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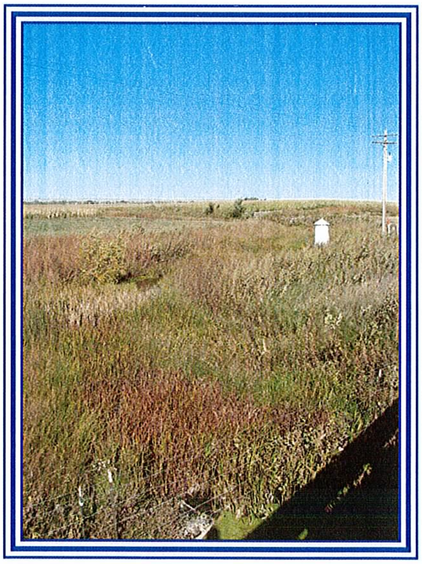
EVALUATION OF THE PUMPKIN CREEK GROUND WATER ALLOCATION BY THE NORTH PLATTE NRD



PREPARED FOR: CNPPID
HOLDREGE, NEBRASKA

OCTOBER 2008

PROJECT NO. 1163-08

640 PLAZA DRIVE, SUITE 170
HIGHLANDS RANCH, COLORADO 80129
WWW.LYTLEWATER.COM

PHONE: 303-350-4090
FAX: 303-350-4095
E-MAIL:LWS@LYTLEWATER.COM

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EVALUATION OF THE PUMPKIN CREEK GROUND WATER ALLOCATION BY THE NORTH PLATTE NRD

INTRODUCTION

The North Platte Natural Resources District (NPNRD) has been setting an annual ground water allocation of 14 inches per certified irrigated acre in the Pumpkin Creek basin since October 15, 2003. According to the NPNRD, the 14-inch ground water allocation would result in a permissible basin withdrawal of 56,092 acre-feet per year (ac-ft/yr) (NPNRD, 2004). In September 2008, the NPNRD proposed that the allocation be reduced to 12 inches.

This allocation is being set at a time when there is compelling evidence of a) significant development of wells in the Pumpkin Creek basin associated with increases in irrigated lands, b) progressive declines in discharge of Pumpkin Creek and a progressive increase in the number of "no-flow" days per year, and c) progressive reductions in surface water diversions of canals drawing water from Pumpkin Creek related to reduced availability of surface water for diversion (Drain, 2002) . These conditions prompted the Central Nebraska Public Power and Irrigation District (CNPPID) to investigate the relationship between the expansion of well use, the expansion of irrigated lands, and the reductions in surface flow of Pumpkin Creek. In particular, the investigation presented herein focuses on the appropriateness of the NPNRD's current and proposed ground water allocation in light of the known facts.

This report, prepared on behalf of CNPPID, summarizes our analysis of the ground water allocation set by NPNRD and our evaluation of whether there is a direct cause and effect relationship between the NPNRD's ground water allocation and depletions of surface water due to well pumping. We have evaluated the proposed allocation (as well as reduced allocation levels) relative to the natural recharge to the basin, surface and subsurface discharge from the basin, and the sustainability of ground water use relative to natural recharge to the basin.

Our evaluation is based on two approaches that use different methodologies to assess the appropriateness of the ground water allocation implemented by the NPNRD. The first, an analytical approach, evaluates relationships between precipitation, runoff, well development, and mass balance estimates to establish the relationship between well pumping and other terms of the water balance within the Pumpkin Creek basin. The second approach relies on the use of a numerical ground water flow processes model of the Pumpkin Creek basin (Pumpkin Creek Model), i.e., a model which represents the principal flow processes that occur within the Pumpkin Creek basin associated with the stream systems and associated alluvial aquifers. The Pumpkin Creek Model was used to investigate the effects of pumping on Pumpkin Creek stream flows. The Pumpkin Creek Model is also further used to predict the response of the basin to several allocation levels, specifically, in terms of the timing and rate of recovery of stream flow in Pumpkin Creek.

HYDROLOGIC SETTING

Basin Attributes

Pumpkin Creek drains an area of 1,011 square miles (mi^2), or approximately 20 percent of the North Platte River drainage area in Nebraska upstream of Lake McConaughy. Pumpkin Creek joins the North Platte River between the Bridgeport and the Lisco surface water gaging stations on the North Platte. There is one gaging station on Pumpkin Creek (Pumpkin Creek near Bridgeport, gage number 06685000) before its confluence with the North Platte. Figure 1 shows the general location of the Pumpkin Creek basin and the location of the gage.

