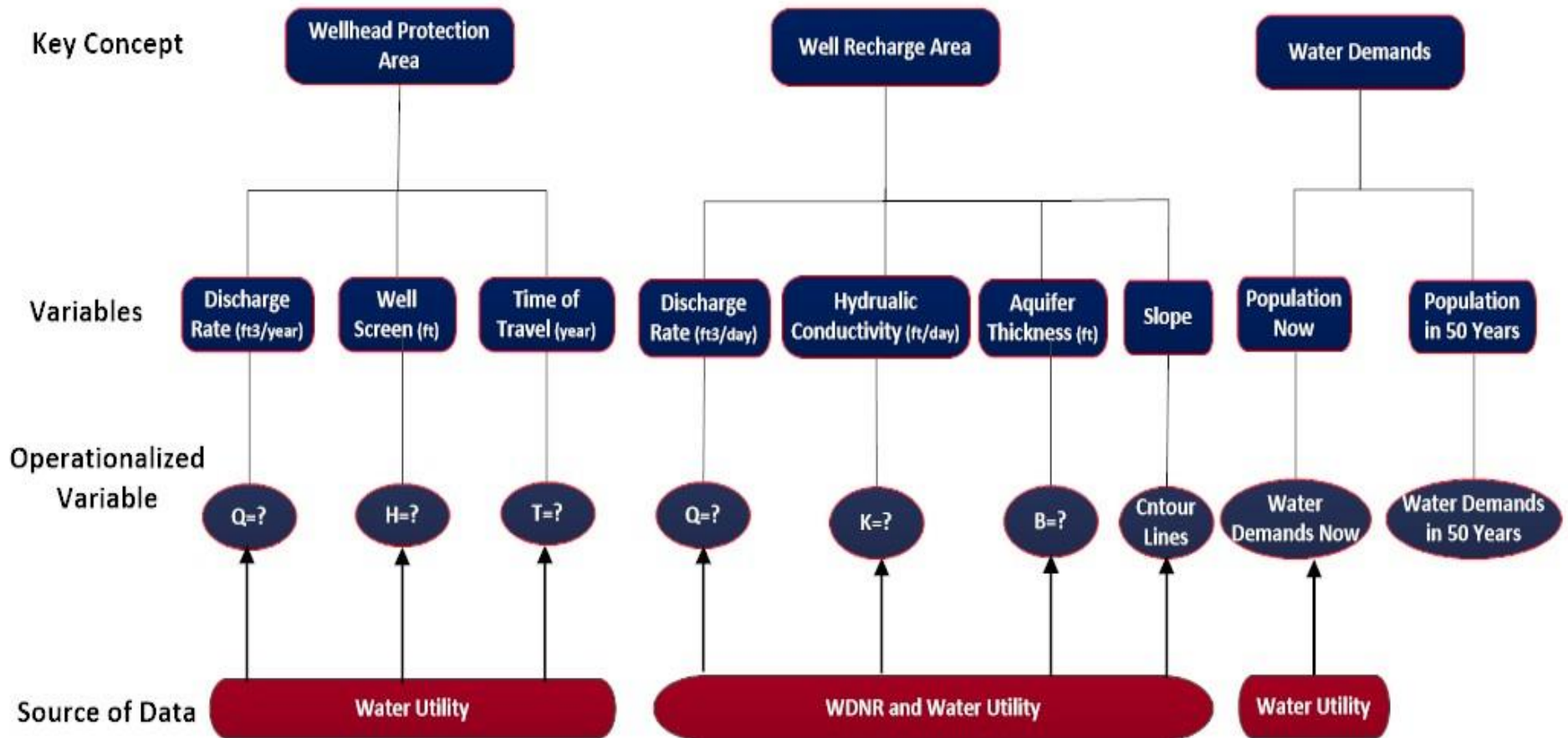


Figure 2. Conceptualization diagram

1. Wellhead protection area

Wellhead protection area was identified by Safe Drinking Water Act Amendments of 1986 as:

“The surface and subsurface area surrounding a well or well field, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such well or well field”. This definition indicates some features of a wellhead protection area should be a circle or like a circle and the well could be its centroid. Another feature is that groundwater and surface water could contribute to wellhead protection area simultaneously. The groundwater table could contribute to the radius of wellhead protection area and direction of groundwater flow could form the shape of the wellhead protection area (that wellhead protection area is not a perfect circle, it could be twisted and squeezed in direction of surface water flow).

There are some requirements for the wellhead protection area in *Wisconsin Administrative Code, Chapter NR 811.12*. Here are some significant details included in the wellhead protection plan:

“(a) identification of the groundwater flow direction.”

“(b) identification of the zone of influence for the well consisting of the distance to one foot of aquifer drawdown at the anticipated final pumping rate when pump age of the well is assumed to be continuous without recharge for 30 days.”

“(c) identification of the recharge area for the well. The recharge area shall be calculated using the Uniform Flow Equation or be computer modeled unless another method is approved by the department” (Wisconsin Administrative Code, Chapter NR 811.12.)

To delineate the wellhead protection area, based on the *Wisconsin Administrative Code, Chapter NR 811.12.*, we come up with a method to calculate the radius of wellhead protection area:

Volumetric Equation or Fixe Radius:

$$R = \sqrt{(QT/\pi nH)}$$

Where:

Q = well pumped volume per day

T = time of travel (5 years)

n = aquifer porosity

$\pi = 3.14$

H = height of the open interval or screen (ft).

We could notice that here are 4 variables for estimating the wellhead protection area: well discharge rate, well screen or open interval, time of travel and the porosity number of the aquifer.

We got most of the wells attribute data such as well depth, casing depth, static water table and the pump age rate from Water Utility, while the aquifer porosity, hydraulic conductivity and aquifer thickness were obtained from Dane County Groundwater Model and Wisconsin DNR.

2. Well recharge area

As stated previously that the Well Recharge area is the total land that contributing water to the well regardless time of travel. The well recharge area could be like a circle, ellipsoid, irregular polygon, a parabolic shape and etc. there is always a shape and size difference in the wellhead protection area and the well recharge area, because the first one is a fixed radius and it mostly rely on the Time of Travel (ToT), while the 2nd one is relying on the water flow direction regardless of ToT.

In *Wisconsin Administrative Code, Chapter NR 811.12.*, it is recommended that “*The recharge area shall be calculated using the Uniform Flow Equation or be computer modeled unless another method is approved by the department.*”

Uniform Flow Equation:

We will use below equation for estimating the well recharge area for all the 22 wells, and as stated in the previous page, we need to figure out or estimate all the variables that we need in below equation before implementation process.

$$X_L = Q/(2\pi Kbi)$$

$$Y_L = Q/(\pi Kbi)$$

Where:

X_L = down gradient null point (ft)

Y_L = side gradient width (ft)

Q = pumping rate (gpd)

K = hydraulic conductivity (ft/day)

b = aquifer thickness (ft)

Kb = transmissivity (ft²/day)

i = hydraulic gradient (ft/ft)

3. Water Demands:

Madison is second largest city in Wisconsin state and according to *Madison City Population, 2016*, the population of citizen in Madison City for 2016 is 252,551 and its annual growth rate is 1.5%. We are going to analyze the demographic change pattern in the past 3 decades and from there we will figured out the average annual population growth and then projected future population for the city of Madison and then the future water demands. In our project, we decided to use **Minor Civil Division** Projection Methodology to evaluate the demographic attributes and predict its change pattern in the future. *In Vintage 2013 Minor Civil Division Projection Methodology: Some Salient Points*, some of main principles governing the projection methodology are summarized by *UW-Madison Applied Population Laboratory* as below:

- *It requires consideration of historical data in the past for the long-term population projection, especially for small group of people, so that past and anticipation time are equal length.*
- *The recent changing tendency should have greater influence in the projection process than older experience.*

From this statement, we could access the reliability and feasibility of our key concept. First, we mainly focus on group of people by block which could be considered as *small area*.

Second, we are interested in the changes during Travel of Time. We could anticipate the future change pattern by past tendency which is equal length.

We used *Minor Civil Division (MCD)* Equation to estimate the annual population growth for the city of Madison and then estimated its projected population for 2068.

$$\text{Growth (G)} = ((P_{2016}-P_{1990}/T_{2016}-T_{1990}) + (P_{2016}-P_{2000}/T_{2016}-T_{2000}) + (P_{2016}-P_{2010}/T_{2016}-T_{2010}))/3$$

Where:

P_{2016} is the final MCD estimate for 1/1/2016;

P_{1990}^{\wedge} , P_{2000}^{\wedge} , P_{2010}^{\wedge} are the adjusted Census values;

T s are the calendar dates for the censuses and most recent estimate; the values produced are treated as quarter-years.

