

Appendix 2

LEGGETTE, BRASHEARS & GRAHAM, INC.

PROFESSIONAL GROUND-WATER AND ENVIRONMENTAL ENGINEERING SERVICES

8 PINE TREE DRIVE
SUITE 250
ST. PAUL, MN 55112
(651) 490-1405
FAX (651) 490-1006
www.lbgweb.com

October 31, 2012

Mr. Richard Soule
Hydrologist
Source Water Protection Unit
Minnesota Department of Health
P.O. Box 64975
St. Paul, Minnesota 55164-0975

Re: **Amendment to the Part I Wellhead Protection Plan**
Moorhead Public Service
Moorhead, MN

Dear Mr. Soule:

The purpose of this letter report is to summarize the portion of the amendment to the Part I wellhead protection plan (WHP Plan) completed by Leggette, Brashears & Graham, Inc. (LBG) for Moorhead Public Service (MPS). MPS is required by the Minnesota Department of Health (MDH) (Minnesota Rule[MR], part 4720.5579, item C, to amend the Part I WHP Plan because eight years have expired since the approval of its last WHP Plan.

This amendment updates the original Part I WHP Plan that was completed for the six MPS wells that supply water to the City of Moorhead, Minnesota (City). The MDH completed the original WHP area (WHPA) delineation in December 2000 for MPS Wells No. 6 and 6B, and Barr Engineering completed the WHPA delineation for Wells No. 8 through 12 in 2001. The reason for the independent delineation work is that the MPS wells pump from two different groundwater sources that are hydraulically disconnected. Wells No. 6 and 6B pump from the deeper Moorhead Aquifer and Wells No. 8 through 12 are completed in the shallower Buffalo Aquifer. The locations of the wells are shown on Figure 1 and well construction details are in Table 1.

As indicated in the MDH's March 21, 2012 letter to MPS outlining the scope of work needed to amend the Part I WHP Plan, the capture zone analyses and associated WHPA delineations for MPS wells in the Buffalo Aquifer was not necessary since the MDH recently completed this task after updating Barr Engineering's 2001 groundwater flow model. As a result, the work completed by and reported herein by LBG does not include any documentation for the Buffalo Aquifer groundwater modeling and associated capture zone analyses. However, LBG utilized the MDH's WHPA delineations to meet the objectives of amending the Part I WHP Plan, which are as follows:

Buffalo Aquifer (Wells No. 8 through 12)

- Use the 20-year travel time WHPAs delineated by the MDH and determine the surface water contribution areas to these zones (i.e., conjunctive delineations). These combined areas determine the final WHPAs; and,
- Determine the vulnerability of the Drinking Water Supply Management Areas (DWSMAs) defined by MPS.

Moorhead Aquifer (Wells No. 6 and 6B)

- Delineate the 20-year time of travel area for these wells by evaluating existing historical hydrogeologic information, refining the conceptual hydrogeologic model and characterizing the groundwater flow field, estimating aquifer transmissivity, and applying a numerical groundwater flow model; and,
- Determine the vulnerability of the DWSMA defined by MPS.

To meet the above objectives, the following tasks were completed by LBG:

- Met with MDH and MPS to discuss the available data and MDH's expectations for addressing the uncertainty associated with the Moorhead Aquifer;
- Worked with the MDH and MPS to define surface water contribution area required for the conjunctive WHPA delineation of Buffalo Aquifer Wells No. 8, 9 and 10;
- Assisted MPS with defining the associated drinking water supply management areas (DWSMAs);
- Refined the conceptual hydrogeologic model of the Moorhead Aquifer using available well logs, historical water level and MPS well pumping data, previous studies, and other delineation criteria;
- Applied the numerical groundwater flow model, MODFLOW, to update the WHPA of the Moorhead Aquifer wells;
- Completed a sensitivity analysis on the model to address the uncertainty associated with the Moorhead Aquifer and used the result to delineate a composite WHPA;
- Provided the WHPA to MPS who delineated the DWSMA of the Moorhead Aquifer wells;
- Completed the vulnerability assessments of the DWSMAs; and,
- Provide recommendations to MPS on activities that could be undertaken over the next ten years to investigate and/or mitigate the potential for contaminants to enter the aquifer via surface water.