Precipitation

There are three precipitation gages within, or in close proximity to, the Pumpkin Creek basin having sufficiently long periods of record for use in this study. These gages are known as the Bridgeport, Kimball and Harrisburg gages. Figure 1 shows the locations of these precipitation gages in the Pumpkin Creek basin, and Table 1 identifies the periods of record for each station and the mean precipitation for the period of record. Table 1 indicates that precipitation at the Harrisburg and Bridgeport gages is very similar, while the Kimball gage indicates a higher long-term precipitation.

Cumulative annual precipitation versus time for each of these stations is plotted in Figure 2. As demonstrated by Figure 2, there is no evidence of a significant long-term increase or decrease in precipitation at any of these stations, as would be noted by a change in slope of the lines.

In addition to the specific Pumpkin Creek precipitation gages, there is also a record known as "Division 1," which represents the average annual precipitation of all stations within the western panhandle area of Nebraska (NCDC, 2008). As such, the Division 1 record provides broader geographic coverage than any of the three gages mentioned above for the Pumpkin Creek basin and surrounding area. The data from the Division 1 record were compared to specific gages in the Pumpkin Creek watershed (Bridgeport, Harrisburg, and Kimball) and were found to be well correlated (Appendix A). This indicates that the Division 1 record provides a reasonable measure of precipitation in the Pumpkin Creek basin, and annual precipitation values for the Division 1 record are shown in Figure 3.

Runoff

Figure 4 shows annual flow (on a calendar year basis) in Pumpkin Creek at the Bridgeport gage for the period 1932–2003. These records were taken from the combined published records of the United States Geological Survey (USGS) (1932–1991) and the Nebraska Department of Natural Resources (NDNR) (1992–2003). As this figure shows, surface flows in Pumpkin Creek averaged 23,200 ac-ft/yr from 1932–1970. Since 1970, flows were in an almost continuous state of decline through 2003, when the Pumpkin Creek stream flow was 1,208 ac-ft. This represents a decrease of 21,992 ac-ft/yr between these two periods, based on the recorded stream flow records. Stream flow records were obtained for 2004–2007 and were 686 ac-ft/yr, 1,964 ac-ft/yr, 2,372 ac-ft/yr, and 1,898 ac-ft/yr, respectively (Mike Jess e-mail communication, 2008).

HYDROGEOLOGIC SETTING

The following geologic units of interest are present in the Pumpkin Creek basin:

- Alluvial Aquifer
- Ogallala Formation
- Arikaree Group
- Brule Formation

Alluvial Aquifer

Pumpkin Creek and its principal tributaries occupy narrow alluvial valleys, and each are underlain by an alluvial aquifer of limited areal extent. The main source of the water supply in both Pumpkin Creek and the associated alluvial aquifer (since it is hydraulically connected with the overlying stream system) is precipitation that falls within the Pumpkin Creek watershed. Ground water wells have developed along the axis of the creek, with the majority of the wells within 0.5 miles of the stream. Generally, the alluvial aquifer is associated with the active stream channel, although there are limited areas where the stream has moved away from the alluvial aquifer. Figure 5 shows the locations of all currently-registered irrigation wells in the Pumpkin Creek basin. The alluvial aquifer consists of loose, stream-laid deposits of sand and gravel. The alluvium is highly permeable and yields large quantities of water to irrigation wells (Babcock and Visher, 1952).

Ogallala Formation

The Ogallala Formation lies on the eroded surface of the underlying Arikaree Group. The Ogallala is a heterogeneous mix of gravel, sand, silt, clay, siltstone, and limestone. There are limited occurrences of the Ogallala within the study area and the areas where these sediments are saturated are even more limited (Smith and Souders, 1975). The Ogallala is exposed over broad areas in the southern portion of the study area. It is typically found at higher elevations and, therefore, has limited saturated thickness. Surface infiltration rates in the Ogallala are high, making it an important factor for recharge into the Lawrence Fork alluvium.

