To: File for controlled ground water area petition 41I-S116636

From: Russell L. Levens, Hydrogeologist
DNRC Water Management Bureau

Date: January 14, 2008

Subject: Review of technical information for North Hills CGWA

This review includes my comments on technical evidence submitted at the hearing held on January 8-9, 2006 in the matter of the petition for the North Hills Controlled Ground Water Area (CGWA) (41I-S116636) and selected evidence obtained during the hearings held on 4/24/2002 and 8/6/2006. Note that I reference well numbers from the Ground Water Information Center (GWIC) using the nomenclature M:212618 with the M indicating a GWIC number. These numbers can be used to access well logs and hydrographs from GWIC.

Overview

Aquifer Characteristics
Dr. Mitchell Reynolds provides the most credible evaluation of lithologies and mapped geologic structures in the CGWA because his evaluation is based on analyses of drill cuttings and his extensive experience mapping lithologies present in the North Hills. Dr. Reynolds interpretation of geology is found in Exhibit Reynolds-1 and a map entitled Generalized Geologic Map Showing Distribution of Quaternary Units and Surface Exposures of Bedrock that was delivered to DNRC on January 11, 2008. I disagree with some of the details of Dr. Reynolds mapping, in particular with relation to the distribution of Quaternary units; however the points of contention do not have a significant bearing on the overall characteristics of aquifers in the North Hills. More importantly, Dr. Reynolds conclusions on permeability of aquifers, rates of recharge, and hydraulic continuity of fractures should be considered speculation because they are not supported by aquifer tests or other ground-water measurements. In addition, the presence or lack of permeability in drill cuttings or the hand specimens presented by Dr. Reynolds at the hearing does not reveal whether fractures are continuous enough to provide production to wells or the nature of drawdown caused by pumping. Bedding-plane fractures and joints with limited extent that are most prevalent in small samples typically do not have significant water transmission properties (Levens, 1994-Part I). M. Kaczmarek, in a report referenced in testimony presented by John Baucus, and in his evaluation of aquifer testing at Skyview Subdivision included in the petition file provides the most credible discussion of the hydraulic properties and response to pumping of the bedrock in the North Hills. Kaczmarek states correctly that the type of fractures and degree of hydraulic interconnection between fractures intercepted by a well determines whether that well is productive. The extent that fractures are hydraulically interconnected in three dimensions and distances of 100’s to 1,000’s of feet is rarely evident from analysis of drill cuttings or hand samples and generally can only be discerned by careful aquifer testing or other ground-water information (Levens, 1994-Part I). Aquifer testing conducted for Skyview and Townview subdivisions included with the petition provide unequivocal evidence of the production potential of the fractured rock aquifer. Aquifer test data from the North Star

subdivision that was posted on the GWIC database and specific capacity of wells listed on GWIC also demonstrates production from bedrock.

The overall connectivity of the aquifer system across the North Hills probably depends most on the nature of the major discontinuities created by mapped faults. Connectivity and successively more local scales depend on successively less continuous fractures. Hydrographs of wells in the northern part of the CGWA, I believe, indicate that drawdown caused by pumping at Skyview and Townview subdivisions may be observed up to two miles away, indicating hydraulic connectivity of fractures at least on this scale. In addition, the absence of area-wide discontinuities in water level measurements indicates there is some degree of interconnection, at least between the major faults. Finally, the proponents seem to be inconsistent whether they believe the bedrock aquifer contains discontinuous fractures that inhibit recharge and ground-water flow or whether bedrock contains “interconnected fractures that can serve as conduits fo unimpeded contaminate flow” as stated in Thamke (2000) and referenced by Vivian Drake in her journal article in Ground Water Monitoring and Remediation.

The lithology of the aquifer in the southern half of Section 17, Township 11 North, Range 3 West in the vicinity of Bridge Creek Estates and the proposed Fieldstone subdivision is disputed by the various experts. Dr. Reynolds concludes the aquifer is fractured bedrock; however, the unusually high productivity of wells in this area and my personal experience with a well at the proposed Fieldstone subdivision creates questions in my mind. Regardless, the lithology of the aquifer is irrelevant given the nature of its response to pumping in numerous aquifer tests. The nature of the aquifer test response is consistent across all existing tests conducted in the area and, I believe can be interpreted using equivalent porous media methods. More important and regardless of whether aquifer tests are amenable to porous-media methods, the high rate of production and stabilization of water levels observed in aquifer tests in Section 17 are unequivocal evidence of an extensive aquifer with a high capacity to transmit water. Therefore, as I concluded in my review of the Madison (2006) report, the aquifer in this area is connected to the Helena Valley Aquifer and is best evaluated in that context.

Water Budget

The proponents identify infiltration from precipitation, Silver Creek, the Helena Valley Canal, and excess application of irrigation water as potential sources of recharge in the North Hills. They identify withdrawals from wells, flow from agricultural drains, ground-water flow to the Helena Valley Aquifer, and flow to Lake Helena as categories of discharge of ground-water from the North Hills. The proponents argue that infiltration from precipitation is very small or non-existent because potential evapotranspiration exceeds precipitation, because of soil moisture deficit, and because of runoff. The proponents argue that the water budget presented by Madison (2006) is flawed because of how he estimated inflow to and outflow from the aquifer, and his disregard for surface water runoff and evapotranspiration. The proponents propose a water budget analysis that only considers withdrawals by wells to explain changes in ground-water storage.

Evapotranspiration exceeds precipitation over the vast majority of Montana, but that does not preclude surface water runoff or ground-water recharge as suggested by the proponents. The reason that runoff and recharge occurs in general is that precipitation that is stored as snow and ice during the winter melts in the spring and because the majority of rainfall often occurs in relatively short duration storms in the spring. In addition, precipitation received in the previous fall builds up soil moisture after the growing season that carries over to the spring. The result is a period from April through June where soil moisture is relatively high and a significant amount of water is available to runoff or infiltrate. In addition, evapotranspiration is determined by the type and density of vegetation and soil type and thickness.

