S. S. PAPADOPULOS & ASSOCIATES, INC.
Environmental & Water-Resource Consultants

Technical Memorandum

Date: September 27, 2006

From: Deborah Hathaway, P.E. and Bryan Grigsby, R.G.

To: Dick Wolfe, P.E., Assistant State Engineer, Colorado Department of Water Resources

Subject: Responses to Review Comments of Coalbed Methane Stream Depletion Assessment Study, February 2006

Comments were received as identified below:

- Reviewer A: BP America Production Company: Comments prepared by Wright Water Engineers, June 2006
- Reviewer B: Southern Ute Indian Tribe: Comments provided by letter from Janice Sheftel to Dick Wolfe, June 23, 2006
- Reviewer C: On behalf of unidentified property owners in the outcrop area: Comments provided by letter from James McCord, of Hydrosphere Resource Consultants, to Dick Wolfe, May 3, 2006.

Primary comments and responses are summarized below, with respect to common topic areas, where applicable.

MODELING METHODOLOGY: THE SIMPLICITY OF THE GLOVER METHOD

All three reviewers were critical of the application of the Glover Method, based on their perceptions that due to the method's simplicity, the method results would be erroneous. Interestingly, there was a lack of consensus on the direction of the perceived error. One reviewer, James McCord, representing property owners near the outcrop, stated that the results would underestimate actual stream, spring and groundwater depletion. On the other hand, the BP and Ute reviewers, representing the extraction industry, believed the opposite, that the results by this method would overestimate the actual depletions.

SSP&A disagrees that there is a specific bias towards underestimation or overestimation of depletion using this method. The Glover method is reasonably-well suited to the project goals, as the problem was structured. Regardless of whether an analytical method, such as the Glover method, or a numerical model (for example, as could be constructed using MODFLOW) is applied, calibrating the model using the historic data provides the best means of improving accuracy. In this application, all of the readily available data were employed in obtaining model parameters through a calibration procedure.

The model parameters thus derived and the model results did not differ substantially from those determined in a previous MODFLOW analysis. It does not appear to the investigators that there is reasonable cause to consider the results of this study as either underestimated or overestimated, particularly, as a function of the modeling technique. This is not to say that additional precision could not be obtained in the future, through additional modeling analysis, if significant new data were developed. However, the results from this study should be of sufficient precision to support general analysis of basin conditions and to make associated management decisions or to develop regulatory guidance.

Some reviewers identify specific areas of concern – these are addressed further below.

> *"The depletion underestimation error relates to problems in their conceptualization and application of the Glover method"* (Reviewer C, p. 1). *"In the higher outcrop areas, unconfined drainage likely does not approach the volumes of water needed to attenuate drawdowns to 'appear' as constant heads in nearby portions of the aquifer"* (Reviewer C, p. 3).

One can apply a simplified volumetric analysis to provide some idea of the magnitude of drawdown likely to occur in the outcrop, this being the underlying concern. For example, if one assumes for this purpose that all depletion impacts were expressed as outcrop drawdown (i.e., there were *no* impacts to any streams, and *all* impacts were transmitted only to shallow groundwater in the outcrop area), given the volume of water in unconfined storage in the shallow aquifer, and assuming typical unconfined storage properties, the decline in water levels as a result of CBM water production would be on the order of a half an inch per year. This very minor amount of drawdown is consistent with the assumption made in the modeling analysis that the outcrop will function hydraulically as a "line-source", and with the idealization of the constant-head boundary. In fact, given the small impact at this location, one could alternatively model the system with a no-flow boundary north of the outcrop, with little difference in results. Such an approach was implicit in the MODLFOW analysis, and as noted, there was little difference in the depletions computed in that study. Other than providing an opinion that the outcrop should be treated as a no-flow boundary, Reviewer C offers no evidence that impacts are underestimated.

Reviewer A indicates (p. 4) that the Glover method is conservative, and that a more rigorous Hydrogeologic evaluation would show that the non-tributary line should be located closer to the outcrop. The reviewer expresses no basis for the opinion that the method is biased conservatively, other than noting that data from the Pine River Ranches Study shows that there is "*no hydraulic connection between Fruitland Formation wells completed beneath the Pine River alluvium and Fruitland Formation wells* *located 1 to 1.5 miles to the south*". This opinion is not documented specifically; however, we infer that the reviewer is referring to the low pressure changes in observation wells in this area. SSP&A notes that the occurrence of small pressure changes is not unexpected; in our modeling analysis of historic responses, this response was reproduced.

Reviewer A recommends (p.4) that a three-dimensional groundwater model be prepared for those areas to more accurately define the tributary boundary. A three-dimensional groundwater model was prepared by previous investigators under the 3M studies. These models did not differ dramatically with respect to quantifications of stream depletion from those of the present study; therefore, unless significant new data is developed, it is unclear that a new three-dimensional numerical model would substantially improve understanding in this basin as it relates to the broad regulatory goals of this study.

IMPACTS OF DEVELOPMENT ON SEEPS AND SPRINGS, AND ON GROUNDWATER LEVELS IN THE OUTCROP AREA

Reviewer C raises the concern that the impacts of CBM development on the flows of specific seeps and springs in the outcrop area have not been quantified; and, similarly, that impacts on shallow groundwater levels are unidentified. He expresses concern that impacts of CBM pumping may cause seeps and springs to dry up, as well as shallow wells.

An analysis of drawdown impacts using the information developed in the study was made prior to the final public meeting in Durango to address this concern and is briefly described above. Impacts to groundwater levels in the outcrop area are expected to be very small. Impacts of this magnitude will not significantly impact wells. Whether or not a seep or spring would be impacted would depend on the potentiometric head at such locations, and their sensitivity to changes on the order of a few inches. The evaluation of specific impacts at localized sites is beyond the scope of this study. However, the data reviewed for this study, as well as some additional data provided by Reviewer A for the Pinos River drainage near the outcrop (Oldaker, 2005), suggests that there is little change in potentiometric surface in the outcrop area.

REPRESENTATION OF THE OUTCROP AREA AS A "LINE-SOURCE" FEATURE

While agreeing with the designation of the outcrop area as an appropriate "line-source" feature for the Glover analysis with respect to the deep basin analysis, Reviewer C questions the validity of this approach with respect to tributary streams, seeps and springs. In response, it is noted that the "source" of water in the outcrop area is not only the water available directly in the surface water features, but also, the "water-table storage" of the unconfined system. In the outcrop area, the unconfined storage will be several orders of magnitude greater than that in the confined portion of the formation, deeper within the basin. Water in storage within the outcrop represents a significant "source" in the context of the basin analysis and is therefore modeled in this fashion. The impacts of deep basin pumping to the springs, seeps and outcrop storage are "lumped" in the depletion results. Impacts to water levels in the outcrop area were not quantified in the report; however, from the analyses provided in the report, one may make inferences regarding the drawdown, which is estimated to average less than one foot over a 20 year period at present levels of pumping (see section above).

OCCURRENCE OF VARIABLE PERMEABILITY AND COMPARTMENTALIZATION

Reviewer B (p. 1) notes that permeability in the basin is variable, and that a reduction in permeability as coal is depressurized occurs. He cites these processes as the reason for considering that the method results in an over-estimation of stream depletion. SSP&A would agree that there is variable permeability and some areas of very low permeability. However, the low value of permeability selected for the model is not inconsistent with the presence of relatively low permeability areas or with local compartmentalization. Because the value of permeability used by SSP&A was selected using a modeling procedure wherein historic production data for the entire basin and pressure changes from numerous wells were evaluated, the selected permeability is a reasonable average that represents all of the formation characteristics, including any historic reductions in permeability or formation heterogeneities. On the other hand, in the fairway region, a suitable "calibration" could not be achieved with the available data, and in this area, it was inferred that either the data were insufficient to determine a single value for permeability that would be applicable for the purposes of this study, or, the formation heterogeneity or gas impacts were of a magnitude that interfered with the application of this methodology.