Arikaree Group

The Arikaree Group is composed primarily of fine-grained sandstone, with lesser amounts of silt, siltstone, and volcanic ash. It is relatively resistant to erosion and forms portions of the bluffs on both the northern and southern margins of the basin. Because many of the rocks of the Arikaree are fine-grained, the permeability tends to be relatively low. The areas in the basin where the Arikaree is saturated are limited (Smith and Souders, 1975). Therefore, the Arikaree is not considered an important aquifer for purposes of this study.

Brule Formation

Generally, the alluvial aquifers in the valley bottom are underlain by the Brule Formation. The Brule consists of "moderately calcareous to very calcareous siltstone that contains much volcanic ash and small amounts of very fine sand" (Smith and Souders, 1975). The Brule is exposed on the floor and sideslopes of the valley and along the valley margins. On the floor of the valley, the Brule is covered by comparatively thin alluvial sediments, terrace deposits, and colluvial sediments.

Except where it is fractured, the Brule yields relatively little water to wells (Steele, et al, 2007). However, where fractured, the Brule can yield significant quantities of water (Gottula, 1980). Fracturing appears to be localized and generally found in valleys which follow the modern stream channels and other topographically low sites (Smith and Souders, 1975). Most wells penetrating the Brule that yield sufficient water for irrigation are found along or adjacent to the axis of Pumpkin Creek and its larger tributary drainage basins. In a USGS report, it is stated that "in some areas where the fractures are overlain by saturated alluvium, sufficient water for irrigation can be developed" (Babcock and Visher, 1952). In areas where the Brule Formation is unfractured siltstone, it forms the base of the shallow aquifer system in the Pumpkin Creek valley and serves as a confining unit for the region (Steele et al, 2005).

Principal Water-Bearing Unit

The principal water-bearing unit within the Pumpkin Creek basin consists of saturated alluvial materials associated with Pumpkin Creek and its tributary and, where present, fractured Brule Formation which underlies these alluvial deposits (personal communication with Steven Sibray of the University of Nebraska Panhandle Research and Extension Center, September 2008). Data on the hydrogeologic properties of the saturated alluvium and the fractured Brule is sparse, and so is insufficient to discriminate between these units for purposes of this study. The combination of saturated alluvium and underlying fractured Brule likely function as a single aquifer in supplying water to wells, in conveying water from upper areas of the basin to the lower areas of the basin, and in terms of their hydraulic interaction with water in Pumpkin Creek.

IRRIGATION AND LAND USE PRACTICES

Surface Diversions, Spills, and Return Flows

Only three canals (Meredith-Ammer, Courthouse Rock, and Last Chance) on Pumpkin Creek (Figure 1) have recorded diversion records. Records from the NDNR data base indicate that there may be other canals and pumps that have historically diverted water from the stream. However, the amounts of these additional diversions are likely to be small compared to the recorded diversions.

The Belmont Canal diverts water from the North Platte River upstream of the confluence of Pumpkin Creek. According to NDNR records, the Belmont Canal spills a portion of the water diverted from the North Platte River into Pumpkin Creek (Belmont Spill) between Greenwood Creek and the Pumpkin Creek near Bridgeport gaging station (Figure 1). Although records end in 1988, the canal spills continue to date. Historically, spills to Pumpkin Creek were "credited" against diversions by the Belmont Canal from the North Platte River. This is no longer the case, and the gage has been removed (personal communication with Tom Hayden of NDNR, September 2008).

There are no direct means for estimating irrigation return flows. In the absence of measured values, an average irrigation return flow of 40 percent of the amount of water diverted was assumed for purposes of this study relative to surface water diversions. This estimate is based on engineering judgment, and reflects the predominant flood irrigation in the basin and additional seepage losses (return flows) associated with historic surface ditch conveyances.

Return flows from ground water pumping, where there is a mix of flood and sprinkler irrigation, were estimated to be 20 percent. The lower value was used due to the increase in sprinkler irrigation with time and because there would not be the canal seepage losses associated with ground water pumping.

While return flows can be variable, our values are appropriate for the types of irrigation being employed and the soil conditions in the Pumpkin Creek basin.

Total recorded diversions, estimated return flows, and recorded spills to Pumpkin Creek are shown in Figure 6.