Implementation Diagram

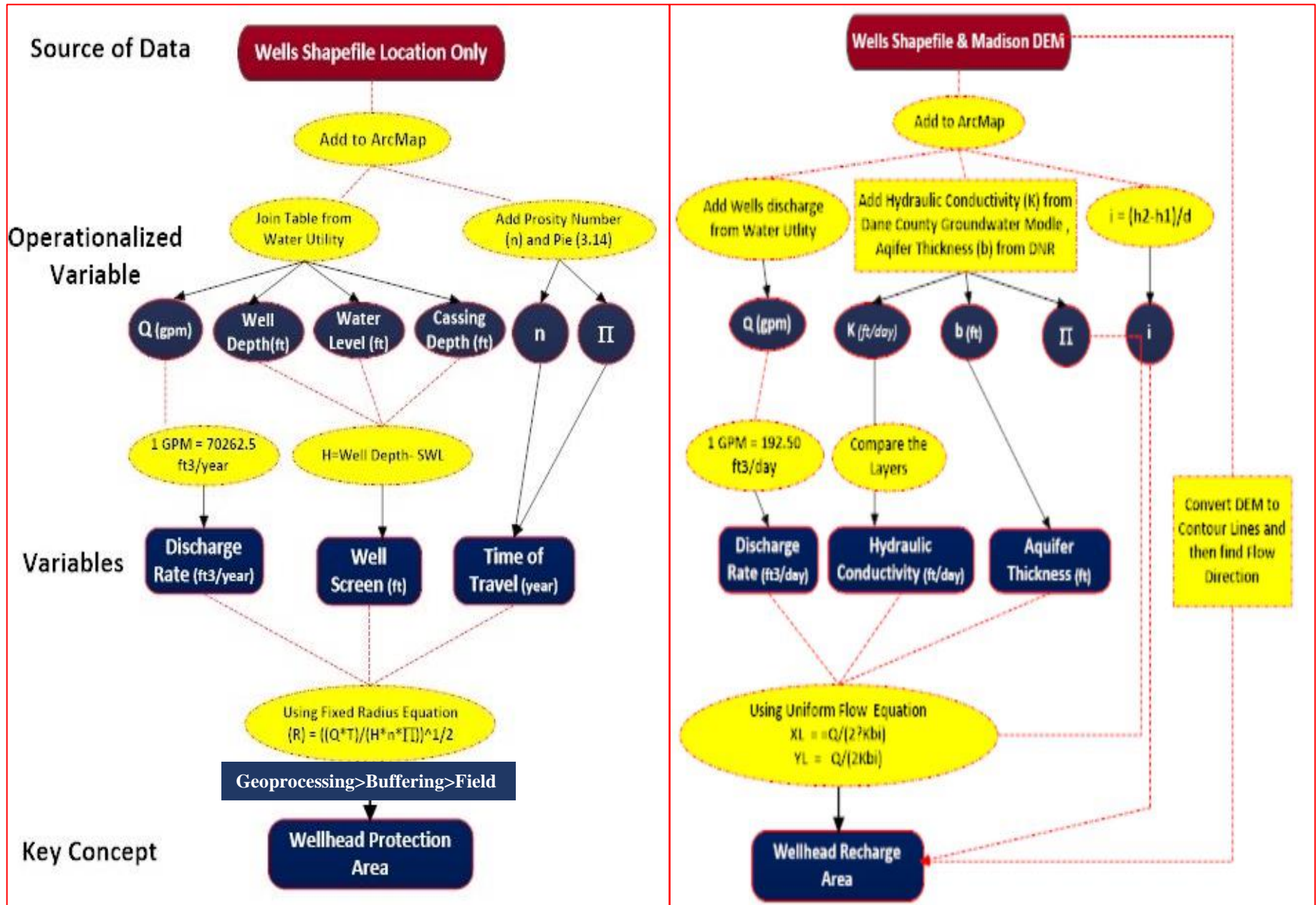


Figure 3.1. Implementation Diagram

Implementation Diagram Cont.

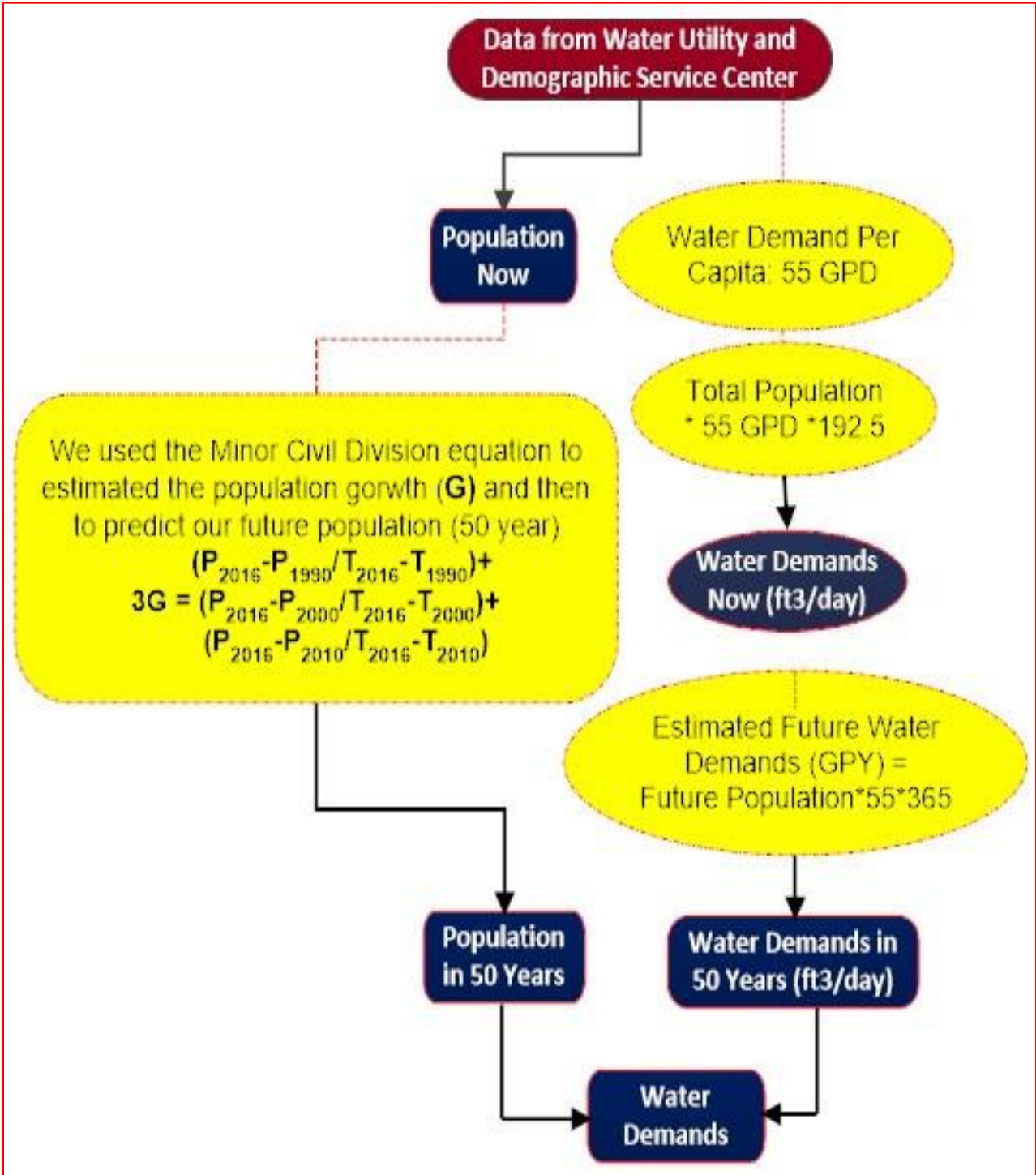


Figure 3.2. Implementation Diagram

Implementation

Here is the list of our original data layers that we got from Dane County Planning and Development Department, DEM from Wisconsin View, Population by Block Group from Census, Madison Wells shapefile from Robinson Library, Aquifer attribute from Wisconsin DNR and Wells attribute from Water Utility.

- Madison Administrative Boundaries
- DEM
- Population by Block Group Dane County
- Madison Wells
- Dane County Aquifer

The Madison Administrative Boundaries map is our study area, and we divided the city into 22 polygons and added the population from the Blocks to each polygon to estimate the number of people round each well. The Digital Elevation Model (DEM) and Static water table in each well helped us to determine the surface water flow direction and groundwater table in the study area. To estimate the Wellhead Protection Area and the Well Recharge Area, we needed to have all of the variables for our two previously stated equations. For that purpose, we searched a lot on the internet and contacted several relevant departments (*WDNR and Wisconsin Geological & Natural Survey*) in the area to help us in finding some of the variables, e.g. aquifer thickness, aquifer porosity and hydraulic conductivity. WDNR and The Capital Regional Planning Commission were very cooperative to share with us the **Dane County Groundwater Model** from which we obtained the hydraulic conductivity(K) and the porosity number (n). As most of the 22 wells are pumping their water from lower sandstone aquifer, so that is why we considered the same hydraulic conductivity and the same porosity number for all 22 wells. In all our calculation, we considered the porosity number (n) = 0.15 and the Hydraulic Conductivity (K) =

15 ft/day. Both number were taken from the Dane County Groundwater Model, while the hydraulic gradient was estimated in a separate spreadsheet based on the static water table in each well. For more detail please see page *16 hydraulic gradients*.

It was not easy to find the aquifer thickness from which the public wells are getting their water, because we didn't have enough time, skills and technology to measure the aquifers thicknesses, but thanks to WDNR for sharing with us all the four layers of aquifer maps with their thicknesses. After we got and obtained all our variables we made an excel spreadsheet with having the fixed radius and uniform flow equations in it and then estimated the wellhead protection and recharge areas for all the 22 wells. Table 2 and Table 3 show our estimation of the wellhead protection and well recharge areas.

Using ArcMap to Estimate WHPA with Creating Buffers with 5 and 50-year ToT

We added the two estimated columns (WHPA 5 years & WHPA 50 years) from the *Wellhead Protection Spreadsheet-Table2* into the Well shapefile attribute table and then from *Geoprocessing* tool in the ArcMap we used buffering to estimate the Wellhead Protection are for 5 and 50 years respectively. Figure 6 and 7 show the Wellhead Protection Area for all 22 wells in the city with 5 and 50 years ToT. The geometry of a wellhead protection area will look like the image below:

Zoon1, Zoon2 and Zoon3
represent WHPA with different

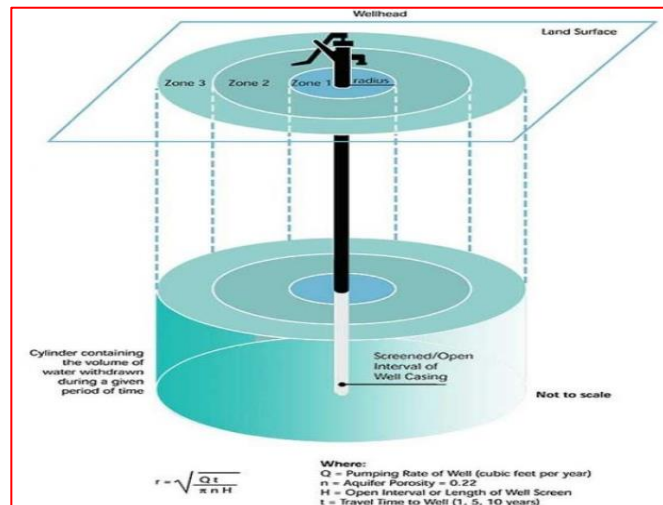


Figure 4. Wellhead Protection Area

Well Recharge Area:

As stated above that we used the *Uniform Flow Equation* for estimating Well Recharge Area, because it was recommended by *Wisconsin Administrative Code, Chapter NR 811.12*. the geometry of the well recharge area is different than the wellhead protection area, because the first one follows the Time of Travel with a fixed radius shape, while the second one follows the surface water flow direction and its regardless of travel of time. The surface water flow direction was found by adding Dane County DEM to ArcMap and then converting it contour lines to see the surface elevation changes and then based on the elevation changes, we made a flow direction map *figure 10*.