The following is a summary of my specific comments on testimony related to the water budget for the North Hills:

- From my experience and evidence presented at the hearing, runoff from the North Hills is an insignificant part of the water budget. In particular, Ron Drake could only state under cross-examination by Madison that he had witnessed runoff a couple times in the 15 years he has lived in the area. Therefore, the proponents conclusions that 25 percent of precipitation runs off because of frozen ground and an additional 20 percent runs off during intense summer storms is overstated. It is my opinion that some portion of this water believed to run off actually recharges ground water.
- I reiterate from my review of the MBMG report by Madison that his estimates of water flow into and out of the North Hills are very uncertain because he uses individual transmissivity values that may not be representative of the entire width of the area. Madison also did not consider the potential contributing area to the northern part of the control area. Staci Stolp provides an analysis by Kyle Flynn, a Department of Environmental Quality (DEQ) hydrologist, that recharge is 1.5 to 3.0 inches per year which is between 10 and 30 percent of precipitation.
- The proponents have not supported their claim that recharge to the North Hills is derived solely from sources within the topographic divides of the North Hills. The presence of a flowing well near the topographic divide in Section 31, Township 12 North, Range 03 West (M:212618) is evidence there could be a source of ground-water inflow from outside the control area. In addition, there is at least one well in Section 02, Township 11 North, Range 03 West (M:216824) is completed into the Madison Formation beneath a low angle thrust fault. Flow along or across faults into the area could explain the large inflow estimate obtained by Madison and water age data presented by the proponents.
- Evidence that precipitation recharges bedrock in the North Hills includes the correlation of ground-water level hydrographs with standard precipitation index, abrupt water level rises observed in several hydrographs following a wet period during 2005, and the very presence of water in the ground.
- I believe the proponents over-estimate consumption from wells in the North Hills. Madison estimates consumption of water withdrawn from 1,620 wells is 550 acre feet based on metered data and assumptions about return flows from domestic use. I obtained the same result using independent estimates of domestic water use and return flows, and an estimate of consumption for irrigation from the Montana Irrigation Guide. I believe the estimate made by Madison and matched by me is conservative because water use in the three subdivisions for which metering data were obtained is much greater than typical use elsewhere in the North Hills.
- Vegetation in undeveloped areas of the North Hills is sparse and consumes very little water relative to potential evapotranspiration.

- The water balance presented by the proponents is incomplete and poorly documented as discussed in my comments on Section 5 of the proponents' report..

Hydrograph Analyses

The proponents identify seasonal and longer-term "secular" patterns of ground-water levels fluctuations or trends. They attribute the seasonal pattern observed in wells located in the southern 20 percent of the CGWA to recharge from canal leakage and excess irrigation. Further, they attribute a generally opposite seasonal pattern observed in non-irrigated areas of the North Hills to the effects of peak pumping during the irrigation season followed by redistribution of water stored in the aquifer. I generally agree with these interpretations. As an aside, to understand the process of redistribution of aquifer storage, visualize the effect of pumping from a straw in the middle of a vat filled with honey. The result will be a depression in the surface of the honey around the straw that is similar to the cone of depression around a well in a uniform aquifer. Once you stop or decrease the rate of pumping from the straw this depression will begin to dissipate as honey from the remainder of the vat flows toward the straw. Patrick Faber testified that monitoring around Skyview and Townview subdivisions creates 60 feet of drawdown during the irrigation season that dissipates to 20 feet in the early spring in a similar fashion as the honey analogy. I believe drawdown from pumping at Skyview and Townview is felt in wells in the Cedar Hills Subdivision to the north and possibly in wells as far as two miles from Skyview and Townview.

The proponents identify multi-year declining trends in 23 of 28 hydographs of ground-water levels in wells within or nearby the North Hills. I agree with their assessment, at least visually, that there are overall declining trends in 10 wells, but I disagree with the proponents' assessment of declining trends in the 13 other hydrographs because there is excessive scatter in these hydrographs or because of questionable regression fits. The proponents appear to associate declining water level trends to withdrawals from wells regardless of evidence that these trends correlate to patterns of precipitation as discussed by Madison.

Effect of Pumping on Ground-Water Levels

Drawdown caused by pumping depends on aquifer properties and the location and nature of aquifer boundaries. It generally does not depend on the rate of precipitation or pre-withdrawal ground-water levels. As discussed in written testimony by the proponents, Patrick Faber, and Michael Kaczmarek (2002 hearing), withdrawals create a cone of depression that grows rapidly at first, but begins to stabilize with time. However, ultimate stabilization of drawdown from pumping does not occur until the cone of depression reaches one or more aquifer boundaries resulting in reduced discharge from the aquifer to balance pumping (typically recharge from precipitation or surface water not hydraulically connected to ground water remains constant). Discharge boundaries to the aquifer system in the North Hills include agricultural drains, the lower reaches of Silver Creek, and Lake Helena.

The time before ultimate stabilization occurs depends on aquifer properties and distance to aquifer boundaries. Aquifer testing indicates that drawdown in wells near discharge boundaries in the southern part of the control area will begin to stabilize almost immediately and probably fully stabilize in less than ten years. Drawdown in bedrock in the northern part of the North Hills will begin to stabilize within a few years (see written testimony by Kaczmarek presented by John Baucus at the 2002 hearing), but may take as long as 20 to 50 years to reach total stabilization. The majority of drawdown in the vicinity of pumping wells does occur within the first few years of pumping as discussed in testimony at the hearing and the report by Kaczmarek.