Ground Water Irrigation and Wells

There are an estimated 592 irrigation wells registered within the Pumpkin Creek watershed, based on the NDNR online data base. The vast majority of these wells are located within 0.5 mile of Pumpkin Creek and its tributaries (Figure 5). Well records indicate the majority of these wells obtain their water from the alluvial aquifer or a combination of the alluvial aquifer and the underlying Brule Formation. As indicated previously, in the vicinity of Pumpkin Creek and its tributaries, the alluvial aquifer and the Brule Formation act as a single aquifer.

Runoff Conservation Measures

Runoff conservation measures involve changes to the land designed to decrease the amount of surface runoff that occurs during precipitation events, and thus “conserve” this water for use by crops and/or livestock. The most notable conservation measures include stock ponds, contouring, and various no-tilling practices.

Based on discussions with Natural Resource Conservation Service (NRCS) personnel (C. Amateis, personal communication, August 29, 2008), a review of aerial photographs and satellite imagery of portions of the basin and a field reconnaissance of the basin in September 2008 (during which an attempt was made to identify conservation measures), the incidence of runoff conservation measures in the Pumpkin Creek basin is judged to be small. As a consequence, runoff conservation measures are not a significant factor in evaluating the water balance in the Pumpkin Creek basin.

ANALYSIS OF DEPLETIONS TO SURFACE WATER FLOWS

Analytical Methods

The total basin outflows measured at the Bridgeport gage (shown in Figure 4) are the combined base flow and storm runoff in the basin. For purposes of this report, *base flow* is defined as contributions to surface flow from ground water recharge through infiltration of precipitation and snowmelt. *Storm runoff* is defined as overland flow to stream channels that results from precipitation events and/or runoff from snowmelt. *Total basin outflow* is defined as the combination of base flow and storm runoff. Since the base flow component of total basin outflow is impacted by ground water development, it is important to understand what portion of total basin outflow is base flow.

A two-step process was used to evaluate the relationship between base flow and total basin outflow. First, Bridgeport gaged flows were adjusted to remove the effect of surface diversions, return flows, and trans-basin imported water ("spills"). This step is necessary so that stream flow records are adjusted to reflect what outflow would have been observed at the gage if no diversions (including return flows) or spills had taken place.

Daily diversion data for the three major canals described above were used to adjust the Bridgeport gaged record of daily stream flow. While the gaged records were adjusted to account for canal diversions (added to the gaged values), irrigation return flows were subtracted from the gaged records to account for the return flows that were measured at the gage. In effect, the gaged records were modified to account for crop consumptive use. The gaged record was also adjusted for the Belmont Spill (only for years with records) by subtracting the record of spills from the gaged daily stream flow at Bridgeport. Figure 6 shows the reported annual values for diversions from the three major canals, the annual values for spills by the Belmont Canal, and the estimated irrigation return flows. These values were used to adjust gaged values of basin discharge recorded at the Bridgeport gage. Figure 7 shows the total basin outflow after the adjustments described above were made.

The second step in the process was performed once total adjusted basin outflows were estimated. This step used a base flow separation tool to separate base flows from storm flows. The base flow separation technique used in this analysis is the automated Web-based Hydrograph Analysis Tool (WHAT) (Lim et al, 2005). The WHAT program uses digital filters to separate high-frequency signals (base flows) from low-frequency signals (storm flows) (Lyne and Hollick, 1979). The WHAT methodology is fully described in the Journal of the American Water Resources Association (Lim, et al, 2005). Once the WHAT methodology separated base flow from storm flow, the medians of the monthly estimates of base flow were selected in lieu of mean monthly values to eliminate extremes from the estimates. To complete the analysis, yearly averages of the monthly median values were calculated and are shown in Figure 7.

This base flow separation technique indicates that the average base flow during the time period when stream flows showed limited impact from pumping (1932–1970) is approximately 20,900 ac-ft/yr (Figure 7). For comparison purposes, in a USGS report (Babcock and Visher, 1952), it was estimated that the average annual base flow in Pumpkin Creek was approximately 21,000 ac-ft/yr (or 27 cubic feet per second (cfs)). The base flow separation values and the USGS estimate of base flow compare well.

The base flow separation results indicate that, on average, the primary source of basin outflow is associated with base flow (84 percent), with only 16 percent of the total basin outflow being associated with storm flow. The relatively low runoff percentage indicated by the base flow separation is consistent with the widespread occurrence of high-infiltration soils in the basin, where surface runoff would be expected to be low.