Data Elements

The Minnesota Rules require several data elements to be used in a WHP Plan based on the hydrogeological setting and vulnerability of the well and the DWSMA. The data elements were considered and most are consistent with those presented in MPS's original WHP Plan. Additional information or changes that were identified in the original plan as a result of this amendment are summarized below:

Precipitation

Precipitation was not applied across the Moorhead Aquifer model domain because of the laterally extensive till from the surface to the top of the buried aquifer.

Geology

The MPS wells are completed in Quaternary sand gravel aquifers within the Lake Agassiz Plain geomorphic region. The sand and gravel deposits vary in extent and thickness across the area and have been characterized based on well logs in the Minnesota County Well Index (CWI) database and reviewing previous studies by the MDH (2000), Wolf (1981), Ripley (2000), and DNR (2000). The conceptual geologic model has not changed significantly from the original plan. Minor refinements were made to the extent of the Moorhead Aquifer by evaluating geologic logs, groundwater levels, and specific capacities from surrounding wells. More detail is provided below in the discussion of the conceptual model. New hydrogeologic cross sections were created and the locations of A-A' through E-E' are shown on Figure 1. The cross sections are in Attachment 1.

The limited number of well logs in the area and the complex deposition of glacial till, outwash, and lacustrine sediments make interpreting the configuration of the Moorhead Aquifer challenging and expose the uncertainty associated with this aquifer. Based on the previous work and other available data, the Moorhead Aquifer appears to be limited in its extent to approximately 0.5 miles to the east and west of the MPS wells, and roughly 2 miles to the north and south as shown on Figure 2. Thicknesses in this area appear to range from 50 to 100 feet. Outside of this general area the sand and gravel layers thin significantly and become more discontinuous, and the degree to which these units are connected to the Moorhead Aquifer cannot be determined.

The aquifer pumping test on Well No. 6B completed in 1997, historical pumping data from MPS and the neighboring City of Dillworth, and water level data from the CWI were also used to refine the conceptual model of the Moorhead Aquifer.

The hydrogeology of the Buffalo Aquifer is presented in the original plan and not provided in this report. LBG did evaluate water levels in this aquifer relative to the Moorhead Aquifer to assist in interpreting the hydraulic connection between the systems.

Soils

The SSURGO soils database was used in the vulnerability assessment of the Buffalo Aquifer DWSMAs. The SSURGO soil unit descriptions for all soil types within the DWSMA are presented in the vulnerability section and shown on Figure 3 and included in Attachment 2.

Water Resources

A micro-watershed analysis was completed for the conjunctive WHPA delineation associated with MPS Wells No. 8, 9 and 10 in the Buffalo Aquifer. No other water resource information has changed since the original WHP plan.

Landuse

MPS completed the delineation of the DWSMA based on recent City, township, and county parcel information. Parcel numbers are provided for the Buffalo Aquifer DWSMA, but not for Moorhead Aquifer parcels because of the City lot detail used to define this DWSMA. A CD with the parcel information is included as Attachment 3. No significant landuse changes have occurred since the original plan that would impact the DWSMAs.

Utilities

The projected daily water volume pumped by MPS wells used for the delineations of the WHPAs was based on the 2015 projection provided by MPS and summarized in Table 2. The annual volume is anticipated to increase from approximately 409.5 million gallons per year (MGY) in 2010 to 417.5 MGY by 2015.

Surface Water Quantity and Quality

These data were not used in the Moorhead Aquifer delineation since the aquifer is classified as “not vulnerable” and is hydraulically disconnected from surface waters by glacial till, and lacustrine silts and clays.

Groundwater Quantity and Quality

LBG obtained appropriation data from the Minnesota Department of Natural Resources (DNR) and from the MDH scoping letter. The eight wells are listed in Table 3. Four of these are in the Buffalo Aquifer, the two City of Dillworth wells are no longer used, and two golf course irrigation wells have no available information. No additional quality data were used in the Moorhead Aquifer assessment.

Delineation Criteria

The following discussion presents a summary of the five criteria for delineating the amended WHPAs, which are specified in MR 4720.

Time of Travel

A 20-year time of travel was used to determine the capture zones and WHPAs of Wells No. 6 and 6B in Moorhead Aquifer. The model sensitivity and uncertainty analysis results described below generated several capture zones and a combined or composite WHPA was created based on the overlapping extents.

MPS Wells No. 8, 9 and 10 in the Buffalo Aquifer required a conjunctive delineation since this aquifer is vulnerable and the capture zone intercepted a portion of the Buffalo River. The conjunctive delineation was based on the 20-year time of travel WHPA determined by the MDH and the micro-watershed analysis completed by LBG and MPS.