Nitrate Concentrations
The proponents discuss the processes that result in contamination of ground water by nitrate and provide at least qualitative evidence that average nitrate levels in the North Hills may be increasing and clear evidence that nitrate concentrations are elevated in specific wells. Vivian Drake concludes in a paper on nitrate trends in the Helena are that *"[nitrate] increases were most evident in areas overlying bedrock aquifers and locales with high density and unpermitted septic systems"*. The strength of this conclusion is limited because very little data are available prior to the 1990's. There is dispute between experts who testified at the hearing regarding background nitrate concentrations and the magnitude and cause of apparent trends.

Comments on Draft Supplemental Technical Information Provided to DNRC and to be Presented at January 8, 2008, North Hills CGA Re-Hearing
The following are my specific comments on the subject report.

2. Groundwater Budget Fundamentals

The proponents provide a good discussion of water budget concepts and overall effects of withdrawals in sections 2.1 and 2.2. I have one comment on the proponents' statement that "under conditions of constant recharge, withdrawal of water by wells results in removal of water from storage or 'mining' of the aquifer". The term "mining" is used to mean different things in different contexts and, in my opinion, should be avoided. Used as the proponents do, "mining" simply means removing water from aquifer storage. In other contexts "mining" is used to indicate an unsustainable development; however simply removing water from storage does not make a ground-water development unsustainable. A sustainable development is achieved if or when a new balance between recharge and discharge is achieved, generally as a result of reduced discharge at aquifer boundaries.

The discussion in section 2.3 on Availability of Water to Wells appears to be come largely from the text Groundwater and Wells (Driscoll, 1986). Unfortunately, there are several fundamental misconceptions in the information gleaned from this text. The appropriate authoritative references on the response of an aquifer to pumping are two papers by Theis entitled "The Significance and Nature of the Cone of Depression in Ground Water Bodies" and "The Source of Water Derived from Wells: Essential Factors Controlling the Response of an Aquifer to Development" published in 1938 and 1940 respectively. A paper by Brown (1963) and papers by Bredehoeft et al., 1982 and Bredehoeft (2002) reiterate the principles presented in the Theis papers. Finally, a publication from the U.S. Geological Survey entitled The Principle of Superposition and its Application in Ground-Water Hydraulics (Reilly et al, 1987) and a related paper by Hubbell et al., (1997) are additional sources of basic principles that need to be understood to evaluate the response of an aquifer to pumping. To summarize information in these documents, the equilibrium extent and depth of cones of depression caused by pumping from wells do not depend on recharge from precipitation, the rate of flow through the aquifer, or leakage. In addition, the radial extent of a cone of depression does not depend on the capacity of a well, only on the distribution of transmissivity and storage coefficients of the aquifer. The impacts of pumping are determined by the distribution of aquifer transimissivity, the aquifer storage coefficients, and the location and nature of aquifer boundaries (Theis, 1940 and Bredehoeft, 2002). A cone of depression will stop growing only when the rate of pumping from a well (less return flows) is offset by increased recharge or decreased discharge at aquifer boundaries. The sum of increased recharge and decreased discharge is defined as “capture” (Lohman, 1972). One implication of these principles is that the aerial extent of cones of depression and time it takes to reach equilibrium will increase with distance from a pumping well to sources of capture and relatively more drawdown in the vicinity of the pumping wells will occur in the interim. Conversely, the cones of depression created by wells that are close to sources of capture will reach equilibrium much faster, will draw water mostly from capture, and will create less drawdown.

Section 2.4 of the proponents report includes a discussion of aquifer recharge. The following are my preliminary comments on this section.

- Return flows from wastewater disposal is a source of recharge to the aquifer system in the North Hills that is not included as an element of aquifer recharge by the proponents.
- The proponents question the future availability of excess irrigation and canal leakage. If recharge from the canal or excess irrigation stops, ground-water levels will decline until ground-water discharge to lower reaches of Silver Creek and Prickley Pear Creek, and Lake Helena are reduced by an amount equal to the historic recharge from the canal and excess irrigation.
- The proponents state in Section 2.4.3 that “little <u>if any</u> of the natural precipitation that falls in the North Hills, is available to recharge groundwater” (my emphasis). The presence of a water table / potentiometric surface and correlation of ground-water level fluctuations to rain events are clear evidence that precipitation does recharge ground water throughout the North Hills CGWA. For example, hydrographs for wells M:198749, M:214684, and M:208488, available from the Ground Water Information Center (GWIC), show the effects of recharge by precipitation in the spring of 2005 on ground-water levels.
- The proponents discuss runoff process, but do not provide evidence of the occurrence or amount of runoff from the North Hills. There are no perennial streams draining the North Hills CGWA and I have not observed extensive surface runoff during my periodic visits to the North Hills. Dr. Mitchell Reynolds characterizes drainages such as Diamond Springs as highly intermittent and Ron Drake admitted under questioning at the hearing that he has observed runoff only a couple times in the 15 years he has lived in the area.
- The proponents discuss evapotranspiration in Section 2.4.3.2 and conclude that potential evapotranspiration exceeds annual precipitation by a significant amount. This is the case in almost all of Montana yet precipitation recharges ground water and runs off as surface water. Potential evapotranspiration is independent of soil properties and vegetation and, therefore does not correspond to actual field conditions. Dr. Mitchell Reynolds in his testimony states that availability of water across most of the area is inadequate to sustain other than vegetation of a dry semiarid or arid habitat (i.e. actual evapotranspiration in nonirrigated areas is depends on water availability and is much lower than potential evapotranspiration). From my observation, vegetation in nonirrigated areas of the CGWA is generally sparse. In addition,

the majority of precipitation in the North Hills occurs in concentrated rainfall events or as snow that melts over short time intervals that exceeds evapotranspiration rates.