HYDRAULIC CONNECTION BETWEEN THE STREAM AND THE AQUIFER

Reviewer B (p.1) expresses concern that the stream is not fully penetrating the aquifer, and that the stream may have reduced bed permeability. SSP&A defined the "line source" for the Glover analysis as a combination of the streams where they cross the outcrop and the outcrop itself. As such, this source is fully penetrating, as the outcrop (with its storage properties orders of magnitude greater than the areas of the aquifer wherein production occurs) is in full hydraulic communication with the dipping aquifer. One may debate timing issues between impacts felt at the outcrop and impacts precisely expressed at the physical streams. Some lagging of impacts to the streams from the outcrop impacts will occur, however, these are not anticipated to be of a magnitude that would significantly impact the study's findings. Regarding the potential for a stream bed to have reduced permeability, it is noted that these streams are located close to the mountain front; as such, they are of relatively high gradient and carry significant flows during the run-off season. Streams with these characteristics are unlikely to have significant and persistent accumulations of clay or silt that would prohibit hydraulic communication between the stream and aquifer.

STORAGE VALUES

Reviewer B (p. 2) states:

> "*using the wrong, lower storage values, greatly overestimates stream depletion, especially near the outcrop*".

The reviewer misunderstands SSP&A's method. The reviewer is critical in that the Glover method did not employ image wells as were used in the Theis analysis from which parameters were derived. The use of the image wells in the Theis analysis were for the purpose of providing consistency among the two methods, because the Glover solution implicitly assumes a constant-head boundary, and it is only by using the image wells in the Theis solution that one can obtain a similar conceptualization. Because the Glover solution already incorporates the constant-head boundary, there would be no need to use image wells in this case exactly as would be simulated is premised on the existence of conditions. Thus, the Glover method used the same storage values as were used for the historic calibration analysis. The reviewer also misunderstands the rationale for using the confined storage in the analysis. The confined, or lower, storage value is representative of the vast basin area through which impacts are propagated to the streams and outcrop. This is the correct value for use in the analysis.

Reviewer A (p. 6, 7) suggests that the use of an unconfined storage coefficient might be a better approximation to aquifer conditions, and that with such an assumption, the non-tributary line would shift towards the outcrop. SSP&A notes that the use of an unconfined storage coefficient for this basin would be inconsistent with the hydrogeologic conditions as reflected in pressure and geologic data; the effect of such a substitution would be to move the non-tributary line towards the outcrop unjustifiably. Only in the immediate outcrop area would an unconfined storage value be appropriate. The structuring of the problem as was done in the report provides a "lumped" depletion, impacting the streams and outcrop storage together. To the extent that impacts from the outcrop to the stream are lagged, the computed impact will not precisely represent the impact on the stream. Regardless, the present study method provides a good sense of the general magnitude of impacts with potential to affect streams, in accordance with the goals of the study.

RECHARGE AND DEPLETION

Reviewer B (p.3) notes that under some scenarios depletion may exceed 500 acre feet per year, but that recharge to the Fruitland Formation has been estimated (by AHA, 2000) as about 200 acre feet per year. For an unidentified reason, this reviewer considers that this situation "pushes the envelope". First, it is noted that recharge is difficult to estimate, and that SSP&A has not determined in this study whether or not the AHA recharge estimate is reasonable. Second, it is noted that the AHA estimate relates to an amount of discharge to rivers crossing the outcrop. But more importantly, SSP&A notes that no rationale exists that would render depletion problematic if it exceeds the baseline outcrop discharge to streams. Depletion is simply a reduction in net stream gains/losses due to a specific event. This may represent a reduction in gains, or, increase in losses, or some combination, depending on the stream elevation as compared to the aquifer head. However, in that there is significantly more than 200 or 500 acre feet flowing in the rivers, the flow in the rivers is more than sufficient to be impacted on the order of a few hundred acre feet (less than 1 cfs) per year.

THE EXCLUSION OF THE FAIRWAY AREA

Reviewer A suggests that the Fairway area not be excluded from analysis. SSP&A notes that the methodology for this study was not appropriate for the Fairway area.

LITERATURE ON SHORTCOMINGS OF THE GLOVER METHOD

Reviewer B (p. 3) provides a reference that addresses shortcomings in the Glover Method. SSP&A has reviewed extensive literature on this topic and understands limitations of the Glover Method and other methods, including numerical models. All modeling methods have limitations, both in computational or solution schemes, and in their ability to represent data fields. The shortcomings of the

Glover Method, and how these were handled in this analysis, were discussed in Section 6.2.2 and in Section 8 of the report.

Reviewer A (p. 5) provides references to several sources in the literature on the shortcomings of the Glover Method. Beyond the general comment noted immediately above, the reviewer is referred to the discussion on hydraulic communication: in this physiographic setting with reasonably high gradient streams actively draining mountainous areas, there is no reason to believe that restrictive stream bed conductivities are present, especially as compared to the already very low permeability assumed in the analysis.

EVALUATION OF ISOTOPIC DATA RELATED TO GROUNDWATER AGE

Reviewer A provides some additional information regarding age dating of the groundwater. The reviewer then argues that groundwater age dating is reason to infer that there is no connection between surface waters and groundwater deep in the Fruitland formation. For purposes of this study, SSP&A is not concerned with the specific source or timing of groundwater in the deep basin. Rather, of importance to this study is the potential for transmission of a "pressure effect", as would be reflected by pressure changes in response to production histories. In the SSP&A report, the CGS provided some discussion of groundwater ages, primarily for background purposes. Regarding the specific comments on groundwater ages (p. 11), Reviewer A is correct, the discrepancy is due to the maximum measurable age for Cl (which is in the neighborhood of 2 million yrs).

SPECIFIC RESPONSES TO DETAILED COMMENTS

Reviewer A provided additional detailed comments (p. 11-16). Where these have not yet been addressed with the responses above, and where clarification is deemed useful, additional clarification is provided below, according to the numbered comments.

1. The reviewer objects to a phrase in a sentence within a general introductory paragraph. This sentence relates the nature of public concerns in the basin, which include the phrase cited. The following sentence explains which of the concerns are or are not addressed in the study. As part of general background material, the sentence is informative.
2. Modeling assumptions are adequately described in the body of the text; inclusion of these in the Executive Summary is beyond the intended level of detail for this summary. SSP&A does not share the reviewer's position that the model results are "worst case" estimates.

3. The statement clearly states that modeling is the basis for the quantified depletion. The reviewer's concern that this could be confused with an observation or a measurement is unwarranted.
4. The cited report, CGS Open-File Report 01-4 by Kirkham and Navarre, was not included in the summary of geologic conditions due to the generalized scope of the overview task. The Colorado Geologic Survey and SSP&A acknowledge this publication and its contribution to geologic knowledge of the basin. The information provided in the report is not considered to impact interpretation of the general nature of flow within the basin.
5. The study does not aim to evaluate localized groundwater elevation changes at specific sites; this is beyond the scope of the study, which focused on characterization of depletion impacts. However, where pressure data were available to the study team to use for model calibration, these data were incorporated into a PEST analysis to obtain a set of hydraulic parameters for the stream depletion analysis.
7. Down-hole video provided by Reviewer A shows calcite in numerous fractures. The occurrence of calcite healing and sealing of fractures is not debated; however, a full discussion of fracture types and conditions is beyond the scope of this report. The presence of a large number of sealed fractures is not at all inconsistent with the hydraulic properties derived for the formation. The assumed transmissivity of 1 ft^2/day, which would relate to a permeability of about 4 to 20 md, is a *very* low value and reflects a considerable amount of resistance to flow and pressure impacts.
8. Data in various locations were examined to address the hydraulic response of the formations to the pumping history. This exercise, described in Section 5.3, provides the basis for the handling of aquifer conditions. The result of this work resulted in the assignment of very low permeability to the CBM-related formation. This is the key feature of the analysis, not whether one chooses to describe this as "through-flowing" or "compartmentalized".
9. SSP&A disagrees that this is a worst-case assumption. The statement is supported by the analysis of many years of production data and formation response.
10. The Pictured Cliffs Sandstone is considered to be part of the aquifer; therefore, the statement that the Fruitland Formation non-coal strata permeability is very low is valid. The statement does not imply anything about the Pictured Cliffs Sandstone permeability.
11. In evaluating changes in potentiometric heads in the basin over time, the maps of Berry and McCord were reviewed. The Kaiser et al. (1994) map was chosen for use in the report (Figure 5.2) because it both includes more data points than the two other maps and is still illustrative of conditions in the basin prior to significant CBM production. More importantly, comparisons between Figures 5.2 and 5.6 allow transient pressure changes from existing wells in response to CBM production to be examined.
12. The reviewer correctly notes that the cited figure should be Figure 5.6.
13. The reviewer misunderstands the analysis. SSP&A stated that evaluation of site-specific impacts is not the goal of the study. That being given as a restriction on study goals, it is not to say that where long-term pressure data are available, they wouldn't be utilized to assist in characterizing basin conditions.
16. The statement made here is based solely on the noted observations; this is not inconsistent with the results of the hydraulic analysis described in report Section 5.