In this project we estimated the well recharge areas for all 22 wells, but due to the lack of time and producing too many maps in our report we decided to only map the well (13) with the largest recharge area and the well (29) with the smallest recharge area. An approximate geometry of well recharge area will look like in the figure below:

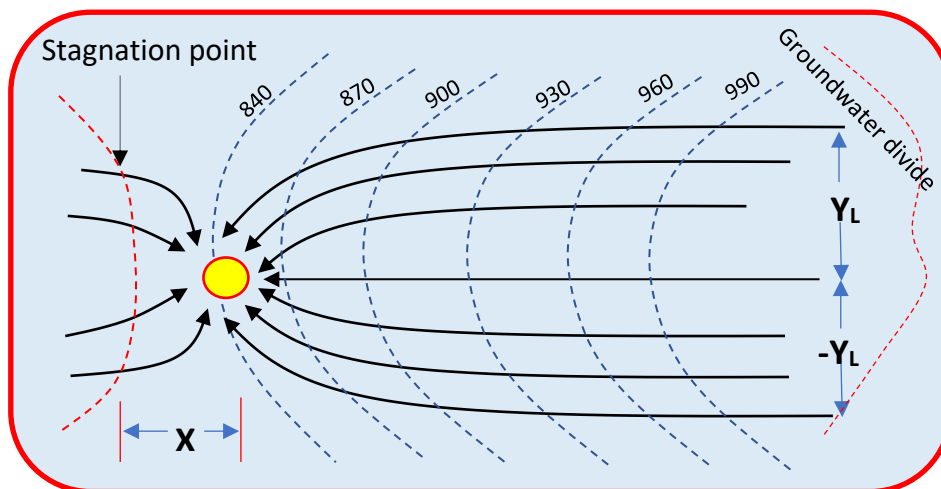
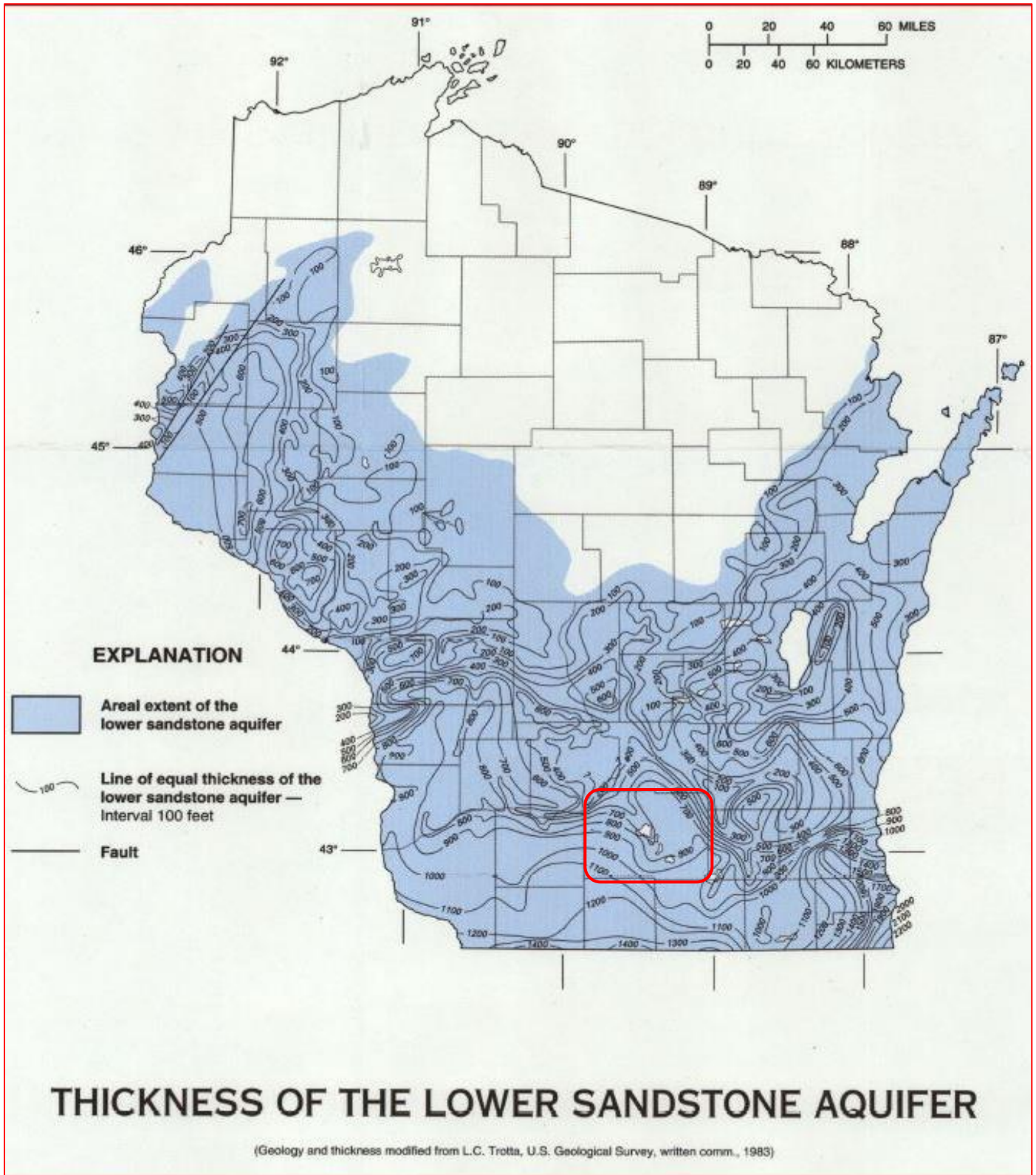


Figure 5. The Geometry of Well Recharge Area

The geometry of recharge area for well 13 and 29 are drawn in ArcMap by creating a new polygon shapefile considering the surface water flow direction. Please see page 25.

Lower Sandstone Aquifer Thickness in Feet



Source: Wisconsin DNR

Pumping Rate Conversation			Wellhead Protection Area									
			1	=	70262.5							
			US liquid gallon / Minute		Cubic foot / Year							
Well-ID	Discharge/Pumpage Rate (GPM)	Discharge Rate ft ³ /year	Well-ID	WHPA (50 years)	WHPA (5 years)	H	Q (ft ³ /year)	n	ToT (50)	ToT (5)	π	
6	2625	184439063	6	6078	1922	530	184439063	0.15	50	5	3.14	
7	1750	122959375	7	5109	1616	500	122959375	0.15	50	5	3.14	
8	1800	126472500	8	5213	1649	494	126472500	0.15	50	5	3.14	
9	1650	115933125	9	4761	1505	543	115933125	0.15	50	5	3.14	
11	2100	147551250	11	4924	1557	646	147551250	0.15	50	5	3.14	
12	2250	158090625	12	4808	1520	726	158090625	0.15	50	5	3.14	
13	2700	189708750	13	5784	1829	602	189708750	0.15	50	5	3.14	
14	2200	154577500	14	5238	1657	598	154577500	0.15	50	5	3.14	
15	1100	77288750	15	3758	1188	581	77288750	0.15	50	5	3.14	
16	2330	163711625	16	4969	1571	704	163711625	0.15	50	5	3.14	
17	2125	149307813	17	5140	1625	600	149307813	0.15	50	5	3.14	
18	1700	119446250	18	4771	1509	557	119446250	0.15	50	5	3.14	
19	2125	149307813	19	5883	1860	458	149307813	0.15	50	5	3.14	
20	2015	141578938	20	5022	1588	596	141578938	0.15	50	5	3.14	
23	1050	73775625	23	4447	1406	396	73775625	0.15	50	5	3.14	
24	2000	140525000	24	5512	1743	491	140525000	0.15	50	5	3.14	
25	1615	113473938	25	4795	1516	524	113473938	0.15	50	5	3.14	
26	1917	134693213	26	4589	1451	679	134693213	0.15	50	5	3.14	
27	1790	125769875	27	5167	1634	500	125769875	0.15	50	5	3.14	
28	2150	151064375	28	5768	1824	482	151064375	0.15	50	5	3.14	
29	1050	73775625	29	4069	1287	473	73775625	0.15	50	5	3.14	
30	1350	94854375	30	4542	1436	488	94854375	0.15	50	5	3.14	