- In Section 2.4.3.3, the proponents discuss the role of soil moisture deficit in limiting recharge from precipitation. This discussion highlights the importance of antecedent soil moisture conditions in determining recharge. The proponents don't discuss that fall rains after the growing season ends and spring snowmelt can increase soil moisture and affect the amount of recharge from spring rains in May and June. I believe this process is evident in recharge that is evident in hydrographs from bedrock wells for the spring of 2005.
- In Section 2.4.3.4, the proponents confuse the age of water pumped from wells and the time it takes for the recharge to affect water levels in wells. The effect of recharge on ground-water levels is a hydraulic response governed by the hydraulic properties of the aquifer and is much faster than the rate the actual water molecules flow through the aquifer. The correlations between the standard precipitation index and ground-water levels presented in the report by Madison (2006) and hydrographs from wells M:208488, M:198749, 214684, and M:206390 are evidence that recharge events translate into water-level changes on the order of months instead of years or decades as implied by the proponents. The age of water pumped from a well is determined by the rate of recharge and the path it follows and requires knowledge of ground-water flow paths to interpret. The presence of a deep flowing well near the crest of the divide in Section 31, Township 12 North, Range 03 West (M:212618) is evidence that the northern boundary of the CGWA is not a simple recharge area and that flow paths of "old" water could be much longer than the proponents espouse.
- Figure 3 in Section 2.5.11 is a useful graph showing average depth and growth in number of wells with time. Factors including the trend toward building at higher elevation and improvements in well-drilling technology may explain increases in well depth. Nonetheless, declining ground-water levels resulting from decreased precipitation and/or the effects of pumping have caused water users to drill deeper wells in areas such as the Cedar Hills Subdivision near the corner of Prairie Road and Montana Avenue (see my review of the Madison report).
- Also in Section 2.5.11, the proponents use water-use data from Townview, Skyview, and Ranch View subdivisions to estimate that consumption for 1,620 households in the North Hills is 1,142 acre-feet. This is equivalent to 0.7 acre-feet or 628 gallons per day per (gpd) household. This value is a gross estimate of water use instead of consumption and therefore neglects return flows to the aquifer from septic effluent and over irrigation. Estimates of typical use and consumption prepared by DNRC for a document titled "Future Exempt Well Growth and Consumption" can be used for comparison. These estimates are based on published data on domestic use and estimates of irrigation requirements using the Montana Irrigation Guide and indicate that diversion for domestic use (180 gpd) and irrigation use for a residence with ¼ acre of irrigated lawn and garden (16" irrigation requirement and 70 percent efficiency) is 0.69 acre-feet per year (616 gpd). Consumption for this same residence is estimated to be 0.34 acre-feet per year (300 gpd). Similarly, a residence with ½ acre lawn and garden irrigation typically pumps 1.16 acre-feet per year (1,040 gpd) and consumes approximately 0.7 acre-feet per year (625 gpd). The gross water use estimates provided by the proponents indicate typical lawn size is approximately ¼ acre in the three metered subdivisions of the North Hills they took data from. Therefore, consumption for 1,620 homes, assuming ¼ acre lawn and garden, is estimated to be 550 acre-feet per year. This is the same value obtained by Madison (2006) from water meter data.

- The proponents report that DNRC has granted water rights for 5,500 acre-feet from wells in the North Hills based on the DNRC water-right database. I did not search the database to confirm this number, but it is not based on actual use.
- In Section 2.5.1.3, the proponents state that "only a small fraction, if any, of water discharged by the agricultural drains is derived from groundwater aquifers in the North Hills". The basis for this argument is unclear, however the proponents may believe that the drains intercept water before it reaches the water table, but shallow water levels in the area (in both deep and shallow wells) support a conclusion that drains intercept the water table and do in fact drain ground water. Regardless, Madison included infiltration of excess irrigation water in his water balance, so it is appropriate that he include drainage from those irrigated lands.
- In Section 2.5.1.3, the proponents are critical of Madison's estimate of ground-water flux used in his water balance. In my memo to the file dated 8/5/2006, I stated that "estimates of ground water fluxes into and out of the control area are most uncertain" and I still believe these calculations are the most uncertain element of Madison's water balance. The proponents go on to state that 60 percent of all water falling in the CGWA that lies above the 3,850-foot potentiometric contour must recharge the aquifer to account for the flux estimated by Madison. I agree that Madison's estimate of flux should to be backed up with an analysis of the area contributing recharge; however, it is unclear why the proponents limited their analysis to the boundary of the CGWA. Ground water divides do not always or generally coincide with surface water divides and there is an area north of the CGWA that is higher elevation than the CGWA that could provide ground-water flow into the CGWA. In addition, the relatively deep flowing well near the topographic divide in Section 31, Township 12 North, Range 03 West (M:212618) is evidence that water may flow into the area from outside its boundaries.
- The proponents state that Madison ignores runoff, evaporation, and evapotranspiration in his water budget. Madison did not include these elements explicitly in his water budget. Madison did include these elements implicitly by estimating net recharge and net consumption associated with water use.
- Section 2.6.1 is a summary of testimony by Dr. Mitchell Reynolds on his geologic characterization of aquifer materials. The basis of my comments is my experience characterizing the hydraulic properties and fracture connectivity in fractured rocks. I have conducted over 30 aquifer tests in fractured rocks of Belt Supergroup rocks and have published the results of those tests and evaluations in journal articles (Levens et al, 1994, parts I and II).

  Reynolds makes conclusions about water availability and connectivity within fractured rocks in the North Hills based on analysis of drill cuttings and drill logs and interpretation of geologic structures. An understanding of the character of geologic formations and structure is necessary to understand the hydrogeology of the North Hills; however it is an insufficient basis by itself to support the conclusions made by Reynolds regarding ground water availability and recharge. Ground water level data and the results of numerous aquifer tests are additional data apparently not considered by the proponents or Reynolds that are key to an accurate understanding of the hydraulic properties and fracture connectivity that controls water availability and the effects of current and future ground-water development.

