Appendix 4-R

Processing Municipal, Industrial, and Domestic Withdrawals and Discharge

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COHYST M & I
Municipal, Industrial, and Domestic Withdrawals and Discharge
Data Acquisition, Estimation, and Incorporation into the COHYST Grid.

To:	COHYST Group
From:	The Flatwater Group
Subject:	M & I write up
Date:	9/19/2011

This memo describes the production of municipal, domestic, and industrial datasets by The Flatwater Group, Inc., for use in the COHYST 2010 numerical ground water model from 1985 to 2010. Using available sources of withdrawals, returns, and population, "baseline" conditions were developed monthly for each entity in the region. Domestic consumptive use was determined from pumping withdrawals and returns converted to a per capita volume, and trended according to annual population estimates. The Industrial consumptive use baseline was developed using data acquired from the surveys mailed to industrial water users. When calculating consumptive use, large industrial uses were separated from municipal uses.

The databases were combined and applied to the COHYST grid in GIS with a descriptive rate of acre-feet per month. Data sources and method used to estimate municipal, industrial, and domestic withdrawals and returns within the eastern and central portions of the COHYST model region are described below.

DATA Sources

Data used in estimating the industrial and municipal withdrawals for the eastern and central portions of the COHYST area were acquired from several locations. The Department of Natural Resources (DNR), local natural resource districts (NRD) (Central Platte NRD, Tri-Basin NRD, Twin Platte NRD), and the United States Geological Survey (USGS) provided pumping measurements and estimates. DNR, NRDs, and the Nebraska Department of Environmental Quality (DEQ) provided discharge measurements and estimates. Information on population and demographics was acquired from the DNR and combined with data from the United States Census Bureau and USGS. The spatial location of the wells was attained from DNR.

DNR circulated two types of water use surveys to industries throughout the COHYST area. In addition, DNR provided population estimates for the COHYST counties and municipalities during several inter-census years. Finally, the DNR provided spatial information on the location of municipal, domestic and industrial wells across the area in the form of the registered groundwater wells database.

The first survey type was titled "Historical Surveys". Many of the industries surveyed receive their water source from municipal water supplies. This was reported in the upper right-hand section of the first page of the survey. Requested information included industry type, method of discharge, location of discharge if into a stream, DEQ NPDES permits, and the technique used to acquire the annual or monthly data (metered or estimated).

A second DNR water use survey was sent to owners of registered industrial wells. The survey included a list of wells used at an industrial location and requested information on any other wells that were used to supply water to the industry. The survey requested information on the industry type, well, DEQ NPDES permits, and the location where waste water was discharged into the stream, along with monthly or annual pumping and discharge values or estimates and the technique used to arrive at these estimates.

The USGS prepares withdrawal estimates in the form of a USGS water use circular titled "Estimated use of Water in the United States". These Water use estimates are published every 5 years. Electronic data on a county-level were available from 1985 to the most current publication in 2005. USGS's water use circular includes withdrawal estimates from publicly supplied water sources, self-supplied domestic water use, self-supplied industrial water use, irrigation, livestock production, mining, thermoelectric power production, and withdrawal totals on a statewide basis, with background data available on a county-level. The water use circulars also include estimates of total population, self-supplied population and publicly supplied population.

For the USGS circulars, the source of all self-supplied domestic withdrawals in Nebraska is assumed to be groundwater. A county's self-supplied population was calculated as the difference between the total county population and the estimated publicly-supplied population. Withdrawals were estimated based upon the self-supplied population and the average zonal[1] residential delivery per-capita rate based on the results from the public water system survey. Data sources for the self-supplied domestic withdrawals in the 2005 water use circular include the following: a public water supply

[1] As defined by the USGS estimation methods for the self-supplied domestic population withdrawals.

database maintained by the Nebraska Department of Health and Human Services System; a DNR 2005 Public Water System Survey; USGS Water Use in Nebraska, 2000 (USGS); DNR 1995 Water Use Report, and a U.S. Bureau of Census, 2006, 2000-2005 County Population Estimates report.

Besides information on withdrawals, estimates of returns were also obtained. Municipal and Industrial water users who discharge waste water into the streams are required to submit discharge monitoring reports (DMR) to the DEQ. These discharge reports were obtained, when available, to confirm the amount of wastewater discharged by the industry or municipality.

United States Census Bureau records were also used to acquire population estimates for the municipalities and counties that were in the eastern and central portions of the COHYST area. Population estimates from the census were available on a ten-year basis.

Industrial Data and Estimates

The data supplied by the industry contacts came in several different formats. Industries typically provided monthly or annual data based upon metered pumping data, while a few provided summaries of utilities statements. However, many of the industries did not have meters on either their water source or discharge point, and several cited this as the reason they were unable to report their water use. Other industries attempted to make good-faith estimates of either monthly or annual values based on their instantaneous pumping rates, consumption rates, or other methods.