The portion of stream flow that is fed by ground water (base flow), as well as the total outflows from the basin, have been declining since approximately 1970 (Figure 7). There are several possible causes for these declining flows:

- A decline in precipitation with time
- Surface modifications to lands which impact surface runoff to the stream
- Increased ground water pumping, resulting in additional capture of surface flows

An evaluation of each of these potential causes is discussed in the following sections.

Precipitation: Average annual precipitation for Division 1 (the Panhandle area of western Nebraska) is shown in Figure 4 (NCDC, 2008). To evaluate whether or not precipitation exhibited a statistically-significant trend (i.e., whether precipitation was increasing or decreasing over time), the Mann-Kendall test (Gibbons, 1994) was performed on these data. The results of the Mann-Kendall test show that there is a slight upward trend over the period of record (1932–2007). The data shown in Figure 4 were also compared to specific gages in the Pumpkin Creek watershed (Bridgeport, Harrisburg, and Kimball) to evaluate if the Division 1 precipitation data were representative. These analyses indicated good correlation of the data (Appendix A). Given these findings, a change in precipitation with time is not the cause for the declines in surface water flow at the Bridgeport gage on Pumpkin Creek.

As a further check of the stream flow and precipitation relationship, a double-mass curve analysis was performed to compare long-term stream flow and long-term precipitation trends. The cumulative stream flow was taken as the gage flow at the mouth of Pumpkin Creek, adjusted for spills from the Belmont Canal into the Pumpkin Creek watershed. This was the only adjustment made for this analysis, as the double-mass analysis began with the period of record starting in 1932, when surface water diversions were already established in the Pumpkin Creek watershed. The cumulative precipitation data were taken from the Division 1 record.

The plot of cumulative precipitation versus cumulative stream flow (Figure 8) shows a linear relationship from approximately 1932 to 1970. However, beginning in 1970, the cumulative stream flows deviate from the linear relationship that was very evident from 1932 to 1970. At the same time, statistical data for precipitation at both the Pumpkin Creek gages and for the cumulative Division 1 record indicate a consistent trend (Figure 2 and Appendix A). This analysis indicates that the decline in stream flow is related to factors other than precipitation.

Reduction in Surface Runoff Due to Modifications in Land Use: Given that there is little evidence of conservation measures implemented within the Pumpkin Creek basin, land use modifications cannot be the cause of the significant declines in total basin outflow over time. Moreover, most land use modifications which reduce surface runoff tend to cause an increase in infiltration and ground water recharge. Therefore, even if limited conservation measures are found to cause changes in the timing of flows, it is our opinion that there would not be a significant change in the overall quantity of water discharging from the system on a long-term basis.

Ground Water Pumping: Ground water pumping in the Pumpkin Creek watershed began in the 1930s. According to NDNR records, by 1950 there were 31 irrigation wells recorded and by 1960 there were 90 irrigation wells in the Pumpkin Creek watershed. By 1970, the NDNR data base indicated that this number had increased to 192 irrigation wells, while by 2006 there were 592 irrigation wells in the Pumpkin Creek watershed (NDNR web site, 2008). Figure 9 shows how declines in surface water flows have corresponded in time with the proliferation of wells. As shown in Figure 9, dramatic declines in surface water discharge from the watershed coincide with the proliferation of wells. The vast majority of new irrigation wells lie along the axis of Pumpkin Creek and its major tributaries (Figure 2). This is significant, not only because there has been a proliferation of wells, but because when wells are drilled adjacent to streams, well pumping induces additional surface water recharge into the ground, thereby supporting ground water production while simultaneously directly reducing surface water flows.

Based on limited records, surface water use for the years immediately prior to 1950 averaged about 6,400 ac-ft/yr (1946–1950) with a maximum of 8,684 ac-ft/yr (Figure 6). Average ground water pumping during the 1946–1950 period is estimated to be 1,600 ac-ft/yr. The pumping average is estimated based on an average amount of water pumped per well using data from 2003–2006, adjusted for variations in pumping related to variations in precipitation. Adding together the average surface water diversions (6,400 ac-ft/yr) and the average pumping (1,600 ac-ft/yr) gives a total average historic water use of approximately 8,000 ac-ft/yr for the years immediately prior to 1950.