17. Noted; this appears to be a typographical error.

18. The presence of water at substantially different water ages may be of interest in identifying their source and flow paths. Regardless, what is of prime importance to this study is the propagation of a pressure impact hydraulically, not the age-dating of waters. Evidence was not encountered that suggested that regionally extensive barriers to the transmission of a hydraulic impact were present.

19. The Fruitland-Pictured Cliffs hydrostratigraphic unit would not be termed an "aquifer" when compared to many units in the Rocky Mountain region due to its very low permeability. Regardless, in the context of this study where its permeability is much greater than that of the surrounding formations, it is conceptualized as the primary unit through which a pressure impact will propagate. In a relative sense, it is the conceptual "aquifer" for the basin. However, SSP&A agrees with the reviewer in that in many respects, given the low permeability, flow in this formation is severely restricted. The formation was modeled with the very low value of permeability supported by the historic data.

20. Discussed in general comments above.

22. This has not been calculated, however, the model has been made available to those wishing to apply it to other questions such as this.

23. The basis for this opinion requires explanation; that an "obvious exception" exists is unclear.

General comment regarding figure titles: All of the figures are titled in the original document and its pdf file. Titles are as reflected in the Table of Contents, p iv. A downloading or software problem is suspected. However, these are provided below for further reference, along with the requested information regarding source material for the CGS figures.

24. Figure 2.1: Outcrop is a compilation from published geologic maps – Carroll et al., 1997; Carroll et al., 1998; Carroll et al., 1999; Carroll and Tremain-Ambrose, 1998; Steven et al., 1974; Wray, 2000. Precipitation information comes from CGS GIS data set used in the Ground Water Atlas of Colorado (Topper et al., 2003)

25. Figure 2.2: Outcrop is a compilation from published geologic maps – Carroll et al., 1997; Carroll et al., 1998; Carroll et al., 1999; Carroll and Tremain-Ambrose, 1998; Steven et al., 1974; Wray, 2000. The drainage basin divides were determined by CGS for this figure.

26. Figure 3.1: Paleogeography by Ron Blakey, http://jan.ucc.nau.edu/~rcb7/crepaleo.html

27. Figure 3.3: Outcrops are a compilation from published geologic maps – Carroll et al., 1997; Carroll et al., 1998; Carroll et al., 1999; Carroll and Tremain-Ambrose, 1998; Steven et al., 1974; Wray, 2000.

28. Figure 3.5: Reference used was Ayers et al., 1994 (originally from Ayers and Ambrose, 1990).

29 and 30. Figures 3.6 and 3.7: Compiled by CGS from Condon, 1997; Tremain et al., 1994; and from geologic maps Carroll et al., 1997; Carroll et al., 1998; Carroll et al., 1999.

34. Figure 5.5: Logic behind comment is unclear. The report does not state that downbasin production is draining the Fruitland Formation. SSP&A calculated an extremely small impact to the outcrop and stream areas; these impacts do not imply that springs would be greatly

diminished or nonexistent. It should be noted that the springs shown are those provided in the two publications referenced on the figure. The Colorado Geologic Survey has not evaluated the springs to determine their actual nature and whether they represent flow from the Fruitland-Pictured Cliffs aquifer or drainage from shallow upslope unconfined materials.

36. Table 3.2: Pine River Ranches 1 is a measured section from Wray, 2000.

REVIEW COMMENTS REGARDING THE REPORT:

"COALBED METHANE STREAM DEPLETION ASSESSMENT STUDY NORTHERN SAN JUAN BASIN, COLORADO"

BY S.S. PAPADOPULOS & ASSOCIATES, INC.
FEBRUARY 2006

For:

BP AMERICA PRODUCTION COMPANY DENVER, CO

WWE

Wright Water Engineers, Inc.

June 2006

001-015.020

REVIEW COMMENTS REGARDING THE REPORT:

"COALBED METHANE STREAM DEPLETION ASSESSMENT STUDY NORTHERN SAN JUAN BASIN, COLORADO"

BY S.S. PAPADOPULOS & ASSOCIATES, INC.
FEBRUARY 2006

For:

BP AMERICA PRODUCTION COMPANY
DENVER, CO

JUNE 2006
001-015.020

TABLE OF CONTENTS

Page

TABLE

REVIEW COMMENTS
REGARDING PAPADOPULOS REPORT

1.0 INTRODUCTION

Wright Water Engineers, Inc. (WWE),[1] and six outside reviewers[2], were asked by BP America Production Company (BP) to review and comment on a February 2006 report entitled "Coalbed Methane Stream Depletion Assessment Study—Northern San Juan Basin, Colorado" (Study). This Study was a joint effort by the Colorado Oil and Gas Conservation Commission (COGCC), the Colorado Geological Survey (CGS) and the Colorado State Engineer's Office, Division of Water Resources (DWR); all agencies are within the Colorado Department of Natural Resources (DNR). The request by BP was in response to an April 4, 2006 letter from the DWR to the general public for review and comments regarding this Study. This report summarizes our review and comments.

2.0 GENERAL OVERVIEW OF THE STUDY

S.S. Papadopulos and Associates, Inc. (Papadopulos) was awarded a contract to develop a quantitative assessment of the levels of stream depletion or reduction in formation outflows in the Northern San Juan Basin that may be occurring as a result of the removal of water by coalbed methane (CBM) extraction via wells. According to the DNR's July 2005 document entitled "Coalbed Methane Stream Depletion Assessment Study—Scope of Work" (scoping document), the co-sponsors of the Study were asked to develop:

---

[1] Wright Water Engineers, Inc. staff who prepared this review are Gary Witt, P.G. and Jonathan Jones, P.E., with assistance from Peter Foster, P.E. and Alissa Krochenski.

[2] WWE requested independent review by the following people: John Rold, C.P.G. (previously Colorado State Geologist and currently consultant), Robert Kirkham, P.G. (past employee of the Colorado Geological Survey, where he conducted geologic surveys in the San Juan Basin and currently consultant), Professor Ray Kenny, Ph.D. (Assistant Dean, Natural and Behavioral Sciences, Ft. Lewis College in Durango), Phillippe Martin, C.P.G. (president of Martin and Wood and expert on groundwater modeling), Paul Oldaker, Hydrogeologist (consultant with over 25 years of experience in the San Juan Basin), Eric Bikis, P.G. (managing partner of Bikis Water Consultants with extensive local hydrologic experience).

- A reliable assessment of the levels of depletions,
- Definition of the areas that might be classified as nontributary where CBM development is ongoing,
- Definition of potential correlations of water quality, geology, aquifer geometry, or formation/well depth that could lead to general guidelines about the potential for stream depletion and that would be useful in either prompting or avoiding more detailed studies, and
- Recommendations for further data collection or investigation.

The resulting 56-page Study by Papadopulos (February 2006) includes a three-page Executive Summary, 27 figures, four tables and four appendices. The document was made available for comment via an April 4, 2006 letter from DWR to the general public.