Aquifer-test data for the North Hills are available on GWIC for tests conducted for water-right applications for Mountain Trades (41I-114950), Fieldstone Estates (41I-11495000), Bridge Creek Estates (41I-30004735), Silver Creek Commercial Subdivision (41I-30004748), and North Star PUD (41I-30001682). Reports of aquifer tests conducted for Town View Estates (41I-P023312-00), and Skyview Water and Sewer District (41I-P092815-00) were submitted with the CGWA petition. Aquifer test data for the Fieldstone, Bridge Creek and Silver Creek consistently demonstrate the wells for these applications pump from a common aquifer that is continuous at least over several thousand feet. For example, drawdown from testing conducted for Bridge Creek Estates propagated to a well at Fieldstone Estates approximately 3,000 feet away in less than five minutes. Drawdown from tests conducted at Fieldstone, Bridge Creek and Silver Creek consistently correspond to a typical response of a leaky confined porous media aquifer with moderately high transmissivity. Madison characterizes the aquifer in the area of these projects as alluvium whereas Reynolds characterizes the aquifer as highly fractured bedrock. In this case the distinction is not important to interpretation of the hydrogeology. If the aquifer in this area is fractured rock as Reynolds concludes, fracturing is extensive enough that the aquifer behaves as a porous media similar to an alluvial aquifer.

Ground-water levels in many wells north of the influence of the Helena Valley Canal follow a similar pattern of fluctuations as discussed by Madison and commented on in my memo to the file dated August 5, 2006 (see hydrographs for wells M:205626, M:206394, M:208573, M:206390, and M:208433 available from GWIC). Madison concluded that this pattern is related to the pattern of recharge by snow melt and rainfall. Madison ruled out withdrawals as a cause partly because of significant water levels fluctuations observed in a well in 11N03W10 (M: 205626) that is located approximately 2.5 miles from concentrated development. I stated in my review that well withdrawals (from concentrated development in 11N03W07) cannot be ruled out as a cause of the pattern of water level fluctuations observed north of the canal. I believe this apparent anomaly may be explained by the dominant orientation of faults in the North Hills. Well M:205626 is located generally along this structural orientation from wells in 11N03W07 and could be hydraulically connected to that area through faulting. One implication of this interpretation is that connectivity throughout bedrock in the North Hills is much greater than inferred by Reynolds based on geology alone. The variation of the magnitude of seasonal fluctuations (or lack of fluctuations) between wells probably is a result of differing degrees of connectivity with the fractured rock mass and not simple due to distance.

- The proponents argue in Section 2.6.2 that aquifer testing conducted in the North Hills is flawed because of inadequate aquifer characterization, testing methods and documentation, and reporting. Many tests conducted in the North Hills in the past do not meet current DNRC aquifer testing requirements and are poorly documented. Better quality tests that meet the current requirements have been conducted at Bridge Creek Estates and Skyview subdivisions. The results of tests that meet current DNRC testing rules generally are consistent with the results of the other testing.

Section 3 Review of Hydrographs

The proponents evaluated hydrographs of ground-water levels in 26 wells located within the CGWA plus 2 monitoring wells near the CGWA. The proponents conclude that 23 hydrographs show clear declining trends based on linear regression. All but one of the five wells from which the proponents did not identify a declining trend are located near the southern boundary of the CGWA. I agree that overall declining trends are evident from visual inspection in 10 of the 28 hydrographs of water-levels in wells evaluated by the proponents (wells 1, 8, 10, 11, 12, 14, 15, 18, 19, and 24). I did not include well 9 in this list because it is located on the same lot as well 8 and, therefore I consider it a duplicate data point. I disagree with the proponents' conclusion regarding declining trends in 13 other hydrographs because there is excessive scatter in these hydrographs or questionable regression fits. The proponents did not include an analysis of the statistical significance of regression fits for these 13 hydrographs (or for any hydrographs) and, therefore cannot conclude the trends are significant.

The proponents identify seasonal patterns of water-level fluctuations that differ between wells in irrigated and non-irrigated areas of the CGWA. They conclude that water levels in wells located in non-irrigated areas peak in early spring and reach a minimum at the end of the irrigation season. They conclude that water levels in wells located in irrigated areas have an opposite seasonal pattern with minimum water levels in the spring prior to onset of irrigation and maximum water levels in the fall at the end of the irrigation season. The proponents argue that minimum water levels observed in non-irrigated areas correspond to periods of peak pumping and are due to the effects of pumping. Further, they conclude that water levels rebound in the fall and winter as aquifer storage is redistributed. With regard to wells located in irrigated areas, the proponents conclude that the seasonal pattern of ground-water levels correlate to patterns of recharge from surface water. I believe the proponents' explanation of seasonal water level fluctuations is credible and I generally agree with their conclusions. I have two comments: the first is a reservation and the second is an additional interpretation. Madison (2006) rejected the idea that the seasonal pattern of ground-water level fluctuations in non-irrigated areas is related to ground-water pumping because of the hydrograph of well M:205626. Water levels in this well fluctuate approximately 15 feet annually with maximum level in the spring and minimum levels in the fall – the pattern the proponents associate with the effects of pumping. However, well M:205626 was never pumped during the period of record (after the driller's yield test), is over two miles from any concentrated pumping, and is in an area where lawn and garden irrigation is minimal or non-existent. Well M:205626 appears to be located very close to a north-south trending fault identified by Mitchell Reynolds. This well could provide a permeable connection to distant pumping centers. For my second comment, I repeat my comment with regard to the seasonal pattern of ground-water level fluctuations in the southern portion of the CGWA that I presented in my review of the Madison report.