Table – 2- Wellhead Protection Area

City of Madison - Municipal Wells Location

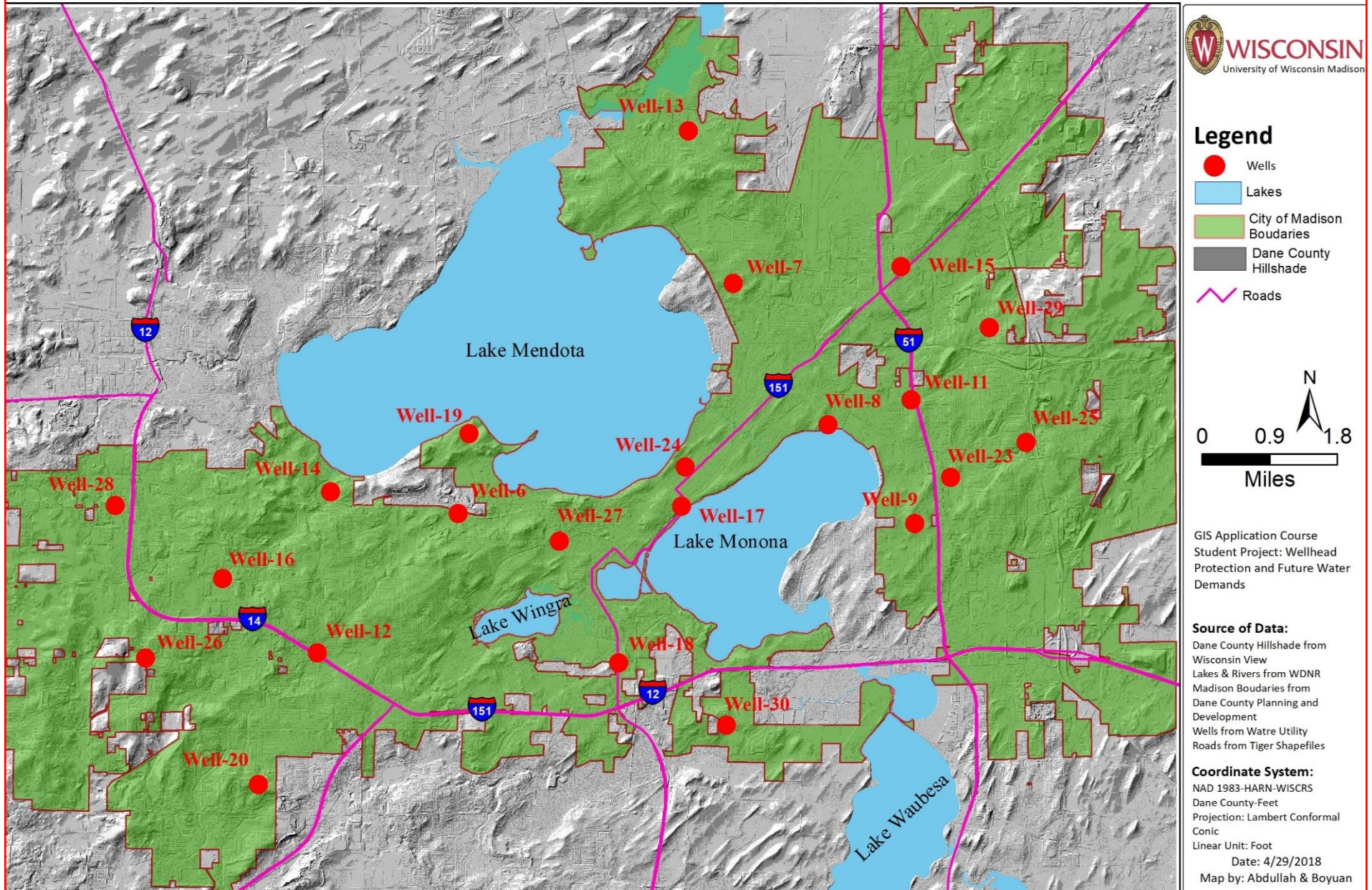


Figure 6. Wells Location Map

Wellhead Protection Area-5 Years

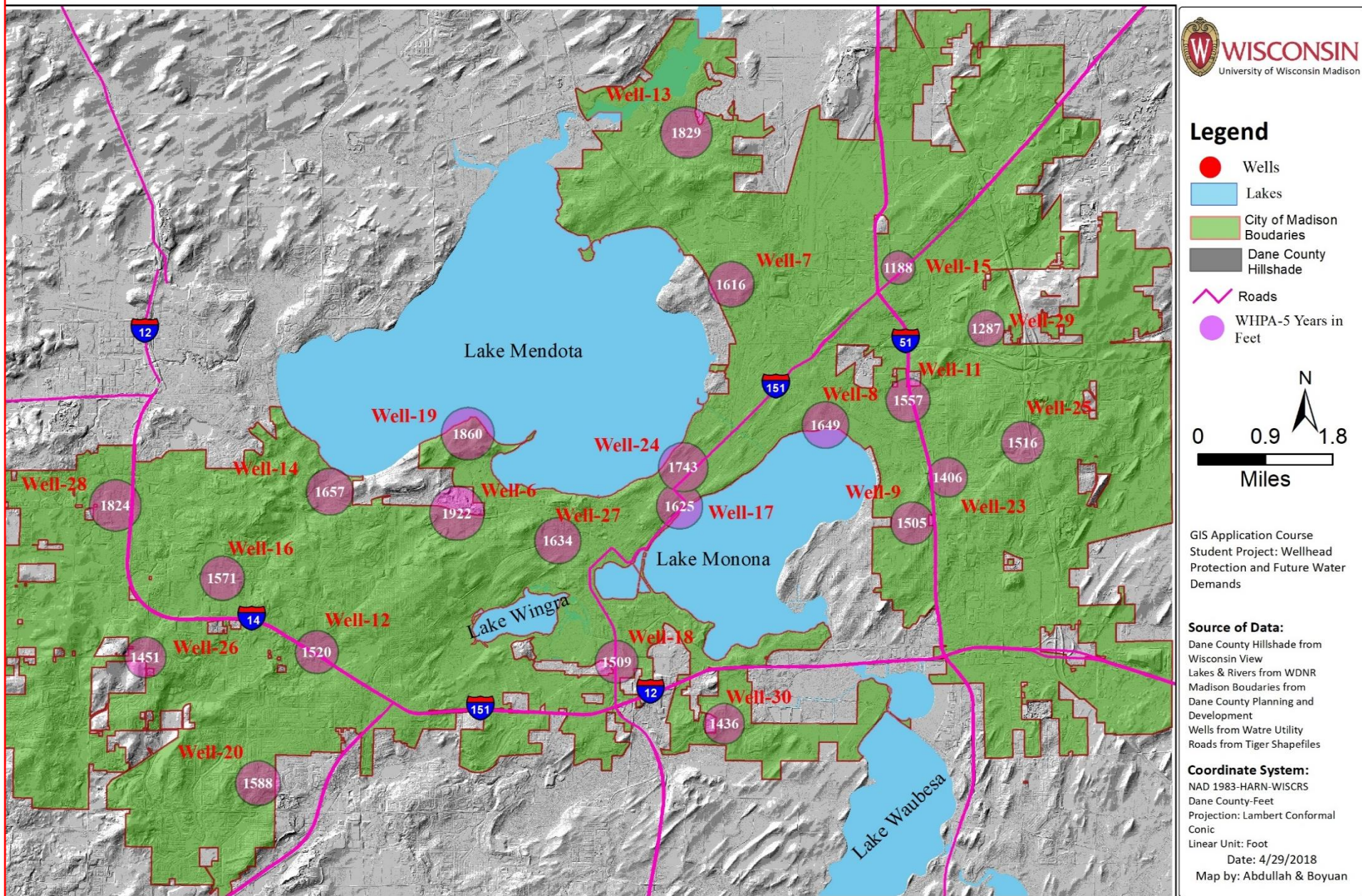


Figure 7. Wellhead Protection Area with 5 years' Time of Travel

Wellhead Protection Area-5 and 50 Years

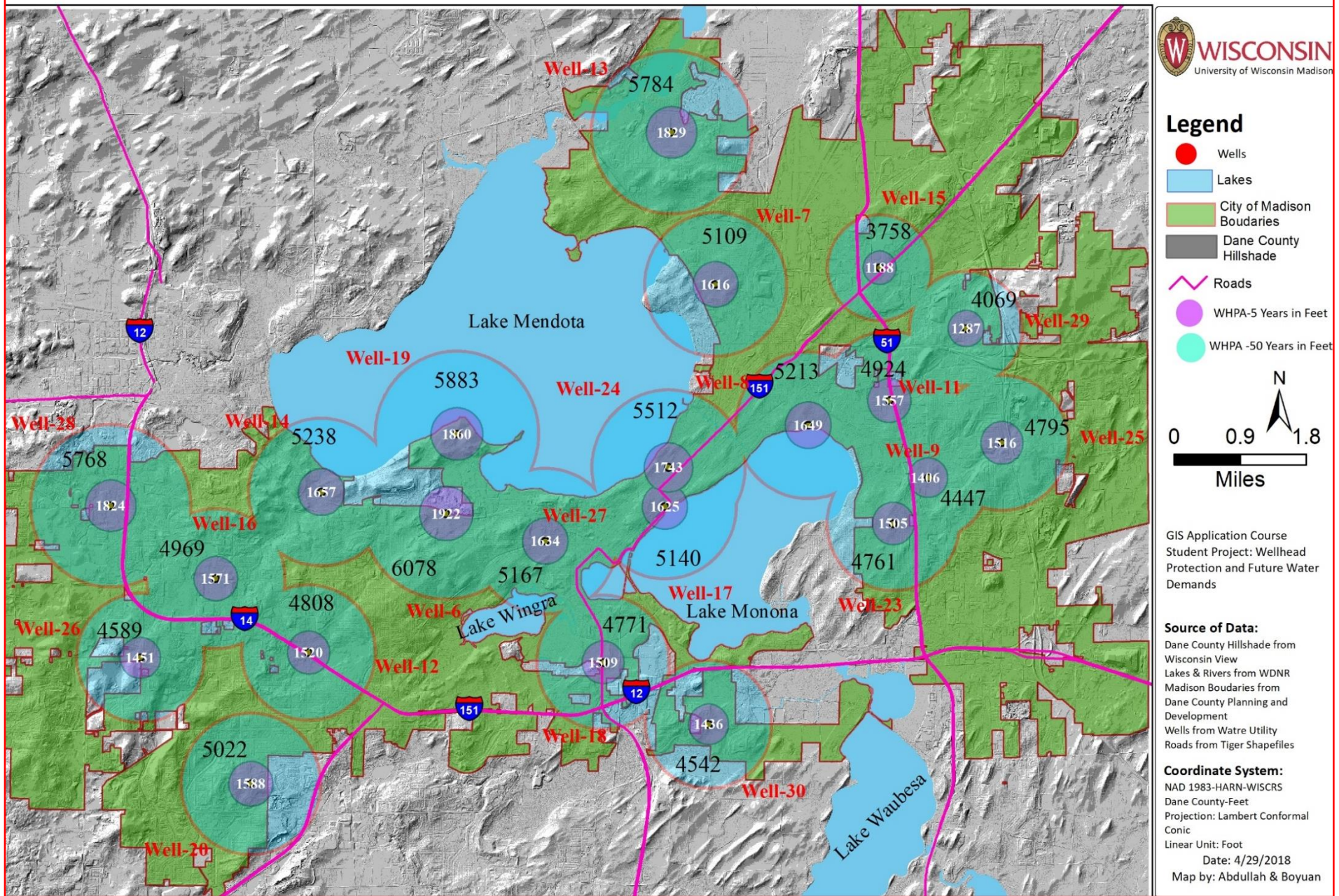


Figure 8. Wellhead Protection 5 and 50 years' Time of Travel

WELL RECHARGE AREA

Well ID	Discharge Rate (GPM)	Discharge Rate ft ³ /day	Well ID	Discharge Rate (ft ³ /day)	K (ft/day)	b (ft)	Hydraulic gradient	π	X _L (ft)	Y _L (ft)
6	2625	505313	6	505313	15	800	0.005	3.14	1341	4211
7	1750	336875	7	336875	15	800	0.005	3.14	894	2807
8	1800	346500	8	346500	15	800	0.005	3.14	920	2888
9	1650	317625	9	317625	15	800	0.005	3.14	843	2647
11	2100	404250	11	404250	15	800	0.005	3.14	1073	3369
12	2250	433125	12	433125	15	800	0.005	3.14	1149	3609
13	2700	519750	13	519750	15	800	0.005	3.14	1379	4331
14	2200	423500	14	423500	15	800	0.005	3.14	1124	3529
15	1100	211750	15	211750	15	800	0.005	3.14	562	1765
16	2330	448525	16	448525	15	800	0.005	3.14	1190	3738
17	2125	409063	17	409063	15	800	0.005	3.14	1086	3409
18	1700	327250	18	327250	15	800	0.005	3.14	868	2727