Aquifer Transmissivity

The transmissivity values were obtained from aquifer pumping test results obtained from Well No. 6B performed by the MDH in September 1997. Results from the test are found in Appendix I of MDH's *Wellhead Protection Plan for the City of Moorhead Wells No. 6 and 6B*, dated December 2000. The same transmissivity value of 19,536 square feet per day (ft²/day) was used in the amended delineation.

Daily Volume of Water Pumped

The daily volume selected for each well used in the WHPA was based on MR 4720.5510, subpart 4 and MDH guidelines, which state that volumes used in the WHPA delineation can be determined from either 1) the projected use of each well as a percent of the total system, or 2) the greatest annual volume of water used over the previous 5 years. The rates used in the delineation from 2015 and are summarized in Table 2. Additionally, the total volume is

slightly greater than the demand projected for 2010 creating a more conservative delineation. The projected demand was supplied by MPS.

Hydrologic Boundaries

Boundaries that could affect the delineation are surface water features, hydrogeological boundaries, high capacity wells, and overland drainage. The discontinuity of the buried aquifer, and high-capacity wells were considered. Surface water and overland flow are not a factor because they do not directly influence groundwater in the Moorhead Aquifer.

Groundwater Flow Field

Groundwater in the project area generally flows east to west and is controlled by the topographical high areas to the east and several rivers and streams to the west (DNR, 2000; and MDH, 2000). The primary discharge point appears to be the Red River, which flows south to north through the project area forming the western boundary of the City. The surficial material in the area is primarily composed of glacial till with sand deposits forming lenses and aquifers within the till. While some of these sand deposits are large (i.e. the Moorhead and Buffalo aquifers) none of the sand bodies appear to be continuous throughout the project area.

Model Update

The existing WHPA for the MPS wells was delineated using the MLAEM computer code. The updated WHPA was created using MODFLOW (USGS, 2005) as implemented in GMS Version 8.2 (Aquaveo, 2012).

Conceptual Model

As described in the previous Part I WHP Plan (MDH, 2000) very little data is available to accurately define the size, shape, and extent of the Moorhead Aquifer. There is some well log data but it is not sufficient to define the aquifer with any degree of certainty. However, MPS has collected pumping and water level data since the early 1900s and this provides very useful information that can be used to make some assumptions for creating the model.

Figure 4 shows the water level and pumping data the City and MPS collected between 1913 and 2010. This figure can be used to infer several things about the aquifer. First, it is likely smaller at the top and gets larger with depth. This appears to be the case as the water level decreases by approximately 75 feet in the first decade of pumping when the average pumping rate remained approximately 100 MGY. This rate of decline continued over the next 25 years despite significantly increased pumping rates. This would indicate that the volume of storage is incrementally larger with depth.

The pumping rate for the Moorhead Aquifer wells continued to increase to a high of 450 MGY in 1948 when the water level in the aquifer dropped to a low of approximately 194 feet-bgs. Starting in 1950 and continuing until 1960 the pumping rate for the aquifer averaged a relatively constant 100 MGY. During this time the water level in the aquifer also remained relatively constant at approximately 175 feet-bgs. This indicates that the water recharging the aquifer, at this water level, is nearly equal to the amount being withdrawn. During the early 1960s, annual withdrawals remained less than 100 MGY and water levels in the aquifer began to rise. As withdrawals increased to above 100 MGY from the mid-

1960s until the late-1980s water levels declined. During the early-1990s withdrawals again stabilized around 100 MGY and the water level remained relatively stable. Since 1998, withdrawals have remained below 100 MGY and the water level has steadily increased as a result.

This information suggests that recharge to the aquifer, at least at the current level of drawdown, is approximately 100 MGY. As water levels increase, the gradient of flow in the surrounding till will be decreased and thus reduce recharge. However, at the current withdrawal rate, the water level in the aquifer would take decades to rebound to near pre-pumping conditions.