In general, the Study authors and DWR summarized their results as follows:

1. The magnitude of the stream depletions associated with current and future CBM development from all wells is small (155 and 170 acre-feet per year [AF/yr], respectively, assuming no infill wells are allowed within 1.5 miles of the outcrop) when distributed across the three major drainage basins (Animas-Florida, Los Pinos [Pine], Piedra-San Juan) that comprise the Northern San Juan Basin in Colorado.
2. Less than 50 AF/yr (or one-third) of these stream depletions are considered to occur out-of-priority (i.e., at times when senior water users would be injured). The remaining amount will occur when there are not senior calls on the rivers.
3. The magnitude of the stream depletions from CBM wells is small as compared to the depletions associated with an equivalent number of exempt domestic wells (600 AF/yr) or the 2,670 exempt domestic wells if developed on each 160-acre tract (1,600 AF/yr). In addition, each CBM well is considered to have a life expectancy of approximately 20 years, while an exempt domestic well can have a production life that is potentially perpetual.

4. While admittedly developed for unconfined conditions, the Glover-Balmer method can be used as a "first order indicator of general conditions" to assess the magnitude of stream depletions and to conservatively identify the horizontal distance from the outcrop (stream) where groundwater resources meet the nontributary statutory definition.

5. The statutory definition of nontributary groundwater is conservatively identified as 10.5 miles from the outcrop of the Fruitland-Pictured Cliffs Formation.

3.0 SUMMARY OF WWE COMMENTS AND CONCLUSIONS

The Study is well written and organized, and contains considerable background data and information. Papadopulos is certainly well-qualified to conduct the work, and their staff members (as well as DNR staff) were responsive to our inquiries. For example, WWE received copies of the Glover-Balmer analysis (conducted by Papadopulos) for review. It appears that nearly all of the subject areas outlined in the scoping document were addressed to varying levels of detail; some exceptions are discussed later in this report.

Conclusions that WWE and our reviewers draw from this Study include:

1. The total estimated depletion of 155 AF/yr is 0.07 percent of the combined average annual flow (227,000 AF/yr) of the three main rivers in the basin (Animas, Florida, and Pine rivers) potentially affected by the CBM production. This is the equivalent of 0.21 cubic feet per second (cfs) or 91 gallons per minute (gpm), which is orders of magnitude below the natural annual flow variation and far less than the accuracy of standard streamflow measurements.

2. Consideration of these depletions on a well-specific basis suggests an average depletion of approximately 0.16 AF/yr or 0.1 gpm per well assuming approximately 1,000 CBM wells within 10.5 miles of the outcrop as cited by DWR in their cover letter for the Study. This is considerably less than the flow of a typical garden hose (6 to 10 gpm per the American Water Works Association, 1975) and the assumed 0.6 AF/yr appropriation allotted individual domestic

exempt well owners for which there is no augmentation requirement as outlined in the April 4, 2006 letter from DWR.

3. The conservatism of the Glover-Balmer method suggests that groundwater located greater than 10.5 miles from the Pictured Cliffs Sandstone outcrop is nontributary and unlikely to be refuted by further analysis. Existing site-specific data and a more rigorous hydrogeologic evaluation using numerical or analytical methods will show that the nontributary line is much closer to the outcrop than indicated by this Study. For example, the existing Pine River Ranches Study described below already shows there is no observed hydraulic connection between Fruitland Formation wells completed beneath the Pine River alluvium (i.e., in the Fruitland Formation subcrop) and Fruitland Formation wells located 1.0 to 1.5 miles to the south.

In summary, WWE recommends that DNR clearly define this Study for what it is: "a first order indicator of general conditions," using an extremely conservative analytical tool. The Study should also state that the boundary between tributary and nontributary groundwater is conservative and that the areas not identified in the Study as nontributary are subject to modification with more rigorous and sophisticated analysis, properly calibrated to reflect available data. WWE recommends that a three-dimensional groundwater model be prepared for those areas to more accurately define this boundary.

4.0 GENERAL WWE REVIEW COMMENTS

This section provides general comments regarding the Study. Detailed (page-specific) comments are addressed in the next section.

4.1 Applicability of Glover-Balmer Method

The scoping document for the Study states that the determination of depletions will be by the analytical "Glover" (Glover-Balmer) method. WWE's outside reviewers of the Study have noted that the use of the Glover-Balmer Stream Depletion Model in this application is not consistent with the various conditions originally cited by Glover-Balmer (1954) for its use, including:

- Stream fully penetrates the aquifer.
- Aquifer is homogeneous and isotropic.
- Aquifer is unconfined.
- Aquifer has a non-sloping water table.
- Flow in the aquifer is horizontal and dominated by one phase.
- All water pumped from the aquifer system comes solely from the stream (not another source).
- Aquifer has direct hydraulic connection with the stream.

Papadopulos makes a commendable effort to justify conformance with these conditions so that the use of the model can be validated. However, many of the assumptions have not been adequately justified.

Professor Ray Kenny (one of WWE's reviewers) referred WWE to three published articles by McCurry (2004), Sophocleous et al. (1995), and Miller and Durnford (2005) that evaluate the Glover analytical model assumptions for the prediction of stream depletions. McCurry concludes that the degree to which the stream is fully penetrating and hydraulically connected to the aquifer is the most significant factor relative to the accuracy of the estimated stream bed depletions. Sophocleous et al. states that the streambed conductivity (i.e., hydraulic connection with the stream) and partial stream penetration affect the accuracy of the Glover method more than aquifer heterogeneity. Miller and Durnford are currently investigating (or recently completed investigation of) errors associated with heterogeneous aquifers and non-ideal conditions. WWE suggests that Papadopulos include a brief discussion of these and similar articles, including their results, conclusions, and implications to the Study.

The use of the Glover-Balmer stream depletion method has been sanctioned by DNR in other settings, particularly in cases involving the identification of nontributary groundwater. The SEO's justification for its use has been that the method is conservative and tends to over-estimate the stream depletions. Assuming that this approach is only a "first-order determination of depletions" as stated by Papadopulos, a supportable conclusion from this Study is that the location of the nontributary/tributary demarcation line is no more than 10.5 miles from the outcrop and would be much closer to the outcrop if analyzed using a method better suited and more closely calibrated to these site-specific conditions.

WWE and many of our reviewers are aware of, or were active participants in, a debate during the 1980s involving the use of the Glover-Balmer method as a means to determine the nontributary groundwater line within the Denver Basin. Its use was rejected in favor of a more sophisticated numeric model that could be constructed to account for the heterogeneities of the aquifer systems to be modeled.

A comparison of the Denver and San Juan basins provides an opportunity to assess the reasonableness of the nontributary groundwater line identified in the study. Within the Denver Basin, hydraulic conductivities are higher than the San Juan Basin, suggesting withdrawal of groundwater will influence a larger area. Consequently, this should result in a nontributary line in the Denver Basin that is greater than 10.5 miles from the Denver Basin outcrop. This is not the case. In general, the nontributary line along the western edge of the Denver Basin (where the upturned geologic units most closely mimic those of the San Juan Basin) is within a few miles of the outcrop. The principal reason for this is the use of a storativity value characteristic of unconfined conditions within the Denver Basin numeric model. Unconfined conditions indicate that there is a considerable amount of water in storage within the formation that can be provided to the well in lieu of active withdrawal from a nearby stream. This results in both a smaller effect on the streams and a nontributary line that is closer to the outcrop. Within the San Juan Basin, Papadopulos assumed a confined storage coefficient that represents limited water in storage within the formation, thus forcing pressure reduction to be felt at greater distances. While the assumed confined values may be representative of the formations at considerable distance from the outcrop, these values are likely too small for areas closer to the outcrop.

Furthermore, it is known that as aquifers are dewatered and approach atmospheric conditions, the apparent storage coefficient increases and may ultimately reflect a value closer to unconfined conditions. An increase in the apparent storage coefficient will reduce the distance from the outcrop to the nontributary line.