19	2125	409063	19	409063	15	800	0.005	3.14	1086	3409
20	2015	387888	20	387888	15	800	0.005	3.14	1029	3232
23	1050	202125	23	202125	15	800	0.005	3.14	536	1684
24	2000	385000	24	385000	15	800	0.005	3.14	1022	3208
25	1615	310888	25	310888	15	800	0.005	3.14	825	2591
26	1917	369023	26	369023	15	800	0.005	3.14	979	3075
27	1790	344575	27	344575	15	800	0.005	3.14	914	2871
28	2150	413875	28	413875	15	800	0.005	3.14	1098	3449
29	1050	202125	29	202125	15	800	0.005	3.14	536	1684
30	1350	259875	30	259875	15	800	0.005	3.14	690	2166

Table – 3- Estimated Well Recharge Area X_L & Y_L

The Geometry of the Well Recharge Area:

As stated previously that the Well Recharge area is regardless of the time of travel and it mostly relies on the flow direction. We needed to figure out the flow direction so that we can make/draw the geometry of the recharge area by showing the estimated X_L and Y_L on the map. For this purpose, we converted the Dane County DEM in to contour lines to show the difference in elevation across the city and then made the surface water flow direction map as shown in *figure10*.

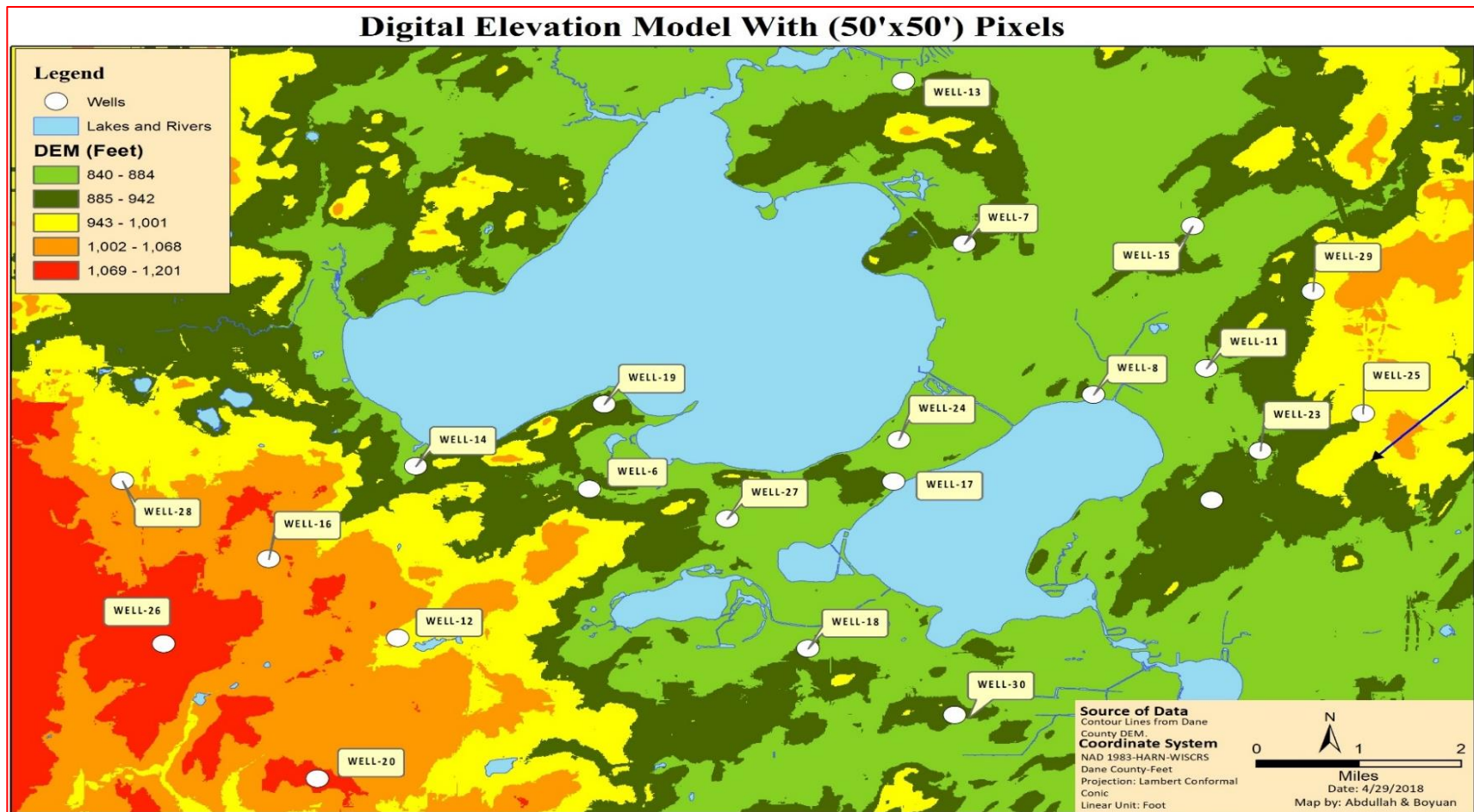


Figure 9 – City of Madison & Its Neighboring DEM

Contour Lines (Feet)