> *"[T]he Quaternary alluvium and possibly parts of the Tertiary sediments in the southern part of the control area are in close hydraulic connection to the Helena Valley Aquifer. The significance of this connection is evident in ground water level monitoring and aquifer testing data from several proposed public water supply wells located near the Helena Valley Canal in 11N03W17 and 11N03W18. Ground water levels in these high-yield wells completed between 200 and 300 feet deep rise and fall in coincidence with operation of the*

canal and the irrigation season, indicating a close connection between the wells and recharge from canal and ditch leakage and return flows. However, shallow wells do not respond during aquifer tests of these production wells, most likely because the aquifer tapped by the high-yield wells is locally confined by overlying fine-grained strata. The most likely interpretation of the pattern of water level fluctuations in these wells is that the fine-grained confining strata are not continuous across the Helena Valley and the seasonal rise and fall of water levels in these wells corresponds to the seasonal rise and fall of the Helena Valley Aquifer which responds to canal operation and irrigation across the entire valley."

Stated simply, I believe the available data indicate that water levels in the southern part of the CGWA rise and fall with water levels in the Helena Valley aquifer as a whole and not only as a result of local recharge.

A final note on the proponents' analysis of hydrographs, they state that "short term water level trends are unreliable and difficult to determine" in limiting their analysis to "long-term" trends. It is unclear what is meant by unreliable, but I disagree that short-term data have no value as implied by the proponents. Ground-water level rises wells M:198749, M:214684, and M:208488 as well as others are evidence of recharge from rainfall during the wet spring of 2005. In addition, the comparisons between ground-water levels and standard precipitation indices presented by Madison provide valuable information about the role of climate variability in controlling ground-water levels. Analyses of the full period of record at different frequencies and comparison to precipitation records is more valuable for the purpose of understanding recharge mechanisms than simple linear regression of gross water-level trends. Last, I again disagree with the proponents statement that recharge is virtually nil as discussed in my comments regarding Section 2.4.

Section 4 Occurrence and Availability of Groundwater to Wells in the North Hills

The proponents present what they describe as a "dynamic water balance" in Section 4.2.1. In this analysis, the proponents use their estimate of withdrawals from wells to calculate expected drawdown resulting from removal of ground water from storage and compare these values to their estimates of declining water level trends. I believe this approach and the proponents conclusions are flawed for the following reasons:

- Recharge is assumed to be zero. Declining recharge can explain water level declines.
- The value of withdrawals used by the proponents is over-estimated by roughly a factor of two as discussed in my comments on Section 2.5.11.
- Estimates of water-level trends for many wells discussed in Section 3 are uncertain or in error (as explained in my comments on Section 3).
- The proponents do not identify the sources of the data they use in their calculations, making it difficult or impossible to verify their calculations.
- Effective porosity is uncertain, highly variable, and an important variable in the calculations.

Changes in aquifer storage that is reflected in declining or fluctuating ground-water levels result from dynamic changes in withdrawals and recharge over different time scales.

Section 5 Wastewater Return Flow Mass Balance

The proponents provide hypothetical calculations of the result of mixing septic effluent with uncontaminated water to demonstrate the potential for increased concentrations of nitrate in ground water. They conclude the pollution of ground water is inevitable based on the following assumptions:

- The rate of recharge and the area contributing recharge to non-irrigated portions of the CGWA is nil or very small and provides little dilution.
- Background nitrate concentration is 0.1 mg/l.
- The rate of septic effluent return flow is 162 gpd per residence.
- Nitrate concentration in septic effluent for a standard septic system is 50 mg/l.

The uncertainties in the proponents' analysis include the rate of recharge, the area contributing recharge, and the background nitrate concentrations.

Section 6 Wastewater Pollution in the NHCGA

The proponents discuss the processes that result in contamination of ground water by nitrate and provide at least qualitative evidence that average nitrate levels in the North Hills may be increasing and clear evidence that nitrate concentrations are elevated in specific wells. Vivian Drake concludes in a paper on nitrate trends in the Helena are that *"[nitrate] increases were most evident in areas overlying bedrock aquifers and locales with high density and unpermitted septic systems"*. The strength of this conclusion is limited because very little data are available prior to the 1990's. There is dispute between experts regarding background nitrate concentrations and the magnitude and cause of apparent trends. The following are my specific comments on the evidence presented in this section:

- The proponents present data on nitrate concentrations from 305 samples taken from domestic and monitoring wells, and 164 samples taken from public water supply wells. It is unclear how many domestic and monitoring wells were sampled and how many of the samples were repeats for individual wells. They did provide this information for public water supplies, however.
- The proponents conclude that Figure 14 is clear evidence that nitrate concentrations in public water supplies in the North Hills are increasing with time. There are results from too many systems on this figure to reach a clear overall conclusion. Nitrate levels in water sampled at Jim Darcy School have increased over time; however, levels from Bob's Market have decreased. Trends in nitrate concentrations from other systems are less clear from this figure.
- The proponents conclude that, in addition to increasing with time, nitrate and other chemicals are posing health risks to individuals drinking from those water sources. Others testifying at the hearing questioned the level of health risks at concentrations below EPA standards or for chemicals without standards. In general, any concentration of a contaminant could pose a health risk. EPA sets standards at levels that are determined to pose unacceptable health risks.
- Table 6 lists average nitrate and chloride concentrations in wells by decade from 1970 to 2000. Information on the location of the wells sampled during each decade and the variability

within the sampled data is needed to evaluate whether there is a trend in these data. In addition, the number of samples from the 1970's and 1980's is less than necessary to obtain a meaningful average.
- There is too much scatter of nitrate and chloride values and clustering of sample times in data presented in Figure 17 and Figure 18 to be able to discern significant trends.

Comments on Testimony by Patrick Faber

Testimony by Patrick Faber consists of his comments on the Summary Testimony of Dr. Mitchell Reynolds and the Draft Supplemental Technical Information of Vivian and Ron Drake. The following are my comments on selected portions of Mr. Faber's testimony.