WWE conducted a sensitivity analysis of the Glover-Balmer method by varying storage coefficients to define the location of the nontributary line (see Table 1). These data confirm the location of the nontributary line at 10.5 miles from the outcrop under the conditions assumed by Papadopulos in their Study. As shown in Table 1, changes to the storage coefficient that are consistent with other basins in Colorado result in considerably smaller distances from the outcrop to the nontributary line using the same Glover-Balmer method. For example, Table 1 shows that the use of a storage coefficient similar to the Laramie-Fox Hills Sandstone within the Denver Basin (S = 0.15) results in a nontributary line that is approximately 0.5 miles from the outcrop in the San Juan Basin. Based on existing data and information, a storage coefficient closer to 0.15 appears to be more supportable and applicable to the San Juan Basin, especially in the vicinity of the outcrop, than the value adopted by Papadopulos. This is an example of the highly conservative and generalized nature of the Papadopulos analysis, which leads to an overestimate of the tributary area. WWE recommends that the Study should include a sensitivity analysis to emphasize the conservative nature of the adopted storage coefficient and resulting conclusions.

Table 1
Glover-Balmer Method Sensitivity Analysis

Distance from Outcrop (ft)	Distance from Outcrop (miles)	Transmissivity (ft^2/day)	Transmissivity (gpd/ft)	Storage Coefficient (unitless)	Depletion % at 100 years	Meets NT* Definition? Y/N
54,912	10.4	1.2	9.0	0.00031	0.106	N
55,440	10.5	1.2	9.0	0.00031	0.094	Y
30,700	5.81	1.2	9.0	0.001	0.101	N
30,750	5.82	1.2	9.0	0.001	0.099	Y
9,700	1.84	1.2	9.0	0.01	0.102	N
9,700	1.84	1.2	9.0	0.01	0.095	Y
2,500	0.47	1.2	9.0	0.15	0.104	N
2,550	0.48	1.2	9.0	0.15	0.082	Y

*NT = Nontributary

4.2 Comparisons to Existing Field Data and Previous Studies

Papadopulos cites numerous references and data sources for the Study. One of those referenced documents is the ongoing data collection and analyses being conducted by Paul Oldaker for BP (referenced in the Study as "Oldaker, P. 2005"). This investigation is especially relevant in that it represents 12 years of data from numerous wells completed in the Fruitland Formation at or near the outcrop in the Pine River drainage. These data show that those wells completed in the Fruitland Formation below the Pine River alluvium have potentiometric elevations above the corresponding Pine River water surface elevations and have not shown evidence of decline due to downbasin gas and water production during the 12 years of observation. This potentiometric surface indicates that an upward groundwater gradient exists from the Fruitland Formation to the Pine River. Therefore, stream losses (depletions) cannot occur at this location. Conversely, other Fruitland Formation wells located downdip from the outcrop do show potentiometric head declines. These data suggest that the Fruitland Formation is not hydraulically connected from the center of the basin to the outcrop. This is further supported by analyzing gas discharge rates from seeps in the Pine River Ranches area; these have a much better correlation with precipitation than with gas production and downbasin potentiometric head changes. The significance of these data is so compelling that we have included this information (a two CD set) as an attachment to the hard copy version of this report.

The Fairway is cited by Papadopulos as an area where gas saturation is higher and water saturation is lower, suggesting that a one-phase flow model may not be suitable for modeling pressure changes in this region (i.e., violating the assumptions used in the Theis and Glover-Balmer analyses). As stated in Appendix B of the Study, "If pressure changes are primarily due to pumping of gas, water pumping data alone is not sufficient input to the Theis model." As a result, Papadopulos elected to remove this area from the Study for purposes of delineating the tributary/nontributary line. However, since the Study is an extremely conservative first order indicator of general conditions, and the remaining area in the basin also includes aspects of these two-phase effects, WWE suggests that the Fairway area should not be excluded. WWE also observes that the specific characteristics of the Fairway area could be better represented by a three-dimensional groundwater model, calibrated with data from that area.

Another reference frequently made by Papadopulos in the Study is to a publication by Snyder et al. (2003) and Riese et al. (2005). These publications include substantial general and isotopic chemical data that have been used to assess the source and age of the water produced during gas exploration and development within the San Juan Basin.

According to the Study, the ionic chemistry data suggest multiple sources for the produced waters but the complexity of the basin precludes the use of major ions to determine sources within the Fruitland Formation. As a result, isotope chemical analysis was undertaken to identify possible sources for this produced water. From these analyses, at least four possible sources were identified. Papadopulos recognizes this complexity by acknowledging that these isotopic signatures suggest local compartmentalization (i.e., site-specific hydrogeologic conditions). To evaluate the subject of age-dating, WWE has prepared the following background text, which is shown in italics.

Defining Groundwater Age

The "age" of groundwater is generally considered to be the amount of time that has elapsed since the water was last in contact with the atmosphere, i.e., its residence time in the subsurface.

The age of groundwater is determined by examining chemical and isotope tracers in the groundwater that change their properties in a predictable way with time. All such properties must have a known value at the time of water entry to the subsurface (aquifer recharge); the measured value at the time of sampling is then an indicator of the elapsed time between the recharge and sampling times.

Certain tracers are more suitable for different age ranges. For young groundwaters, the most common dating method is one that measures the relative abundances of tritium (^{3}H) and helium-3 (^{3}He). Tritium is a radioactive isotope of hydrogen that decays to ^{3}He with a half-life of 12.4 years.

Another well-known dating method for older groundwater uses carbon-14 (^{14}C) dissolved in the water. ^{14}C is formed in the upper atmosphere as a result of cosmic ray bombardment. The ^{14}C is incorporated into carbon dioxide and becomes distributed throughout the atmosphere. Carbon dioxide containing ^{14}C ($^{14}CO_2$) is a small fraction (about 10^{-12}) of the total atmospheric CO_2. $^{14}CO_2$ dissolves into the oceans and surface freshwaters and becomes part of the normal hydrological cycle. Once dissolved, $^{14}CO_2$ enters the subsurface in groundwater and becomes isolated from the atmosphere (it ceases being replenished from the atmosphere). The normal radioactive decay of ^{14}C then becomes a clock indicating the subsurface residence time of a groundwater sample. ^{14}C decays with a half-life of 5,730 years, providing a useful dating method for groundwaters up to about 40,000 years old. Having said this, it is important to recognize that the use of ^{14}C is invalid for water-bearing units containing carbon (i.e., coal, oil, gas, etc.) because of the age of the carbon and its influence as a large reservoir of contamination.

The long-lived radionuclides, chlorine-36 (^{36}Cl, half-life = 301,000 years) and iodine-129 (^{129}I, half-life = 17,000,000 years) are also used to study groundwater flow systems. Like ^{14}C and ^{3}H, both ^{36}Cl and ^{129}I are produced in the upper atmosphere by cosmic ray bombardment and become part of the hydrological cycle dissolved in precipitation. Their long half-lives make them suitable for measuring very old (millions of years) groundwaters. Helium-4 (^{4}H) is another useful radionuclide for age-dating. However, ^{36}Cl, ^{129}I, ^{3}H, and ^{4}H are also generated in the subsurface via the decay of uranium. As a result, care must be exercised in evaluating such results so as to draw appropriate conclusions from both the individual and comparative results.

With this as a background, WWE respectfully suggests that Papadopulos should review and potentially revise its section on age dating, because its relevance is incorrectly characterized by Papadopulos as "having too many discrepancies… to use… in a stand alone manner." The apparent "discrepancies" appear to stem from a misunderstanding of the age data published by Riese for different isotopes. For example, Papadopulos cites a discrepancy between an ^{129}I age of 57.0 million years (Ma) and a corresponding ^{36}Cl age of 2.4 Ma. What appears to be misunderstood is that the cited ages represent the minimum age of the sample and not the absolute age. The ^{36}Cl age represents the maximum age of the range for which this isotope can be used. The sample result indicates an age of at least 2.4 Ma. The ^{129}I analysis (capable of analyzing ages to about 80 Ma) was therefore used to determine how much older than 2.4 Ma the sample represented.