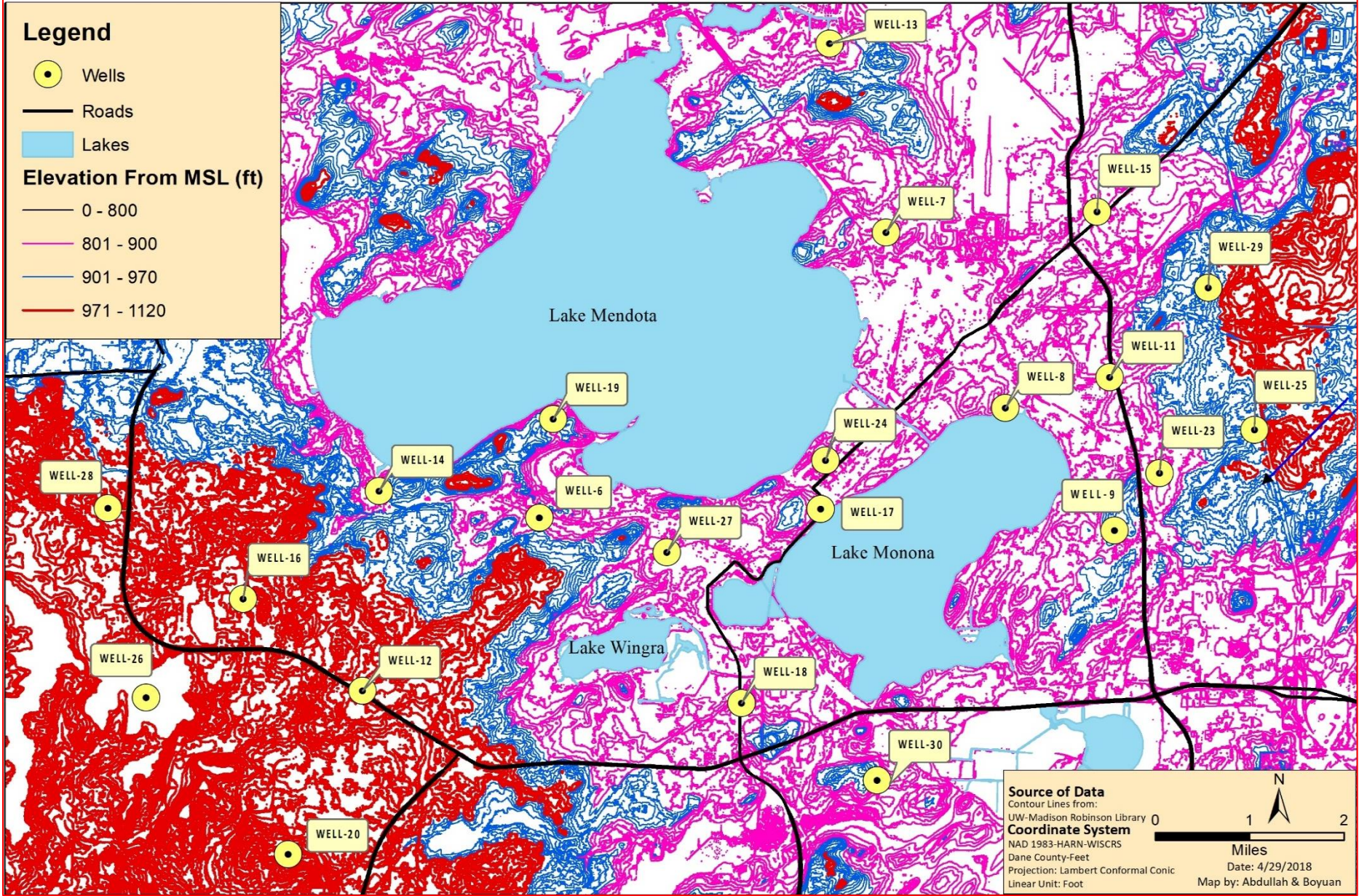


Figure 10 – Contour Lines Maps

Surface Water Flow Direction

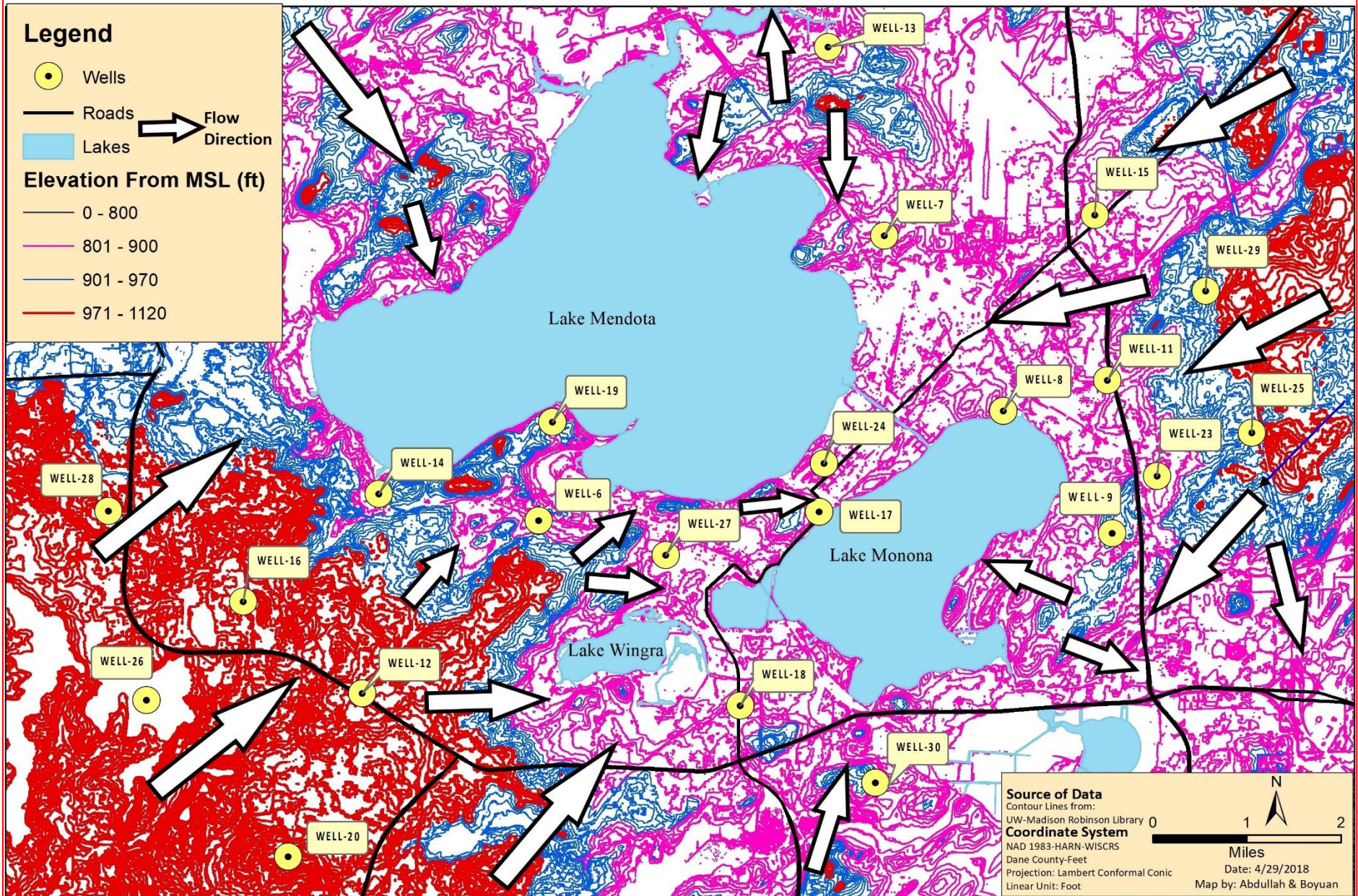


Figure 11 – Flow Direction Map

Recharge Area of Well 13 and 29

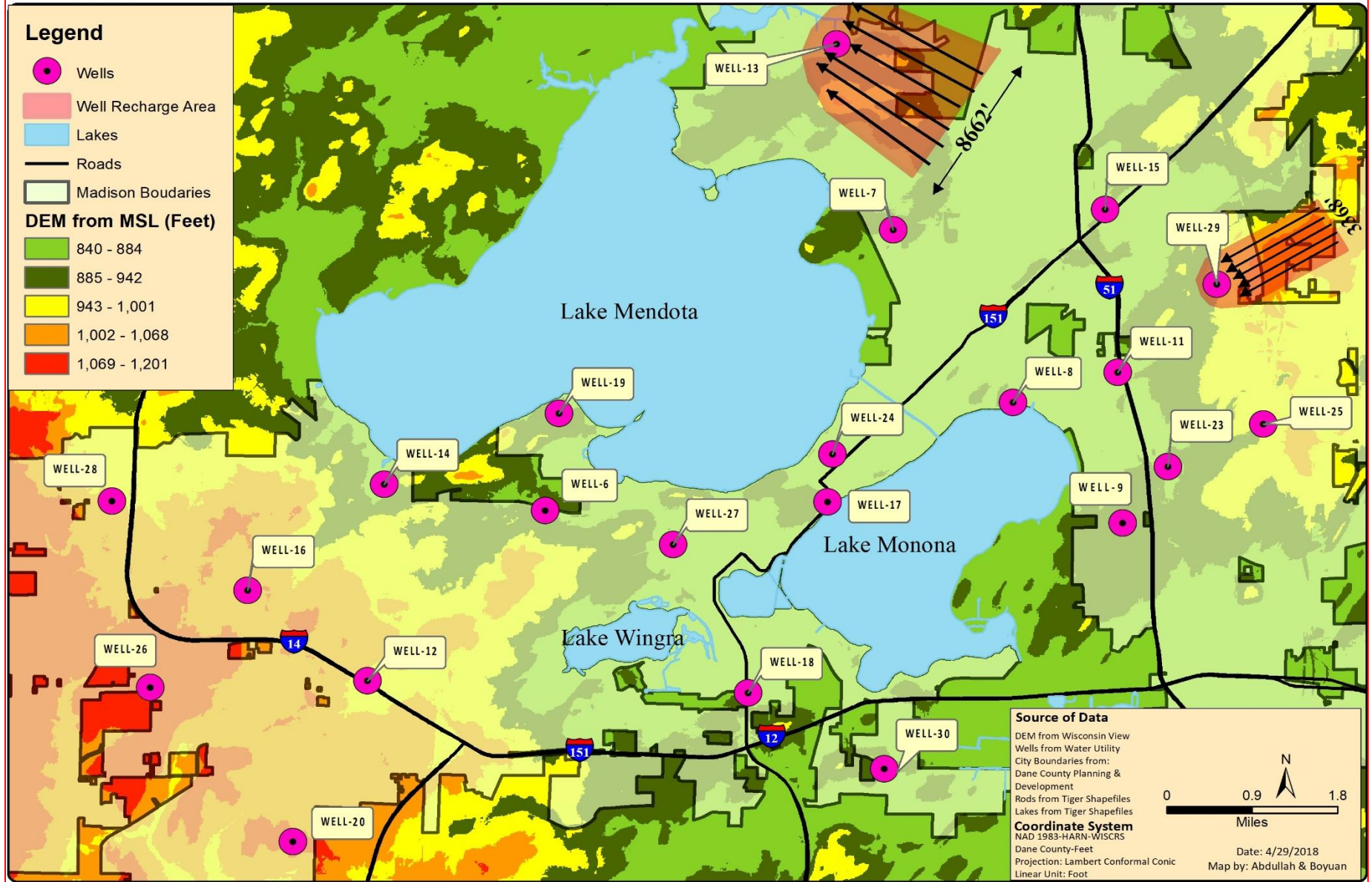


Figure 12 – Well 13 and Well 29 Recharge Area

Wellhead Protection and Well Recharge Area

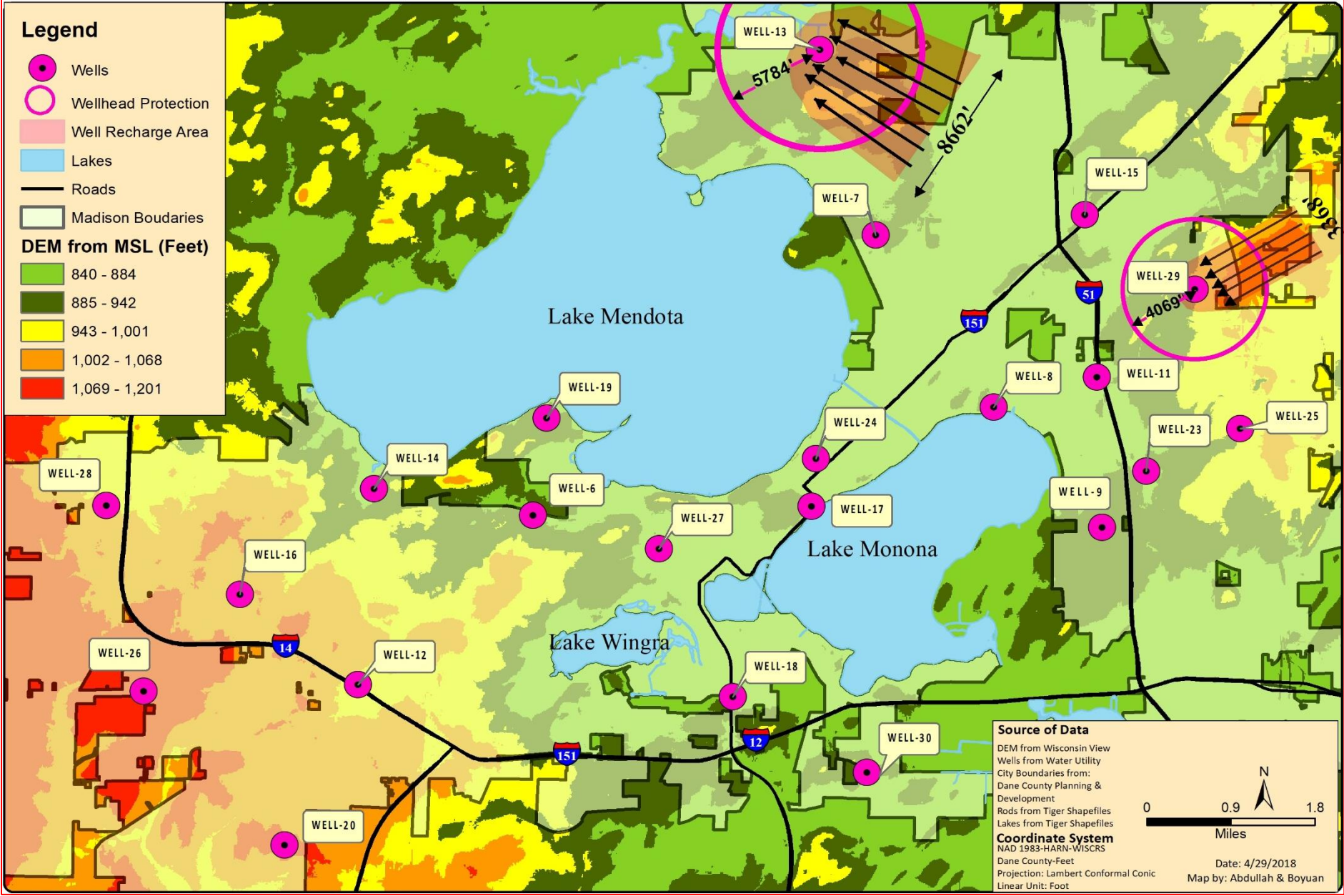


Figure 13 – Overlay of Wellhead Protection Area and Well Recharge Area

Water demands:

Water demand analysis could be divided into two parts: the population and water consumption part now and the population and water consumption part in 2068. As the population keeps growing in the past and might be increasing in the future as well, the water consumption will change too. The water demand now and in the future should be equal to product of the population and water consumption usage per-capita. We have gathered the historical population data for city of Madison from *Wisconsin Society Library* highlighted in the table below and numbers of wells and water consumption per capita during the past decades from *Water Utility* as shown in the figures on page 28.

Population and water Demands now:

Based on the graph we got from the **Water Utility** the water consumption per capita per day is changed from 80 gallons to 55 gallons, so we will consider the 55 gallons per day per capita as our norm for estimating the water demands now and as well as in the future. As we can see from *Number of Wells Table* on page 29, the total Pumpage rate for all 22 wells now is: **41392 GPM** which is equal to **2483520 GPH**

Total Deepwells Pumpage (GPM)		41,392
Total Estimated Population – As of July 2016		252,551
Hours Wells Operate (Hours)	Total Pumpage in (GPH)	Total Consumption in (GPH)
1	2,483,520	578,763
2	4,967,040	1,157,525
4	9,934,080	2,315,051
6	14,901,120	3,472,576
10	24,835,200	5,787,627
14	34,769,280	8,102,678
18	44,703,360	10,417,729
20	49,670,400	11,575,254
24	59,604,480	13,890,305

Table - 4 Deep Well Pumpage Rate and Water Consumption Now

From the estimation in the above table, all 22 wells should operate as an average 6 hours a day to meet the current population water demand.

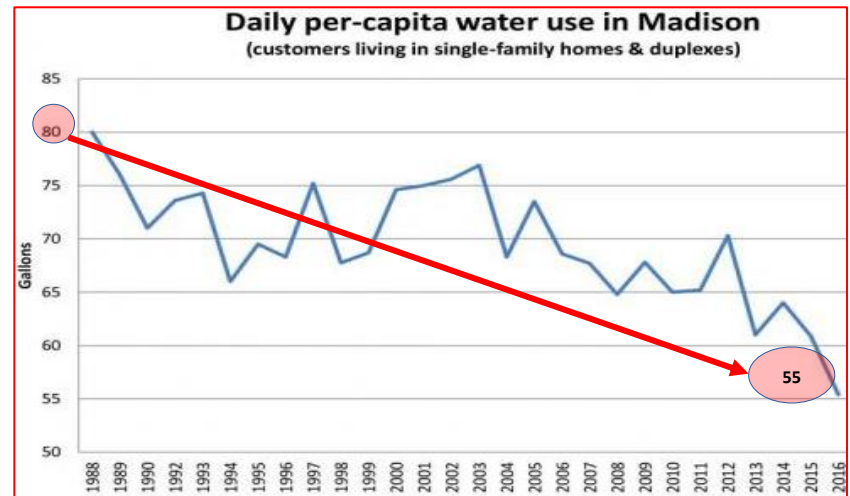
Data Tables Used in the Estimation of Projected Population and Water Demands in 2068

Dane County Population 1850-2000								
	1930	1940	1950	1960	1970	1980	1990	2000
Dane County	112737	130660	169357	222095	290272	323545	367085	426526
Albion Town	1334	1325	1386	1881	1926	1918	1984	1823
Belleville Village	564	594	668	787	972	1203	1349	1795
Berry Town	830	862	811	826	898	1116	1098	1084
Black Earth Town	316	346	312	396	379	406	365	449
Black Earth Village	490	531	655	784	1114	1145	1248	1320
Blooming Grove	2749	3015	5428	9709	1608	1965	2079	1768
Blue Mounds Town	698	650	596	585	675	637	667	842
Blue Mounds Village	182	196	207	227	261	387	446	708
Bristol Town	1057	1073	1107	1213	1491	1723	1835	2698
Brooklyn Village	134	144	149	216	217	250	406	502
Burke Town	1844	3003	2569	1511	1742	2967	3000	2990
Cambridge Village	500	577	552	805	672	785	883	1014
Christiana Town	1298	1147	1088	1111	1261	1209	1182	1313
Cottage Grove Town	1072	1033	900	568	1818	2952	3525	3839
Cottage Grove Village	261	310	372	1195	478	888	1131	4059
Cross Plains Town	909	908	901	853	995	1003	1206	1419
Cross Plains Village	302	374	464	1066	1478	2156	2362	3084
Dane town	808	796	749	781	894	945	921	968
Dane Village	280	301	305	394	486	518	621	799
Deerfield Town	842	811	838	832	855	1111	1181	1470
Deerfield Village	501	611	614	795	1067	1466	1617	1971
Deforest Village	540	598	805	1223	1911	3367	4882	7368
Dunkirk Town	1316	1276	1294	1510	2139	2098	2121	2053
Dunn Town	828	969	1793	2433	3391	4966	5274	5270
Edgerton City								42
Fitchburg City	1058	1257	2315	2880	4704	11973	15648	20501
Madison City	57899	67447	96056	126706	171769	170616	190766	208054
1st Ward	1652							

Source: Wisconsin Historical Library

Number wells from 1930 - 2016

Years	Total Population	Well Pupage Rate (GPM)	# of Wells
1930 - 1940	67447		4375
1940 - 1950	96056		1800
1950 - 1960	126706		11950
1960 - 1970	171769		9380
1970 - 1980	170616		4015
1980 - 1990	190766		5322
1990 - 2000	208054		2150
2000 - 2016	252551		2400
Total			41392
			22



Source: Water Utility

According to the data we got from Water Utility (*number of wells from 1940 – 2018*), it looks like the first two wells were constructed during 1940s. So, our initial condition is the water consumption and population in 1940. Based on the annual records from 1940 to 2016 for the population and number of wells, we could notice that the number of wells kept increasing as the population growing. Base on the population tendency and number of wells graph below, we could anticipate that how population change will affect the number of wells in the future.

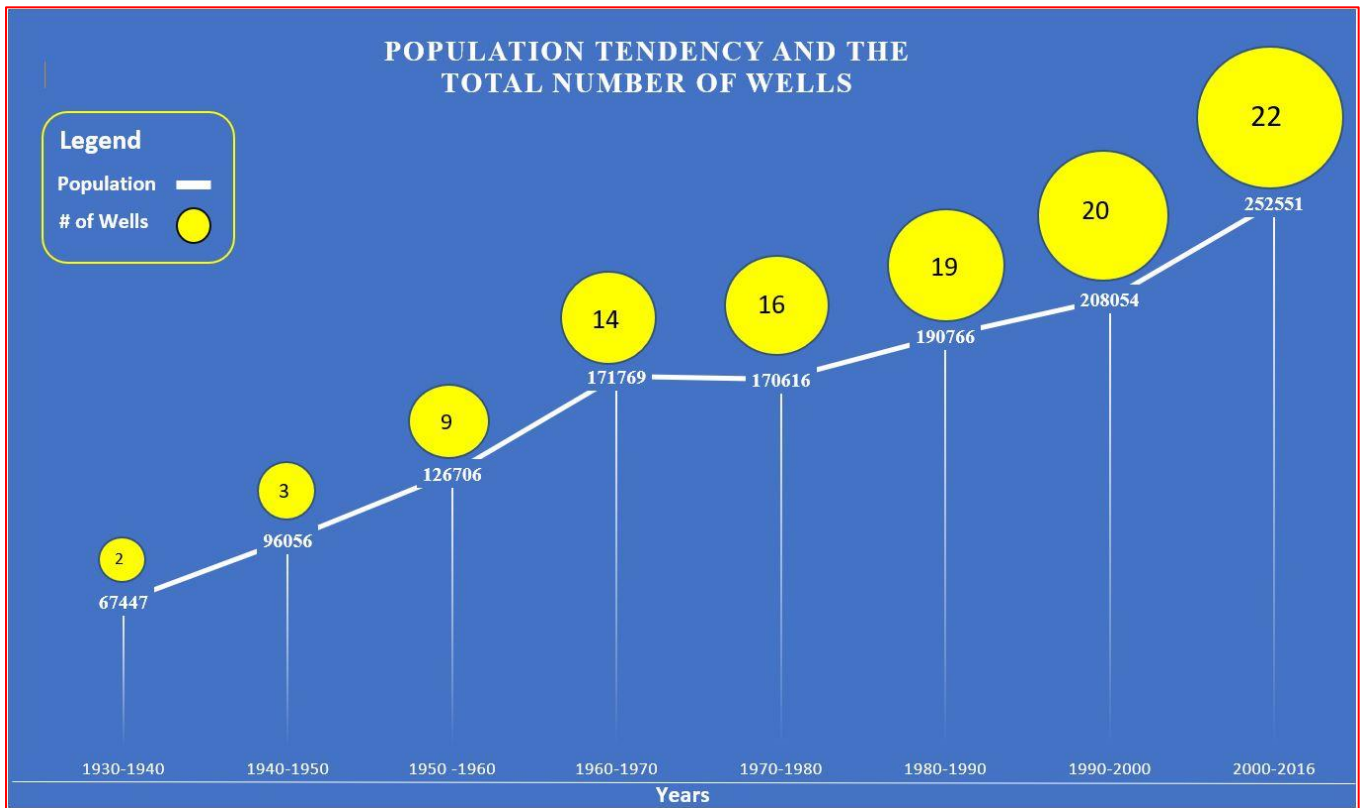


Figure 14. Population and number of wells from 1940 to 2016

Population and water Demands in 2068:

As mentioned previously that we used *Minor Civil Division* formula to estimate the annual average population growth. In the conceptualization part we wrote that, it is a moderate demographic linear growing pattern. We tried lots of different growing pattern such as power growing pattern or polynomial growing pattern, but these patterns did not fit with the projected population by Demographic Services Center of Wisconsin in 2040 as shown in Table 1. The annual estimated population growth and the projected population for 2068 is estimated as below:

$$3G = (P_{2016}-P_{1990}/T_{2016}-T_{1990}) + (P_{2016}-P_{2000}/T_{2016}-T_{2000}) + (P_{2016}-P_{2010}/T_{2016}-T_{2010})$$

$$3G = (252551-190766/2016-1990) + (252551-208054/2016-2000) + (252551-233209/2016-2010)$$

$$G = 2770$$

$$\text{Estimated Projected Population in 2068: } 252551 + (2770 * 50) = 391,051$$

Thus: The estimated water demands in 2068 would be $391,051 * 55 = 21,507,805 \text{ GPH}$

Total Wells Capacity (GPM)		41,392
Total Estimated Population - 2068		391,052
Hours Wells Operate (hrs)	Total Pump age in (GPH)	Total Consumption (GPH)
1	2,483,520	896,161
4	9,934,080	3,584,642
8	19,868,160	7,169,284
10	24,835,200	8,961,605
20	49,670,400	17,923,210
24	59,604,480	21,507,852

Table – 5 Pumpage Rate and Water Consumption Rate in 2068

The estimation in the above table shows that in 2068 all the 22 wells need to operate as an average of 10 hours a day to meet the projected population water demands in 2068, otherwise we may need additional well(s).

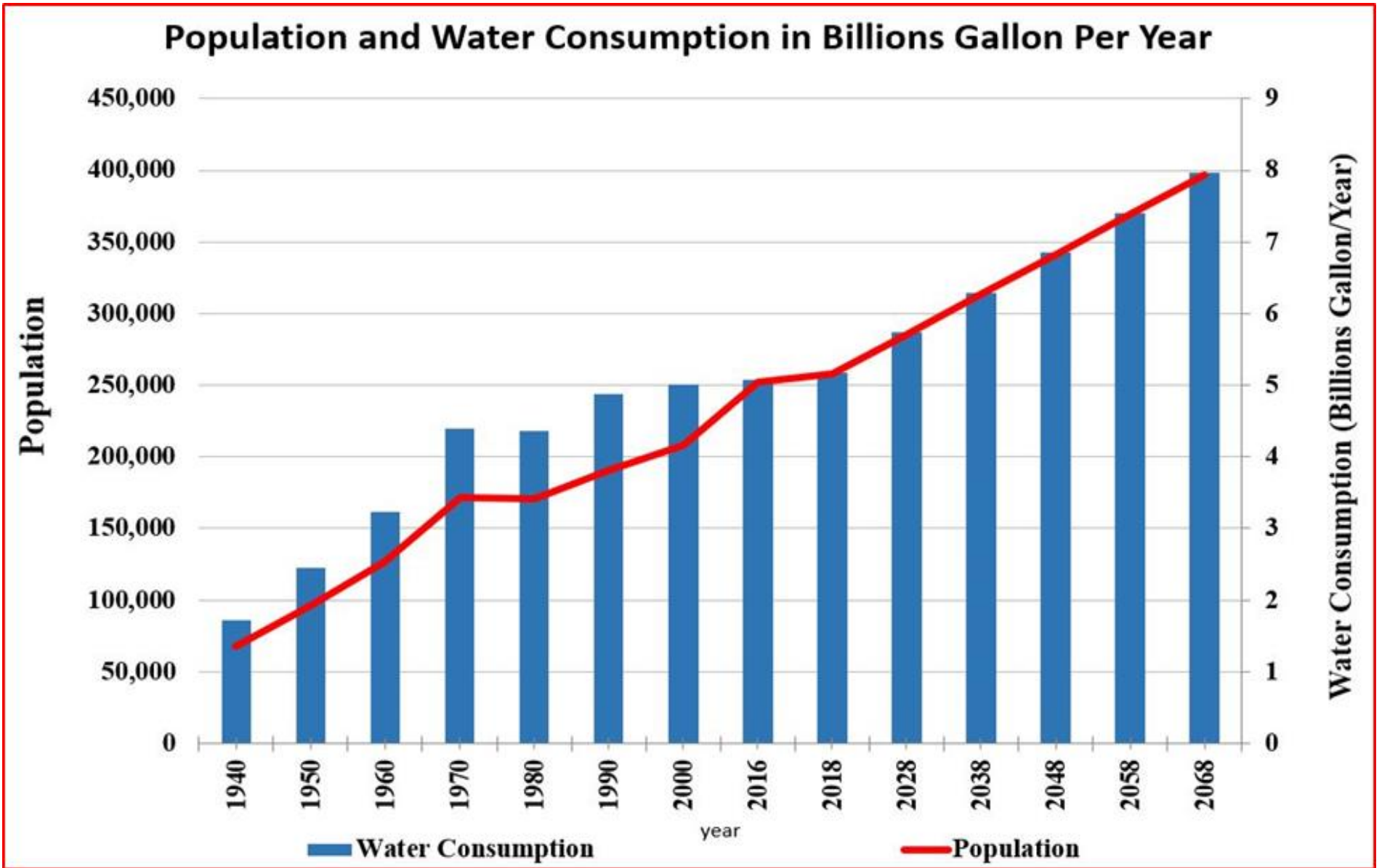


Figure 15. Population and Water Consumption Rate from 1940 - 2068

Population Density and Deepwells Pumpage in GPM

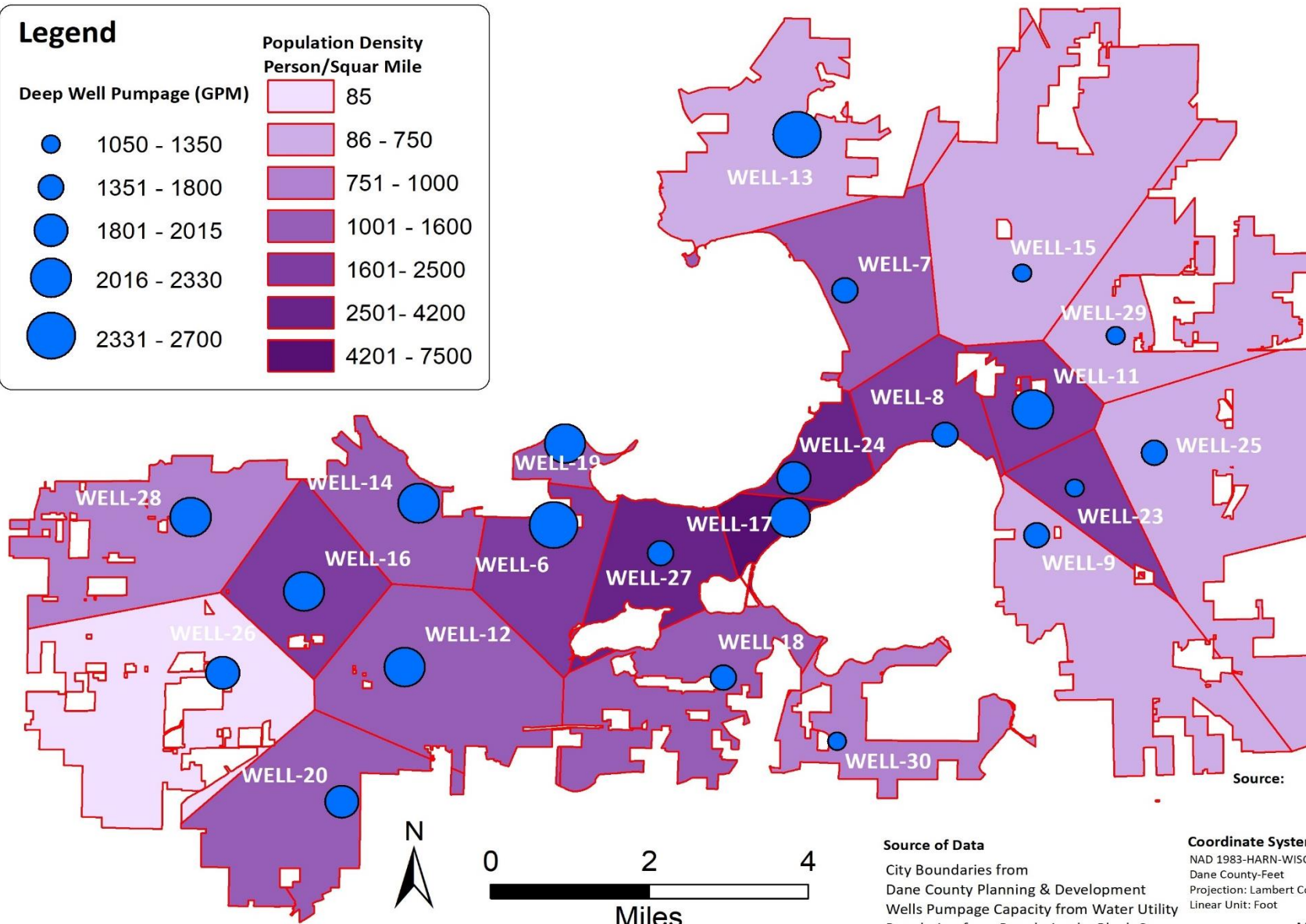
Legend

Deep Well Pumpage (GPM)

- 1050 - 1350
- 1351 - 1800
- 1801 - 2015
- 2016 - 2330
- 2331 - 2700

Population Density Person/Squar Mile

- 85
- 86 - 750
- 751 - 1000
- 1001 - 1600
- 1601- 2500
- 2501- 4200
- 4201 - 7500



Source of Data

City Boundaries from
Dane County Planning & Development
Wells Pumpage Capacity from Water Utility
Population from Population by Block Group

Coordinate System:

NAD 1983-HARN-WISCRS
Dane County-Feet
Projection: Lambert Conformal Conic
Linear Unit: Foot

Date: 4/29/2018

Map by: Abdullah & Boyuan

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