The previous model included areas north of the City in the Moorhead Aquifer based on the combination of sand at a similar depth as well as similar static water levels on well logs in that area. However, further examination indicates that specific capacity testing produced much more significant drawdown of the water level than would be expected in the Moorhead Aquifer in some of those wells (e.g. MN Unique ID 143188) suggesting no connection or only a very limited connection exists. This shortened the aquifer in the north-south direction from the original model. It is also possible, however, that the Moorhead Aquifer has, or at one point had, connections to other, similar aquifers that provide or provided water to the aquifer. For example, looking at cross-section A-A' (Attachment 1, Figure 1), there appears to be the possibility that a connection exists between the aquifer utilized by the former City of Dillworth wells and the Moorhead Aquifer. However, it also appears that the water level in the two sand bodies decreased to the point that the connection is no longer saturated. Reductions in the water level in the Moorhead Aquifer could eliminate other such connections, should they exist, while increases in the water level could re-establish connections to storage areas that were once dewatered.

MODFLOW Model

The GMS MODFLOW model was created by defining the project area surface using USGS DEM and map data to create the land surface and define rivers and streams in the area. The model domain was divided into a three-dimensional, non-uniform grid as shown on Figures 5 and 6. The model has 276 rows, 189 columns, and ten layers. Finer grid spacing was applied in the area of the site where the MPS wells are located. This grid spacing, seen on Figure 6, provides better definition in the area of the flow field where simulating the influence of pumping from the wells was critical. The base of the model is at an elevation of 175 meters (m) above mean sea level and the top of the model is ground surface as defined by USGS digital elevation data.

The size of the domain and the general flow-field characteristics of the model were chosen to include the surface water bodies to establish the ambient head in the glacial till and to extend the model far enough from the area of interest that the outside boundary conditions would not have a significant effect in the area of interest. While the study focused on the area immediately adjacent to the MPS wells, placing the boundaries far away allowed for the testing of various aquifer geometries and to provide for possible expansion of the model as part of future studies in the area.

Model Input Parameters

Discretization of aquifer properties in *MODFLOW* involves assigning initial values to each cell in the model domain. Hydraulic properties input for this model included horizontal components for hydraulic conductivity (k_x and k_y), vertical hydraulic conductivity (k_z), and

effective porosity (n_e) (required for MODPATH to calculate linear flow velocity). Again, all values, except for the till conductivity value, were obtained from the earlier MLAEM model. The conductivity of the till was adjusted through calibration to provide the required amount of recharge to the Moorhead Aquifer. The calibrated horizontal conductivity of 0.03 meters per day (m/d) and vertical conductivity of 0.006 m/d are consistent with values determined as part of other studies in the area (Stark, et. al, 1994).

Model Calibration and Sensitivity

The lack of data in the area makes traditional calibration of the model impossible. The method used in this case was to configure the aquifer in such a way that pumping 100 MGY would produce a constant head value at the wells with approximately the same drawdown seen during the periods where the measured water level stabilized.

The configuration of the flow field using the calibrated model and under steady-state pumping conditions is presented on Figure 7. It can be seen that the regional flow is from east to west as indicated in the previous model and MGS data. The configuration of the capture zone in the MODFLOW model simulation, shown in Figure 8, is nearly identical to the original MLAEM model.

Model Uncertainty

All models require that certain assumptions and generalizations be made because of lack of data and to reduce complexity when building the model. The aquifer in this model is a fairly simple shape and composed of homogeneous material, while the actual aquifer is almost certainly much more complicated and variable.

To account for some of this uncertainty, several models were run with different possible aquifer configurations. A 20-year capture zone was delineated for each of these different configurations. All of the individual capture zones were then plotted together and outlined. This composite capture zone (shown in Figure 9), while being conservative in size, is more likely to include the actual capture zone than any of the individual ones.

It is possible that there are small parts of the aquifer that extend out on all directions and that none of the models cover all of it. The possibilities are too numerous to simulate. The models that were created were based on the characteristics of some of the better-defined sand bodies in the area, that is: long and narrow, generally extending in the north-south direction, and wider at the depth than near the top.

Delineation of the WHPAs

Moorhead Aquifer

Once the 20-year composite capture zone was determined, the WHPA was delineated as the outer extent of the capture area as shown on Figure 9. Because a conjunctive delineation was not necessary, the WHPA is also the combined wellhead protection area and the boundary used to create the DWSMA.

Buffalo Aquifer

Delineation of the north Buffalo Aquifer WHPA was determined by the 20-year capture zone (Figure 10). A conjunctive delineation was not completed for the north Buffalo Aquifer wellfield DWSMA. The south Buffalo Aquifer wellfield WHPA did include a

conjunctive delineation, and as a result, the combined wellhead protection area includes the 20-year capture area and the conjunctive delineation (Figure 10). These respective WHPAs were used to create the DWSMAs for the north and south Buffalo Aquifer well fields.