In summary, the Riese and Snyder studies indicate that the majority of Fruitland Formation groundwater is tens of millions years old with no connection to the surface waters in the region. The Study should be revised to more accurately present these findings and the supporting data.

5.0 DETAILED COMMENTS

The following is detailed list of comments.

1. Page ES-1, 1st Paragraph, 3rd Sentence – The comment regarding "how the production of water may be affecting CBM gas seepage at the surface" is not addressed in the report nor is it a stated objective. This should be removed.

2. Page ES-2, 2nd Paragraph, 2nd Sentence – The major assumption of the modeling is that there is a hydraulic connection between the Fruitland subcrop and downbasin production. This major assumption should be described in the summary. This is a valid and verifiable assumption for determining worst case conditions. It should be stated as such.

3. Page ES-2, 2nd Paragraph, 2nd Sentence states: "According to the modeling, the depletion as of August 2005 for the CBM wells within the basin in Colorado was

determined to be about 155 AF/yr." This sentence appears to state observed or measured facts. The word "estimated" should be inserted in front of "depletion" since this volume of water was neither measured nor observed.

4. Section 3.0 (in general) – Reference to geologic mapping along the outcrop belt of the Fruitland Formation and Pictured Cliffs Sandstone occurs in several places. These references do not cite the geologic map of the Basin Mountain Quadrangle (CGS Open-File Report 01-4 by Kirkham and Navarre). This publication includes considerable information on fractures within the Pictured Cliffs Sandstone and cleats within the Fruitland Formation. Of particular interest might be the 10 to 30° difference in orientations between the "face-cleats" of the Fruitland Formation and the fractures within the Pictured Cliffs Sandstone.

5. Page 3, 3rd Paragraph, 5th Bullet – This is apparently true given the lack of discussion about the observations at the Pine River Ranches study area (see above), but it appears that the parameter estimation analysis did look specifically at localized groundwater elevation changes at specific sites as a means to calibrate the analysis.

6. Page 9, 2nd Paragraph, Last Sentence – This sentence should include the Paleocene Nacimiento Formation as one of the formations deposited during the Laramide Orogeny.

7. Page 13, 2nd Paragraph, Fracturing – There is no mention that calcite fills a majority of fractures in the San Juan Basin, as shown by the down-hole videos. Calcite healing and sealing of fractures should be discussed.

8. Page 26, Section 5.2.2, Compartmentalized Aquifer Conceptual Model – The Pine River Ranches report should be included in this discussion.

9. Page 27, 2nd Bullet, "… there is hydraulic connection…" – Again this is a worst case assumption, not a statement of fact and should be stated as such.

10. Page 28, 3rd Paragraph, Last Sentence – Further explanation and justification should be provided for why the permeability of the Pictured Cliffs Sandstone is not considered significant. Particularly given that this formation was one of the original "pay zones" in many of the original gas wells in the basin.

11. Page 33, 3rd Paragraph, Section 5.3.6, Water Level Conditions – Berry, Oldaker, and McCord all presented potentiometric head maps that should also be referenced.

12. Page 34, 1st Line – Reference is made to Figure 5.7, but we were unable to find this figure. It would seem that the reference should be to Figure 5.6.

13. Page 34, 2nd Paragraph, Last Sentence – If site-specific data were not evaluated, how can it be stated that "pressure trends reflect connection to the saturated unconfined aquifer at the outcrop?" This should again be stated as a worst case assumption.

14. Page 36, 3rd Paragraph, Section 5.4.2, Isotope Chemistry – This section should be titled "Stable Isotope Chemistry" since radiogenic isotopes are discussed in the next section.

15. Page 36, 3rd Paragraph, Last Sentence – Chlorine-36 and iodine-129 are radiogenic isotopes and should be discussed in the next section.

16. Page 37, Carry-over sentence from Page 36 states "…it appears that the aquifer does behave as a single system, at least within several miles of the outcrop." This sentence is somewhat contradictory with the assumption of hydraulic continuity throughout the basin and a tributary distance to the outcrop of 10.5 miles.

17. Page 38, 1st Paragraph, Last Sentence – the sentence should include ^{129}I rather than ^{139}I.

18. Page 38, 2nd Paragraph, Last Sentence – Given the discussion of isotopic age dating provided above, it would seem that substantially different water ages at various geographic locations throughout the basin may suggest a conclusion contrary to this summarizing sentence.

19. Page 41, Last Paragraph (and elsewhere) – reference to the Fruitland-Pictured Cliffs hydrostratigraphic unit as an aquifer is misleading given its reported permeability of 0.01 to 0.1 darcy. This would be considered a barrier to flow in many basins in the Rocky Mountain region.

20. Page 44, 1st Full Paragraph – This paragraph seems to provide justification for concluding that the assumptions used by Papadopulos in their use of the Glover-Balmer method forces the timing of depletions to the streams to be equivalent to the timing of depletions at the outcrop (i.e., is overly conservative in that there is additional travel time from the outcrop to the stream). This is significant in that the statutory definition of nontributary groundwater is time specific. If the timing of the depletions calculated in this manner are "shifted forward in time… on the order of months to a few years" according to the Study text, the location of the nontributary line can arguably be moved toward the outcrop accordingly.

21. Page 44, Last Paragraph, 2nd Sentence – An obvious exception to this is the Pine River Ranches data, which should be noted.

22. Page 45, 1st Full Paragraph, 2nd Sentence – If <u>all</u> wells pumping within the San Juan Basin in Colorado create a depletion of 156 AF/yr, what is the combined effect from the nontributary wells and what is the resulting depletive effect from the tributary wells only?

23. Page 50, 3rd Paragraph, Last Sentence – An obvious exception to this is the Pine River Ranches data, which should be noted.

24. Figure 2.1 – Untitled with no source reference.

25. Figure 2.2 – Untitled with no source reference.

26. Figure 3.1 – The source of this information should be cited.

27. Figure 3.3 – Untitled with no source reference.

28. Figure 3.5 – The source of this information should be cited.

29. Figure 3.6 – Untitled with no source reference.

30. Figure 3.7 – Untitled with no source reference.

31. Figure 3.8 – No figure number.

32. Figure 5.1 – The general location of this cross section (and others) should be provided on one of the planimetric maps.

33. Figure 5.2 – Untitled.

34. Figure 5.5 – If one assumes that downbasin production is draining the Fruitland Formation, then spring flows at the highest elevations of the outcrop should be greatly diminished or nonexistent. Perhaps the existence of these springs (as indicated on this figure) is an indication of a lack of downbasin connectivity.

35. Figure 6.2 – This is one of the very few plan views of the basin that includes Township and Range numbers. Inclusion of this information on each figure would help to orient the reader (particularly Figure 6.1).

36. Table 3.2 – The Pine River Ranches 1 well does not exist. WWE is unclear which well is being referenced. Reference to a well with only four seams and 15 feet of coal does not match with any of the ongoing monitoring wells at Pine River Ranches.

37. Table 5.1 – The Gurr well is part of the Pine River Ranches study area and data from this well were included in this table. However, there are seven other Fruitland and Transition zone wells at Pine River Ranches which are not included. It should be noted that the Gurr well potentiometric head has not responded to any infilling production and is now flattening out.

6.0 REFERENCES

American Water Works Association. 1975. *Sizing Water Service Lines and Meters. AWWA Manual M 22.* Denver, CO: AWWA.

McCurry, G., 2004. Comparing methods of estimating stream depletions due to pumping. *Southwest Hydrology*, Pgs. 6 and 31.

Miller, C.D. and Durnford, D.S., 2005. Modified use of the “SDF” Semi-Analytical Stream Depletion Model in bounded alluvial aquifers. Hydrology Days 2005, Colorado State University, Fort Collins, Colorado, Pgs. 146-159.