Industries that possessed a DEQ NPDES permit often did not include discharge data, and instead referred to the DMRs submitted to the DEQ. Discharge data were acquired for sites with NPDES permits to match the time period for which the industry supplied withdrawal records.

The metered and estimated data, as well as the DEQ DMR discharge values, were compiled into a database for each surveyed location. While the scope of the project was to investigate municipal and industrial water use from 1985-2010, none of the industrial records were complete for the entire time period. To account for these limitations, estimation techniques were developed to fill in the gaps.

Partially completed set of monthly data points for a year

This first technique was used for those situations where there were unknown monthly water withdrawal values in partially reported years. Water use was not consistent throughout the year for many industries; there were periods where withdrawals were relatively higher or relatively lower. This

may be due to a variety of reasons, but when estimating unknown values, it was important that an attempt be made to account for these temporal patterns.

Using years where a complete set of monthly data was available, the monthly distribution for each year was developed by calculating the average proportion of the annual withdrawals that occurred during each month. Using this average monthly distribution, the total amount of withdrawals were estimated by averaging the quantity of the known monthly value divided by the average monthly withdrawal proportion for those months where withdrawal data were available.

$$\widetilde{W_a} = \frac{\sum_{i=1}^{n} \frac{W_i}{\overline{P_i}}}{n}$$

$\widetilde{W_a}$ Estimated annual withdrawals

W_i Known monthly withdrawal for month i

$\overline{P_i}$ Average monthly proportion of the annual distribution of withdrawals $\left(\sum_{i=1}^{12} \overline{P_i} = 1.0\right)$

n Number of months with available monthly withdrawal data

The unknown monthly values were estimated by multiplying the estimated annual withdrawals by the corresponding average monthly proportion of the annual distribution of withdrawals. This same technique was applied to the discharge values to estimate missing monthly data points in an incomplete year.

Missing annual and monthly data

For some industrial withdrawal records, entire years' worth of records were missing. For these situations, annual withdrawal data were estimated, using an established procedure. The industries were investigated to ensure that they were operational during the investigation period, and that if they had private wells, that those wells were present during a given year. If the industry had multiple wells, and one or more of those wells was completed during the investigation time period, the estimated withdrawals by the industry were prorated according to the pumping capacity of active wells compared to total pumping capacity for the years prior to the completion date of the well or wells in question. If the industry used a consistent amount of water each year, it was assumed that the pattern for the known period persisted during periods with missing records, and this annual amount was then applied to all the missing years.

Withdrawals for industries that saw fluctuating annual amounts were estimated by considering the average portion of non-irrigation pumping within a respective county that could be attributed to the particular industry. Using the supporting data from the USGS circulars for the years 1985-2005, estimates for the total irrigation withdrawals and the total county withdrawals were obtained. Irrigation encompasses the majority of the total withdrawals for most of the counties of interest. By removing the irrigation estimate from the total estimate, an estimate of the non-irrigation withdrawals was developed. The non-irrigation annual withdrawals for the year 2010 were estimated as either the average of 1985-2005 withdrawals if the volume of water being withdrawn was fluctuating up and down over time, or using a linear regression trend if there was a persistent growth or decline over the time period. Linear interpolation was used to determine the intermediate values.

$$W_t = W_a + (W_z - W_a)\left(\frac{Y_t - Y_a}{Y_z - Y_a}\right)$$

W_t	Estimated non-irrigated withdrawals for a year between Y_z and Y_a
W_a	Estimated non-irrigated withdrawals for a known year prior to the year of interest
W_z	Estimated non-irrigated withdrawals for a known year following the year of interest
Y_t	Year of interest
Y_a	Year of available data prior to the year of interest
Y_z	Year of available data following the year of interest

Initially, the USGS industrial withdrawals estimate was considered as the benchmark for comparisons. However, the USGS water use circulars do not always have a consistent format from publication to publication, and some categories have been eliminated and/or combined to form other categories. This appears to have been the case for industries that use a municipal source. Occasionally, withdrawal estimates obtained for a single industry within the DNR survey data exceeded the annual self-supplied industrial water use estimates in the USGS circular. Because of these circumstances, non-irrigation withdrawal values were developed instead.

These estimates were derived by removing the major source of withdrawals (irrigation) from total USGS county withdrawal estimates. Having estimated the county's non-irrigation withdrawal, the proportion of non-irrigation withdrawals associated with a given industry was determined for each year in which industry withdrawal data were available. These annual proportions were then averaged across all years of available records. This average proportion was then used to estimate annual pumping volumes for each unknown year in the period of interest by multiplying that fraction by the USGS non-

irrigation withdrawal value for each year with missing data. The final step was to distribute the annual value to monthly values, which was done by using the average monthly distribution.