Delineation of the DWSMAs

The criteria used to delineate the DWSMAs for the Moorhead and Buffalo Aquifers (Figure 11 and Figure 12) are based on parcels that encompass the maximum time of travel simulated as defined in MR 4720.5100. In the case of both aquifers, the DWSMA delineations encompass the combined model-delineation WHPA, and conjunctive delineation (south Buffalo Aquifer only).

The surface water contribution areas will not include the watersheds of the South Branch Buffalo River, which overlaps a portion of the WHPA for Wells No. 8 through 10. As an alternative, the surface water contribution areas will be based on smaller watersheds where overland flow water could potentially enter the 20-year travel time area and easily enter the aquifer where the DNR vulnerability rating is high.

The surface water contribution area for the south Buffalo Aquifer conjunctive delineation was delineated using 1-meter LIDAR data and aerial imagery. The specific surface contribution was defined by including all micro-watersheds that, in the occurrence of precipitation, would produce surface flow that could potentially intersect or enter the predetermined 20-year capture zone. LIDAR data and aerial photos were analyzed for culverts and other potential surface flow diversions to more accurately delineate localized watershed divides. The resulting conjunctive delineation is shown on Figure 12.

Well Vulnerability

The well vulnerability assessment was conducted in accordance with the MDH guidance document, *Assessing Well Vulnerability for Wellhead Protection* (MDH, 1997). A well's vulnerability is scored based on the following six categories: DNR geologic sensitivity rating, casing integrity, casing depth, pumping rate, isolation distance from contaminant sources, and chemical and isotopic information.

The assessment of geologic sensitivity is a useful metric when estimating the relative vertical downward travel time of contaminants from grade level to the water table or source aquifer. The DNR geologic sensitivity rating is an empirical value determined by dividing the cumulative thickness of low permeability units (e.g. clay) above the aquifer by 10 (DNR, 1991). The resulting score is termed the "L-score". A higher L-score indicates more low-permeability material above the aquifer, and therefore a lower vulnerability. A low L-score represents higher vulnerability. For example, a rating of L-1 has a higher vulnerability than L-9, because there is less low-permeability material present above the aquifer. This type of assessment is defined by the DNR as Level 3. A Level 3 assessment was conducted for the MPS wells, and DWSMAs for the Moorhead and Buffalo Aquifers, since the aquifers are overlain by varying thicknesses of clay. In cases where low permeable units are not encountered, as with Wells No. 8 and 9 in the Buffalo Aquifer, a moderate or high geologic sensitivity is assigned depending on the overlying geology. As mentioned above, points are also assigned to casing integrity and depth, pumping rate, isolation distance to contaminant sources, and chemical data, in addition to the geologic sensitivity.

Vulnerability assessment rating sheets and vulnerability scores for Wells No. 6 and 6B completed in the Moorhead Aquifer and 8 through 12 completed in the Buffalo Aquifer are presented in Attachment 2. The vulnerability worksheets were obtained from the MDH and reviewed by LBG. LBG suggested revising the vulnerability sheets and changes were made by MDH. Per MDH guidance, any well that receives an assessment rating of 45 points or greater, or has a tritium detection greater than 1 tritium units (T.U.) is considered a vulnerable well.

As a result of this rating system, Wells No. 6 and 6B are rated as not vulnerable. Wells No. 8, 9 and 11 are rated as vulnerable because they had tritium detections greater than 1 T.U., which automatically makes it vulnerable. Wells No. 10 and 12 are vulnerable due to their high geologic sensitivity.

DWSMA Vulnerability

In the proposed DWSMAs, the groundwater that supplies the MPS wells is from the Moorhead and Buffalo Aquifers consisting of sand and gravel glacial deposits. (Regional Hydrogeologic Assessment Series – RHA-3, Part B, Plate 3 of 4). The glacial deposits are composed of Des Moines Lobe outwash and glacial till. This information was considered when determining the geologic sensitivity of the DWSMA.