Sophocleous, M., Koussis, A., Martin, J.L. and Perkins, S.P., 1995. Evaluation of simplified stream-aquifer depletion models for water rights administration. *Ground Water*, Volume 33, No. 4, Pgs. 579-588.

\\Alice\PF\001-015\020ard\Review Report\report review legal.doc

DENVER
2490 W. 26th Avenue Suite 100A
Denver, Colorado 80211
Phone: 303.480.1700
Fax: 303.480.1020

GLENWOOD SPRINGS
818 Colorado Avenue
P.O.Box 219
Glenwood Springs, Colorado 81602
Phone: 970.945.7755
Fax: 970.945.9210

DURANGO
1666 N. Main Avenue Suite C
Durango, Colorado 81301
Phone: 970.259.7411
Fax: 970.259.8758

www.wrightwater.com

WWE

Wright Water Engineers, Inc.

Maynes, Bradford, Shipps & Sheftel, LLP
Attorneys at Law

THOMAS H. SHIPPS
JANICE C. SHEFTEL
PATRICIA A. HALL†
SAM W. MAYNES
JOHN BARLOW SPEAR
STEVEN C. BOOS*†

BYRON V. BRADFORD (1907-1985)
FRANK E. (SAM) MAYNES (1933-2004)

ASSOCIATES:

ELISABETH J. TAFT◊
KRISTINA N. JOHN±
KATHERINE A. BURKE

†ALSO ADMITTED IN ARIZONA AND NAVAJO NATION
*ALSO ADMITTED IN CALIFORNIA, NEW MEXICO AND UTAH
◊ ALSO ADMITTED IN WASHINGTON
±ADMITTED ONLY IN NEW MEXICO AND NAVAJO NATION

(970)247-1755
(970)247-8827 – FACSIMILE
jsheftel@mbsslp.com

September 27, 2006

Dick Wolfe, P.E.
Office of the State Engineer
Division of Water Resources
1313 Sherman Street, Room 818
Denver, CO 80203
VIA E-MAIL: dick.wolfe@dwr.state.co.us

Re: *Coalbed Methane Stream Depletion Study - Northern San Juan Basin, Colorado,* prepared by S.S. Papadopulos and Associates, Inc., dated Feb 2006 ("Report")

Dear Dick:

As you know, Maynes, Bradford, Shipps and Sheftel, LLP, represents the Southern Ute Indian Tribe ("Tribe"). Attached please find further comments of the Tribe on the Report. Thank you for your consideration of the Tribe's concerns. Because of the Tribe's major financial interest in coalbed methane ("CBM") development, the accuracy of any study dealing with stream depletions from CBM production is vital to the Tribe.

Sincerely,

MAYNES, BRADFORD, SHIPPS AND SHEFTEL, LLP

Janice C. Sheftel

Janice C. Sheftel

JCS:sps
cc: Dick Baughman
attachment
H:\sps\SUIT\Letters\Wolfe 02.doc

WEST BUILDING – 835 EAST SECOND AVENUE, SUITE 123
POST OFFICE BOX 2717
DURANGO, COLORADO 81302-2717

re: Additional comments on *Coalbed Methane Stream Depletion Study – Northern San Juan Basin, Colorado*, by S.S. Papadopulos and Associates, Inc. ("SSP") Feb. 2006

Conceptual model

The hydrologic modeling portion of the Ignacio Blanco Field 3M study, performed in 2000 by Applied Hydrology Associates, Inc., shows that Fruitland Formation permeabilities are variable, and that there are some areas that are partially or largely compartmentalized, primarily evidenced by blocks of higher-TDS groundwater. In contrast, the SSP Stream Depletion Study (Report) recognizes that "plumes" of low-TDS water occur in the basin, but ignores the large areas of non-plume high-TDS water. The Report also references studies by Riese and the Colorado Geological Survey (CGS), that state that there are complex chemical and isotopic differences in the groundwaters flowing through the coalbeds of the Fruitland Formation, and that these differences indicate localized compartmentalization. The Glover method, required by the Division of Water Resources ("DWR") for the Report, however, allows only one permeability value, and thus is incapable of factoring in the effects of compartmentalization. The Glover method, used to model hydrologic flow in the multi-permeable coalbeds of the Fruitland Formation, is, therefore, inadequate.

The Report made two major assumptions: (1) uniform permeability, in order to provide input values to the Glover equation, and (2) that any discontinuities do not have "regional": effects. Most importantly, the Report does not allow for reduction in water permeability due to the relative permeability effects of desorption. In fact, the Report excluded dual-phase flow dynamics, as being outside the scope of the Report. As soon as CBM production starts, however, dual-phase flow dynamics quickly apply and these dynamics always operate to reduce effective water permeability. In addition, coal permeability reduces as the coal is depressurized. Ignoring this reduction in permeability results in an over-estimation of stream depletion

All these factors, particularly relative permeability effects, result in an over-estimation of stream depletion. The Report states that the Glover model is not applicable to the high producing fairway due to the presence of gas, but, in fact, the same argument applies to the entire area under CBM production.

Application of Glover method

The Glover method assumes an idealized and simplified stream-aquifer interaction, in which the stream completely penetrates the aquifer and has perfect hydraulic connection with the aquifer. In reality, the streams and alluvial bodies crossing the Fruitland outcrop are shallow, partially penetrating, and may have reduced stream bed permeability.

All these factors lead the stream depletion to be overestimated by the Glover Method.

Additionally, the Glover method applies a uniform value of aquifer permeability, which is unrealistic.

Transmissivity and storage estimates

It is not clear why the Report's transmissivity estimates use image wells at outcrop boundaries, as this methodology ensures zero drawdown at the outcrop and may be unrealistic.

The Report does explain that the image well methodology is expected to reflect the effect of the higher storage values near the outcrop. Those higher storage values, however, were not used in The Report's Glover equation. As a result, the Glover method, using the wrong, lower storage values, greatly overestimates stream depletion, especially near the outcrop, which is the most important area from the point of view of stream depletion. The Report uses the Glover method with the wrong, lower storage values, but elsewhere points out that "…water level declines in the outcrop area of the aquifer will be very small, essentially, dampened due to the contrast in storage." (p.31).

The transmissivity estimates also assume a constant storage value, whereas, in reality, the area near the outcrop has a very large unconfined (porosity) storage value while the deeper parts of the basin have a much lower, confined (compressible) storage value.

The fact that there are large differences between the transmissivity determined for non-Ute monitoring wells and for Ute production wells indicates that (1) permeability is in fact very variable, and (2) relative permeability effects operate and are very significant in areas affected by production. Again, these estimates assume fully water-saturated conditions and do not take account of relative permeability effects, a significant drawback.

A further minor criticism of the Report is that SSP converted bottom hole pressure to water heads using a density of 2.307 g/mL which applies to fresh water, whereas some areas of groundwater are quite saline and, hence, denser.

Applicability of Glover method

Despite the shortcomings of the conceptual model, the transmissivity and storage estimates, and the use of the Glover method, described above, the Report suggests that "… the error associated with divergence from the ideal case can be minimized". The Report admits numerous sources of error,but does not provide convincing supporting evidence that error minimization has been achieved. Notably, the aquifer is not homogeneous or isotropic, and approximating to "average" values does not resolve that issue.

The input parameters of permeability and storage have basic flaws in the method of their determination and in the use of approximated values. As a result, these parameters are likely to lead to significant over-estimates of actual outcrop influence and stream depletion.

The fact that the Glover method estimates stream depletion, under some scenarios, of over 500 ac-ft/year, whereas the estimated recharge to the Fruitland Formation over the entire San Juan Basin is only ~200 ac-ft/year, suggests that the Report pushes the envelope beyond the applicability of the Glover method. Several authors have addressed the shortcomings of the Glover method (e.g., Zlotnik et al, 1999, *Evaluation of stream depletion considering finite stream width, shallow penetration, and properties of streambed sediments*, in *Water 99 Joint Congress*, Brisbane Australia, July 6-8, 1999).