The self-supplied industrial withdrawals were geospatially referenced by assigning those values to the COHYST cells where their wells were located. If an industry acquired its water from a municipal supply, the industrial withdrawals were applied to the cell representing the centroid of the municipality. Several municipalities contained multiple industrial sites, in which case the withdrawal values were simply summed and applied to that location.

Estimating Discharge

When discharge values were present in conjunction with the withdrawal values, the annual ratio of discharge to withdrawals was computed. The average relationship was then applied to the years when no annual estimates or values were present, by multiplying the annual withdrawals by this average ratio. This process was undertaken to approximate the annual discharge in unknown years, including years where the withdrawals were estimated. Once the annual amounts had been estimated they were partitioned using the average monthly discharge proportion of total discharge.

Some industry sites included only annual values or estimates. If there were industries that served the same purposes (i.e. two alfalfa pelleting plants) and only one of them had monthly values, the monthly distributions for that industry were applied to the industry that included only annual values. Otherwise the withdrawals or discharges were spread uniformly across the year.

The discharge values were assigned to the COHYST cell that contained the location of discharge, but only if the industry had a known discharge location into a stream. If no discharge locations were identified, it was assumed that the industry had a zero-discharge facility.

Municipal Data and Estimates

Municipal withdrawals and discharges were acquired for 36 communities and estimated for an additional 12 communities in the COHYST model area. Monthly withdrawal and/or discharge data were provided by the Twin Platte NRD, Central Platte NRD, and the Tri-Basin NRD. Supplemental discharge data were acquired from the DEQ DMRs.

Municipal pumping estimates were heavily dependent on the size of the municipal population. Population estimates supplied by the DNR for the years 1994-1999 and 2005 were combined with data

from the U.S. Census Bureau from 1980, 1990, 2000, and 2010 to estimate the population for each year during the investigation period. Linear interpolation between two known annual population values was used between the known data points.

Once the population was estimated, the per capita withdrawals or discharges were calculated on a monthly basis for the years with available data. For years with missing data, a moving average of the previously calculated per capita withdrawals or discharges was used to calculate the monthly withdrawal or discharge by multiplying the moving average with the estimated population.

$$\widetilde{W}_{m,y} = \frac{P_y \sum_k C_{m,k}}{n}$$

$\widetilde{W}_{m,y}$	Estimated withdrawal or discharge for the municipality for a given month and year.
$C_{m,k}$	Per Capita withdrawals for a given month (m) and year (k).
P_y	Estimated Population of the municipality during a given year y
n	Number of years in the moving average. An 8 year moving average was used except for those cases with less than 8 years of available data.
m	The month being estimated
k	The years being used in the moving average (n years total).

The next step was to remove the municipally supplied industrial withdrawals from the municipal withdrawals, which was done on a city-by-city basis. Lexington, NE, municipal withdrawals were approximately half of the withdrawals used by Tyson Fresh Meats, the largest industrial user. While the Tyson Fresh Meats water use survey from DNR states that Tyson's water source was from the municipal supply, it was assumed that the industrial withdrawals have already been removed from the municipal withdrawals in Lexington. The municipal withdrawals were then assigned to the COHYST cell containing the centroid of the municipality.

Estimating discharge when no data were present

If no discharge data were available, the annual discharge was estimated as a proportion of withdrawals. The proportion used was calculated in different ways, depending upon the population of the municipality. For municipalities smaller than 1,500, between 1,500 and 10,000, and greater than 10,000, ratios of .341, 0.438, and 0.630 were used to estimate discharge, respectively.

The annual discharge was then distributed by using distributions calculated for other nearby municipalities or municipalities with similar populations. For each town that lacked discharge data, the

average monthly discharge distribution for the four closest towns was compared to the average monthly discharge distribution of the four towns with similar population size regardless of location (with the caveat that the towns used to calculate the averages needed to have discharge data available). The difference between these two discharge distribution estimates was rarely greater than 1%, and often below 0.5%. With this in consideration, estimates were made using the distribution of similar sized towns.

Blank values for partial years were estimated using the same procedure explained for the industries. If only the annual amount was reported, it was distributed according to the average distribution based upon municipalities of similar size.

Discharge values were assigned to the COHYST cell at the location where the municipality discharged into a stream. For municipal discharges with no known discharge locations, it was assumed that they employed zero-discharge wastewater facilities.