Figures 13 and 14 illustrate the geologic sensitivity for the DWSMAs. In total, 172 well logs were reviewed in the vicinity of the Buffalo Aquifer north and south DWSMAs, and 41 in the vicinity of the Moorhead Aquifer DWSMA. Geologic sensitivity rankings were based on review of each geologic log and comparing the descriptions to those listed in MDH's Geologic Sensitivity Assessment Rankings table dated August 2008. As a result, the geologic sensitivity in the vicinity of the Buffalo Aquifer MPS wells, and across their respective DWSMAs, ranges from very low to high (Figure 13). Geologic sensitivity in the vicinity of the Moorhead Aquifer MPS wells ranges from very low to low (Figure 14).

Pursuant to MDH guidance (MDH, 1997), all geologic sensitivity ratings for the Buffalo Aquifer were automatically increased by one classification due to the presence of tritium. No tritium has been detected in the Moorhead Aquifer wells (6 and 6B), and therefore the sensitivity remains very low. As a result, the vulnerability in the vicinity of the Buffalo Aquifer MPS wells and across their DWSMAs ranges from low to high, and the vulnerability in the vicinity of the Moorhead Aquifer MPS wells is very low (Figure 15 and Figure 16).

Recommendations

Recommendations that could be undertaken by MPS over the next ten years to investigate and/or mitigate the potential impacts aquifer by better understanding the hydrogeology and the groundwater/surface interaction include the following:

- Develop a groundwater level monitoring plan to better understand the hydraulic connection/disconnection between aquifers. The degree of hydraulic connection between the Moorhead Aquifer, the Buffalo Aquifer, and the buried sand and gravel used by the former City of Dillworth wells is still somewhat uncertain. Having a better understanding of the connection or disconnection between these aquifer units would be helpful when considering future aquifer management strategies, defining the extent of the

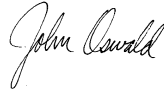
aquifers, and long-term wellhead protection. Therefore, LBG recommends that MPS develop a groundwater level monitoring plan that:

- Identifies a select number of existing wells for monitoring;
 - Evaluates existing water level data including the DNR observation well data as part of the selection process and data evaluation phase; and,
 - Determine the optimum measurement frequency and data collection methods to capture the information necessary to evaluate the data and obtain results;
- Select existing wells in each aquifer for chemical analysis that can be used to type the groundwater. The chemical makeup of the groundwater from different areas and well depths can be used to better characterize the type, relative age, and movement of groundwater and whether it comes from a similar or different source. This can be useful in determining the hydraulic connection between different aquifers and in developing future aquifer management strategies.
 - Continue collecting groundwater samples from the MPS wells for analysis of select regulated contaminants.
 - Monitor surface water quality at multiple locations along the drainage ditches and Buffalo River in the Buffalo Aquifer DWSMAs to effectively evaluate contaminants and transport pathways across the contributing areas. This task could be a collaborative effort with other local government units, the MDH, the soil and water conservation district, Department of Agriculture, Natural Resource Conservation Service, and local residents. Information gained from this type of assessment may determine whether certain portions of the conjunctive delineation are not necessary to be included in the DWSMA, or if additional refinement of the DWSMAs should be evaluated. This may result in smaller or larger DWSMAs. Surface water monitoring locations could be located at bridge crossings, culverts, and other easily accessible locations so as to facilitate a manageable monitoring program. Locations should be focused on tributary streams to the drainage ditch and along the drainage ditch through the City. Data and water samples should be collected a various times throughout the year to monitor for temporal variations in flow volume and chemistry. It is also beneficial to collect abundant data initially and then scale back the monitoring efforts if the data supports a reduction. Collecting sufficient data upfront is generally more time and cost effective compared to an expanding or phased approach.
 - Given the proximity of the Buffalo River, the vulnerable Buffalo Aquifer, and the know hydraulic connection with surface waters, particularly at Well No. 8, 9, and 10, it is recommended that the City take a preventive approach to educate residents, land owners, and business owners on the importance of the WHPA and DWSMA, and what they can do to minimize and properly manage the surface application of chemicals (such as nitrogen or pesticides) that may be prone to runoff and accumulation in local streams that transect the City's WHPAs. Local residents may also be willing to volunteer their time to wellhead protection activities once they understand its importance. Much of this work can be redefined as part the Part II amendment process.

Please call me at (651) 558-9207 or John Oswald (651) 558-9211 if you have any questions or need additional information.

Sincerely,

LEGGETTE, BRASHEARS & GRAHAM, INC.