H:\sps\SUIT\SSP Report.doc9/27/06

HYDROSPHERE
Resource Consultants

May 3, 2006

Mr. Dick Wolfe, P.E.
Assistant State Engineer, Division of Water Resources
Department of Natural Resources
1313 Sherman Street, Room 818
Denver, Colorado 80203

Re: SSPA Report on Stream Depletion due to Coalbed Methane Development in the San Juan Basin, Colorado

Dear Mr. Wolfe:

With this letter, I summarize my findings and opinions related to the report entitled *Coalbed Methane Stream Depletion Assessment – Northern San Juan Basin, Colorado* prepared by S.S. Papadopulos & Associates and released by the State of Colorado on April 4, 2006; below I refer to this as "the SSPA report." In general, I found the report to yield results that understate actual expected stream, spring, and groundwater depletion. To fully evaluate the amount of error in their depletion estimate would take a significant amount of further data collection and analysis. The depletion underestimation error relates to problems in their conceptualization and application of the Glover method. Furthermore, the study completely fails to address the key issue of how seep and spring flows, and drawdowns to shallow groundwater, in the outcrop area will be impacted by water production of CBM wells. Given that there are numerous water users who rely on supplies associated with springs, seeps, and shallow groundwater in the outcrop area, this omission seriously limits the scope of the findings on how CBM production may impact senior water rights in the northern San Juan Basin. After summarizing my findings and opinions related to Chapters 1 through 5, I describe in detail my concerns related to their depletion analysis.

Chapters 1 through 5

Chapter 1 of the SSPA report lists the project objectives to include an evaluation of the suitability of the Glover method to estimate stream depletion due to northern San Juan Basin CBM development. This chapter also lists sources of various data considered in the report, including well production, stream and spring flows, water quality, and future CBM production estimates. We have acquired and/or accessed all easily available sources of hydrologic and hydrogeologic data (e.g., gas and water production histories), and these data agree with data as presented in the SSPA report (e.g., Figure 1.2). Chapters 2 and 3 provide broad descriptions of the geographic and geologic settings of the study area, and I found no glaring omissions or misstatements based on my previous independent reviews of data and information on the study area. Similarly, Chapter 4 on CBM production history and expected future trends seems appropriately targeted and accurate. Of particular interest in Chapter 4 is the fact that the "Fairway" area exhibits significantly higher gas-water production ratios compared to the other parts of the study area (inferred from Figures 4.3 and 4.4). This fact coupled with lower derived permeabilities for Ute / Fairway area wells (presented subsequently in Section 5.3.2.2) suggests that the Glover-type hydrologic analysis may be inappropriate for estimating water depletions due to pumping wells in the Ute/Fairway area; this conclusion was also suggested by SSPA.

Chapter 5 describes hydrogeologic conditions in the study area as inferred from available data. Included in their analysis, SSPA employ water production and pressure data in conjunction with a Theis-type analysis to estimate permeability to be used subsequently in their Glover analysis. I concur with SSPA that using a simplified model built on the same assumptions as the Glover approach provides the most appropriate permeabilities to use in the Glover depletion analysis. Also notable in Chapter 5 is SSPA's finding, based on a review of a diverse set of hydrogeologic data and information, that a through-flowing aquifer conceptual model better matches observed conditions than a compartmentalized aquifer model promoted by some (Section 5.2.3). I also concur with this finding.

Chapter 6. CBM Produced Water Stream Depletion Analysis

In this Chapter, SSPA describes previous stream depletion studies for the area undertaken using a MODFLOW model, and they describe their approach for application of the Glover method. In describing their approach for applying the Glover method, they note that the streams actually cross the Fruitland – Pictured Cliffs outcrop in limited, discrete locations. They further describe that the streams "more resemble a series of small ponds in their intersection with the aquifer than they do linear streams" (p. 43 of SSPA report). I agree with this perspective. Then, however, they go on to note that between the streams along the outcrop zone are located tributaries, seeps, and springs. Based on this situation, they go on to argue that "when compared to the basin, the outcrop itself is stream-like."

While I agree that from the perspective of wells deep in the basin, the outcrop area is stream-like, I would argue that from the perspective of localized conditions along the outcrop, be it the major rivers, minor tributaries, or higher altitude springs and seeps, the hydrologic response of these features exhibit varying degrees of consistency with the Glover model. One of the key assumptions underlying the Glover method is that the stream can be represented as a constant head boundary that provides an essentially unlimited supply of surface water leakage into the aquifer to negate water level declines that would occur in the absence of the stream. This assumption likely holds true for the major rivers, it is less true for tributary streams, and is likely patently untrue for seeps and springs. In fact, for these types of hydrologic features, the outcrop actually begins to exhibit conditions better represented by a no-flow boundary than by a constant head boundary.

The impact of a no-flow boundary would be a compounding of effects (i.e., depletions) on those features that act as constant head boundaries. In other words, depletions to the major streams and tributaries are likely larger than predicted by the Glover model. While one may contend that these compounding effects are actually lumped into the overall depletions computed using the Glover approach as implemented by SSPA, I would maintain that this is not necessarily true. In the higher outcrop areas, unconfined drainage likely does not approach the volumes of water needed to attenuate drawdowns to "appear" as constant heads in nearby portions of the aquifer. Rather, at this time based on my limited review without the benefit of having the basic data, it appears that the surface water depletion values computed by SSPA using their Glover model represent a minimum estimate with an unknown uncertainty.

Major Omission of Study: Impacts on Springs, Seeps, and Shallow Groundwater Levels in Outcrop Area

Beyond the concerns raised above related to estimated depletions to surface water flows, the actual hydrologic response likely involves a significant lowering of the unconfined water table in the higher elevation areas, causing seeps and springs to dry up, as well as shallow wells. Consistent with the conceptual model of the Fruitland-Pictured Cliffs aquifer described by SSPA, one can envision the aquifer as a relatively flat confined system which is "upturned at the lip" (the outcrop area). In the outcrop area, conditions are unconfined (p. 34) and recharge to the aquifer occurs (p. 32). While SSPA acknowledges that in some cases springs in the outcrop may actually be discharging from the Fruitland-Pictured Cliffs (p. 33), based on my limited review it seems that an additional subset of the springs and first-order tributary flows in the outcrop area actually represent "rejected recharge" due to the unconfined water table intersecting the land surface (i.e., the aquifer is full and thus can accept no more recharge at that location).

Under these through-flowing aquifer conditions, one should reasonably expect that water extraction associated with CBM development will cause regional declines in water level that will propagate all the way to the outcrop. Such declines will directly impact spring and seep flows, as well as water level in shallow wells that penetrate the Fruitland – Pictured Cliffs aquifer. Water users who rely on and put to beneficial use these types of water supplies will be severely impacted by the CBM water production, and the Glover analysis used to estimate depletions provide no way to evaluate this type of injury to senior water rights.[1]

Conclusions

This letter report summarizes my findings and opinions related to the SSPA report on expected water depletions due to CBM water production in the northern San Juan Basin of Colorado. While there are numerous aspects of the report that I agree with, with regard to expected water depletions, I found the report to yield results that understate actual expected stream, spring, and groundwater depletion. The depletion underestimation error relates to problems in their conceptualization and application of the Glover method, and I describe my concerns in detail above. To fully evaluate the amount of error in their depletion estimate would take a significant amount of further data collection and analysis. Finally, the report fails to explicitly address the expected water level declines to the unconfined portions to the Fruitland – Pictured Cliffs aquifer in the outcrop area, and how these water level declines will impact water users who rely on springs, seeps, and shallow groundwater in this area.

If you have any questions, please call me at 505-835-2569.

Sincerely,
Hydrosphere Resource Consultants, Inc.

by:_________________________________

James T. McCord, Ph.D., P.E.

Cc: Debbie Hathaway, SSPA

[1] It is interesting to note that the SSPA report (as well as the AHA, 2000 and Cox et al., 2001 MODFLOW modeling reports) do not provide modeling results on expected water level declines in the outcrop area.