Domestic Self-Supplied Withdrawal Estimates

Self-supplied domestic withdrawals were calculated based upon the USGS water use circulars published in 1985, 1990, 1995, 2000, and 2005. A value for 2010 was estimated using either 1) the average over the period 1985-2005 if there were sigmoidal fluctuations (Figure 1) every five years or 2) a linear regression model if there was a persistent rise (Figure 2) or decline in the withdrawal rate. Withdrawal rates for years between USGS circulars were estimated using linear interpolation. The monthly distribution developed for a municipality with a population less than 1,500 residents was used to partition the annual withdrawals into monthly values.

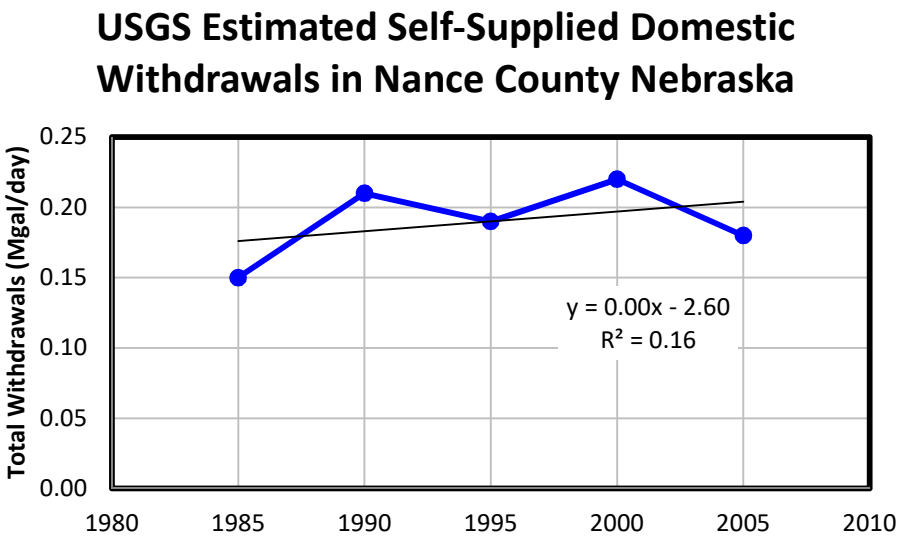

Figure 1. Fluctuating self-supplied domestic withdrawals in Nance County, Nebraska.

A list of all domestic wells with their geographic location was acquired from the DNR registered groundwater well database. The monthly self-supplied domestic withdrawal values were then assigned to the COHYST cells based upon the number of wells present in each cell. A uniform quantity of water withdrawals was assigned to each well and the cumulative amount was assigned to the cell. This process was done for 32 counties wholly or partially contained in the middle and eastern sections of the COHYST model area.

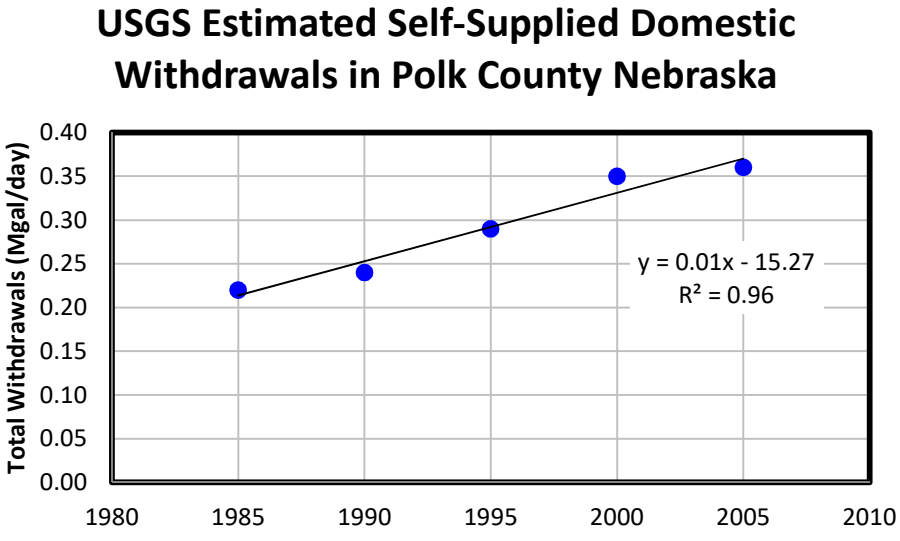

Figure 2. Upward trending self-supplied domestic withdrawals in Polk County, Nebraska.

The maximum level of withdrawals in any given cell was 275,000 gallon pumped in a single month. This occurred during January, 2005, in cell 85066, which was located in Hall County, Nebraska, and contains 49 domestic wells. If the pumps were run 24 hours a day for the entire month, the combined capacity of the 49 wells would need to be less than 6.4 gpm, or 0.13 gpm per well. Assuming the wells were active a quarter of the time, the combined capacities of the well would need to be 25.5 gpm, or 0.52 gpm per well. These values appear to be within the pumping capabilities for a typical domestic well.