- Mr. Faber comments on Dr. Reynolds' statement that bedrock within the CGWA has "very low porosity and permeability". Mr. Faber points out that Dr. Reynolds does not present the results of aquifer testing, and goes on to describe fracturing in rocks equivalent to those found in the North Hills that are visible along I-15. Faber concludes that fracturing evident in outcrop indicates the potential ability of those rocks to transmit water at depth and to receive recharge. Dr. Reynolds questioned Mr. Faber at the hearing regarding how representative fracturing in outcrops along I-15 of conditions in the North Hills.

  I agree with Faber's comment that Dr. Reynolds did not use the results of aquifer testing to support his claim the bedrock has very low permeability. In general, fractured rock has low porosity relative to unconsolidated sediments. However, evidence of the properties of rock hand specimens or cuttings does not address the key question of the continuity of fracturing over 100's to 1,000's of feet.
- Mr. Faber states that Dr. Reynolds does not present a map of aquifers or a mass balance as alternatives to those presented by Madison (2006). Dr. Reynolds does present an interpretation of the geology in Exhibit Reynolds-1. In addition, Dr. Reynolds provided the map titled *"Generalized Geologic Map Showing Distribution of Quaternary Units and Surface Exposures of Bedrock"* following the hearing. Again, Reynolds does not present an alternative mass balance assessment.
- Mr. Faber disagrees with Dr. Reynolds regarding the role of unconsolidated surficial deposits on enabling recharge to bedrock. Faber believes that infiltration is enhanced by the absence of surficial deposits whereas Dr. Reynolds believes surficial deposits are necessary to enable infiltration. I believe the answer to this question is site specific. Surficial deposits can store water that gradually infiltrates underlying lower permeability bedrock, thereby enhancing recharge. Surficial deposits that have lower permeability than bedrock may inhibit infiltration. Surficial deposits also retain water as described by R. Drake in his testimony and can support vegetation as stated by Faber, resulting in consumption of water before it can reach bedrock.
- Mr. Faber comments on the importance of recharge from the Helena Valley Canal. He points out that Madison identified effects of recharge from the canal on water levels in wells more than a mile upgradient of the canal resulting from mounding. Ground-water levels in wells on both sides of the canal respond to operation of the canal in a very regular and predictable fashion. Water that leaks from the canal seeps downward to the water table through underlying unsaturated sediments or rocks. It is true that the water is carried down-gradient once it reaches the water table; however, the hydraulic effect raises water levels both up and

down-gradient. This phenomenon can be explained by the principle of superposition (Reilly et al., 1987). The extent of the effect of recharge from the canal on ground-water levels is mapped by Madison in his plate 3.

Mr. Faber inferred that water leaking from the Helena Valley Canal is available for capture by wells located up-gradient from the canal. This is incorrect because the canal is not hydraulically connected to ground water and, therefore pumping will not alter the rate water leaks from the canal.

- Mr. Faber disputes Dr. Reynolds interpretation of drill cuttings from a well drilled at Bridge Creek Estates. He also provides anecdotal information on a well at North Star that he believes penetrates gravel and clay sediments instead of bedrock as mapped by Dr. Reynolds. I believe Dr. Reynolds is the best authority on lithologies found in the North Hills. However, from my perspective, I have difficulty reconciling the high productivity of wells at Bridge Creek Estates, Silver Creek Commercial, and the proposed Fieldstone Estates property with a fractured bedrock aquifer. The flow rates and limited drawdown observed at Fieldstone Estates in particular are remarkable for a fractured bedrock aquifer that is not in cavernous limestone. Nonetheless, for all practical purposes the classification of the aquifer is irrelevant. Aquifer test data demonstrate that if the aquifer generally south of the canal is in bedrock it is extensively fractured to the point that it responds to pumping similar to a porous alluvial aquifer and is closely connected to the alluvial aquifer to the south.
- Mr. Faber questions why there are gravel pits along Lincoln Road if the aquifer at Bridge Creek is bedrock as Dr. Reynolds testifies. Essentially, the gravel pits owned by the county and Valley Excavating near the intersection of Lincoln Road and Applegate are excavated in sediments that Dr. Reynolds identified as coming from the Diamond Springs drainage. It is worth addressing the question raised as to why there is no water in these gravel pits. Water level data from a well owned by Valley Excavating (M:209187) demonstrates that the depth to ground water in this area is in excess of 95 feet and, therefore below the bottom of the pits. That does not mean that water levels are not elevated in this area by leakage from the canal. Water levels from M:209187 and M:191534 which is located between the gravel pits, fluctuate regularly in response to leakage.
- Mr. Faber argues that faults may provide a possible “mechanism of water transport from areas beyond the topographic drainage of the North Hills”. I do not have an opinion on the presence of the fault Mr. Faber believes runs SW to NE across the western part of the CGWA; however, I believe there is evidence that water may flow into the CGWA across or along fractures or faults from outside the topographic drainage. Water levels in two wells monitored in the Douglas Circle area near the extreme north boundary of the CGWA are relatively constant and one well flows at the surface. Testimony by Mike Kaczmarek submitted by Mr. Baucus describes typical water level fluctuations in recharge areas in his section on Aquifer Storage Considerations.
- Mr. Faber uses the example of Giant Springs to argue that fractured bedrock can transmit copious water. There was some discussion upon questioning by Dr. Reynolds as to whether Mr. Faber was referring to flow through the Madison Aquifer which consists of carbonate rocks. Mr. Faber made it clear he was referring to flow through non-carbonate rocks overlying the Madison Aquifer.
- Mr. Faber argues that Dr. Reynolds presents no testimony about “aquifer tests, transmissivity values, or mass balance equations”. As I mentioned in my comments on Dr. Reynolds

testimony, I believe Dr. Reynolds testimony on bedrock geology and structure is valuable, but his conclusions on hydraulic connectivity and permeability are merely hypotheses without consideration of ground-water data.