John Oswald
Environmental Engineer II



David S. Hume, PG
Senior Associate

DSH
Attachments

cc: Kris Knutson, MPS
Cliff McClain
George Meinrich, MDH

S:\Tech\Moorhead PS WHP\Report\Moorhead part I amended.doc

References

MDNR, Division of Water, 2000, *Southern Red River Valley Regional Hydrogeologic Assessment, Part B, Regional Hydrogeologic Assessment Series, RHA-3, Plates 3 and 4*. MN DNR, Division of Waters.

Ripley, David P., 2000, *The Water Resource Characteristics of the West Fargo Aquifer System*. North Dakota State Water Commission.

Stark, J. R., D.S. Armstrong, and D.R. Zwilling, 1994, *Stream-Aquifer Interactions in the Straight River Area, Becker and Hubbard Counties, MN*. USGS Water-Resources Investigations Report: 94-4009.

Walsh, James, 2000, *Wellhead Protection Area Delineation for City of Moorhead Wells Nos. 6 and 6B*. Minnesota Dept. of Health. Dec. 2000.

Wolf, R. J., 1981, *Hydrogeology of the Buffalo aquifer, Clay and Wilkin Counties, West-Central Minnesota*. USGS Water-Resources Investigations Report: 81-4,.

TABLES

Table 1
Public Water Supply Well Information
Part I WHP Amendment
Moorhead Public Service
Moorhead, MN
October 2012

Local Well Name	Unique Number	Use/ Status¹	Casing Diameter (inches)	Casing Depth (feet)	Well Depth (feet)	Date Constructed/ Reconstructed	Well Vulnerability	Aquifer
10	222051	P	16	84	124	1952	Vulnerable	Buffalo Aquifer
11	511085	P	16	148	190	1988	Vulnerable	Buffalo Aquifer
12	511086	P	16	147	203	1988	Vulnerable	Buffalo Aquifer
6	241492	P	20	233	273	193	Not Vulnerable	Moorhead Aquifer
6B	437645	P	12	230	266	1987	Not Vulnerable	Moorhead Aquifer
8	222049	P	16	63	116	1947	Vulnerable	Buffalo Aquifer
9	222050	P	16	78	114	1947	Vulnerable	Buffalo Aquifer

Note: 1. Primary (P) Well

Table 3
Permitted High-Capacity Wells
Part I WHP Amendment
Moorhead Public Service
Moorhead, MN
October 2012

Unique Number	Well Name	DNR Permit Number	MDH Aquifer	Aquifer Name	Use	Annual Volume of Water Pumped (Millions of Gallons)
147201	LANDFIELD, RUTH G	1977-1097	QWTA	Buffalo	Major Crop Irrigation	81
166254	DILWORTH, CITY OF *	1963-0687	QBAA	Buffalo/ Moorhead?	Municipal Waterworks	115
222045	DILWORTH, CITY OF *	1963-0687	QBAA	Buffalo/ Moorhead?	Municipal Waterworks	115
222081	HORN, PAUL T	1977-1077	QBAA	Buffalo	Major Crop Irrigation	70
232378	LUCILLE L FORD LTD PARTNERSHIP	1979-1123	QBAA	Buffalo	Major Crop Irrigation	144
240102	GLYNDON, CITY OF	1984-1094	QBAA	Buffalo	Municipal Waterworks	40
Unknown	MOORHEAD, CITY OF	2000-1038	Unknown	?	Golf Course Irrigation	45
Unknown	MOORHEAD, CITY OF	2000-1038	Unknown	?	Golf Course Irrigation	45

* Wells no longer in service.

Table 2
Annual Water Volume Pumped from MPS Wells (MGY)
Part I WHP Amendment
Moorhead Public Service
Moorhead, MN
October 2012

Well Name/ Number	2006	2007	2008	2009	2010	Projected 2015	Percent change from 2010 (% +/-)
222051 (10)	0.0	0.0	0.0	0.5	35.6	40.9	13 +
511085 (11)	104.4	82.2	28.5	90.2	69.7	102.7	32 +
511086 (12)	70.0	56.8	40.2	115.6	135.7	102.7	24 -
241492 (6)	48.6	41.9	19.7	76.3	41.6	44.7	7 +
437645 (6B)	31.1	28.2	29.0	8.4	47.8	44.7	6 -
222049 (8)	30.5	36.8	34.2	27.3	49.1	40.9	17 -
222050 (9)	45.7	86.1	57.9	18.5	29.9	40.9	27 +
Totals	330.3	332.0	209.5	336.8	409.4	417.5	

Source: DNR State Water Use Database System Permit No. 1947-0014