- Mr. Faber identifies an analysis of an aquifer test at Skyview Subdivision conducted by M. Kaczmarek as an example of a rigorous evaluation of the fractured rock aquifer in that area. I agree that this analysis which is included in the petition file is a valuable example of analysis of an aquifer test in fractured rock.
- Mr. Faber states the proponents identify runoff as a mechanism that reduces the amount of recharge from precipitation, but do not provide actual field work or attempt to quantify runoff. Under questioning by James Madison, Ron Drake confirmed that the Drakes had only observed runoff a couple times in their 15 years living in the North Hills. Therefore, I agree there is no evidence that runoff is a significant element of the water budget of the North Hills. Mr. Faber states there are many small streams that terminate within the Helena Valley and contribute recharge. I am not familiar with the streams he speaks of, but they appear to terminate outside the CGWA and it is unclear how much they might contribute recharge to the CGWA.
- Mr. Faber questions the accuracy of pumping water levels from well logs relied on by the Proponents to conclude that pumping creates large vertical gradients affecting migration of septic effluent and age dating results. I believe Mr. Faber's comment is valid; however a more important consideration is the general low efficiency of individual wells constructed with open ended casing. Drawdown outside the well casing of a low efficiency well is a fraction of drawdown in the casing and, therefore vertical gradients in the aquifer are much less than is apparent from pumping water levels measured within a well by any method.
- Mr. Faber states that age dates presented by the Proponents are evidence of recharge from outside the CGWA. As I stated previously, age dates as well as ground-water level data from wells near the topographic divide may indicate there is flow from outside the CGWA that the Proponents do not consider when they conclude there is minimal recharge.
- Mr. Faber argues the Proponents need to consider standards, rules, and regulations in their determination of whether septic effluent must contaminate water near wells. I believe the simple statement that septic effluent will reach ground water is obvious. The question of whether that effluent will flow to a well is site-specific, but in general constituents form septic effluent (after varying degrees of mixing and dilution) are likely to eventually be drawn into a well.
- Mr. Faber argues that data on average well depth presented by the Proponents is misleading because they fail to consider changing drilling technology, progression of development to higher elevations, and choice by well owners to drill deeper. These factors all contribute to the trend toward deeper wells; however, data on replacement wells included in my review of the Madison report demonstrates that water users in Cedar Hills Subdivision and other areas of the North Hills have drilled deeper than previously to obtain useable ground water.

Comments on Testimony Submitted by Staci Stolp

Staci Stolp presented written testimony that includes an analysis by Mr. Kyle Flynn using the Blaney-Criddle method to estimate recharge in a 7,805-acre subset of the CGWA. Mr. Flynn is a hydrologist who works at DEQ. The conclusions of the analysis is that recharge is 1.5 to 3.0 inches (1,002 to 1,860 acre-feet total annual recharge) and that "carrying capacity of one household is 10 to 20 acres using DNRC estimates of general household use. Mr. Flynn did not consider any recharge from outside the CGWA in his calculations. Figure 2 in Thamke (2000) is a map of average annual precipitation for 1960 to 1991. This map indicates average annual precipitation in the CGWA ranges from 10 to 16 inches. Based on this range, recharge estimated by Mr. Flynn is between 10 and 30 percent of average annual precipitation.

Mr. Flynn incorrectly uses standards for diversion rates of 1 acre-foot per year (890 gpd) for domestic and 1.25 acre-foot per year (1,120 gpd) for irrigation in his calculations; these rates exceed measured values and do not account for water that returns to the aquifer. As discussed in my review of the petitioners' testimony, average metered water use (diversion) in three subdivisions in the North Hills is 0.7 acre-feet per year (628 gpd) per residence and typical consumption is 0.34 acre-feet per year (300 gpd) per residence. Approximately 3,000 to 5,500 households would consume an amount of water equal to the recharge estimated by Mr. Flynn for approximately 12 square miles. Further, this estimate does not consider contributions from any other sources of recharge or sources of recharge outside the CGWA.

Comments on Witten Testimony by John Herrin

Mr. Herrin presented testimony primarily related to his proposed Green Meadows Vistas Subdivision located in the southwest corner of the CGWA. He also presented testimony on the Lincoln Heights Subdivision and Jim Darcy School. Mr. Herrin primarily provides opinions and not what I would consider an independent assessment.

Mr. Herrin's main points and my comments are summarized as follows:

- Mr. Herrin argues that there are additional sources of nitrate other than wastewater. Mrs. Drake acknowledged that there are other sources of nitrate in response to questions following her testimony so I don't believe there is a dispute.
- Mr. Herrin argues that precipitation in the CGWA is approximately 15 inches above treeline based on vegetation. Figure 2 in Thamke (2000) supports this estimate.
- Mr. Herrin argues that water demand is low (approximately 650 gpd per household). This equates to 0.72 acre-feet per year which is comparable to the diversion rate of 0.7 acre-feet per household determined by the proponents from metered data.
- Mr. Herrin argues that nitrate is less than 5 mg/l in most areas and increasing slowly; however, he does not provide data or analysis to support this estimate.
- Mr. Herrin argues that nitrate background is 1 to 2 mg/l. Again, the basis for his conclusion is unclear.
- Mr. Herrin states that pharmaceuticals at parts per billion levels should not be considered a health threat. He discussed existing studies and argues that results are preliminary and should not be a basis for policy decisions. I agree that we have a poor understanding of the occurrence and threats posed by these contaminants.

Comments on Written Testimony by Michael Kaczmarek presented by John Baucus at Initial Hearing and referenced in his testimony during the January 2008 hearing

Testimony by Mr. Kaczmarek was submitted at the original hearing on April 8, 2002 and, therefore includes data that is out of date. However, Mr. Kaczmarek includes pertinent discussions of fractured rock, aquifer storage considerations, and stabilization of pumping effects at Skyview.

The discussion of fractured rock considerations addresses conditions in fractured rock that explain variability of well production. Mr. Kaczmarek emphasizes the importance of aquifer testing.

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