For comparison purposes, the NPNRD reports ground water pumping of 36,145 ac-ft in 2006 (Table 2). At the same time, surface water use in 2006 was negligible; therefore, total use in 2006 was 36,145 ac-ft. This represents an expansion in total use of 28,145 ac-ft since 1950 (36,145 ac-ft minus 8,000 ac-ft). This expansion of use exceeds the average annual outflow for the Pumpkin Creek watershed (23,200 ac-ft). Clearly, water use above the average annual outflow of the basin cannot be sustained on a long-term basis.

While the expansion in water use since 1950 is estimated to be 28,145 ac-ft, the expansion in ground water use is greater than the change in water use since 1950, because ground water use has supplanted most surface water use that was occurring in 1950. The expansion in ground water use is estimated to be 34,545 ac-ft (total use in 2006 of 36,145 ac-ft, all of which was ground water, minus 1,600 ac-ft of ground water use in 1950). The magnitude of stream depletions caused by ground water pumping can be estimated analytically by examining the change in base flow over the period of expansion in ground water use.

As described previously, the base flow separation technique indicated that the average base flow over the period of time before dramatic declines in stream flow were observed (1932–1970) was 20,900 ac-ft/yr. In 2003, the base flow was 100 ac-ft (Figure 7); therefore, the change (20,800 ac-ft) is a decline in base flow that can be directly attributed to ground water pumping.

The average total adjusted stream outflow over the same time period (1932–1970) is 24,900 ac-ft/yr (Figure 7), indicating that storm runoff was, on average, 4,000 ac-ft/yr. This means that 84 percent of the total flow in Pumpkin Creek is base flow. As base flow declined, storm runoff declined proportionately, so that base flow has averaged 84 percent of the total outflow over the entire period of record. The reduction in storm flow is an indicator of increased infiltration due to lower ground water levels.

The foregoing analyses indicate that water use has expanded by about 28,145 ac-ft/yr between approximately 1950 and 2006, while the estimated stream depletion associated with this pumping is about 20,800 ac-ft/yr.

In conclusion, changes in precipitation, changes in runoff conservation, and ground water pumping were all possible explanations for the decline in surface water outflows which have been observed at the Bridgeport gage. However, all of the analyses using analytical methods show that the principal reason for the surface water declines is related to the increase in ground water use.

Numerical Model

While the analytical methods described previously used available data bases to evaluate cause and effect relationships between ground water pumping and surface water flows, the Pumpkin Creek Model was developed to investigate the time-dependent relationship between ground water pumping and the effects on Pumpkin Creek flows, as well as to evaluate the impact of NPNRD allocations.

A numerical model can provide significant additional benefits over analytical approaches, while still being consistent with analytical approaches. Major attributes of the Pumpkin Creek numerical model are:

- Flow processes in the alluvial aquifer, and between the alluvial aquifer and stream, can be simulated.
- Time-dependent recharge to the alluvial aquifer can be estimated based on variable basin hydrology from season to season and year to year.

- The numerical model, once calibrated, is constrained based on known inputs so that it provides representative results.

- The numerical model requires accounting for all of the terms of the ground water budget, giving confidence that the results are representative.

- Impacts of well pumping with time on surface ground water flows can be predicted.

- Effects on well pumping rates when surface water recharge rates decline can be predicted.

- Timing of recovery of stream flows can be predicted as ground water pumping is reduced.

- Effects of the NPNRD ground water allocations on surface water flows can be evaluated.

Overview of the Model: The Pumpkin Creek Model represents the principal flow processes that occur within the Pumpkin Creek basin. As such, this model does not simulate all of the movement of water within the basin, but is instead limited to major flow processes. The Pumpkin Creek Model focuses on ground water within the principal aquifer, namely the combined alluvial sediments and fractured Brule along the main channel of Pumpkin Creek and within tributary valleys containing significant water-bearing sediments. The determination as to which tributary valleys contained significant water-bearing sediments was based on the incidence of high-capacity wells.

The Pumpkin Creek Model uses MODFLOW (McDonald and Harbaugh, 1988). Much of the underlying structure of the Pumpkin Creek Model is based on the representation of the Pumpkin Creek basin contained in the Western Model Unit developed by the Cooperative Hydrology Study (COHYST) program. The COHYST program constructed a ground water model (also using MODFLOW) that covered the North Platte and part of the South Platte River basins in the western panhandle of Nebraska. The Western Model Unit, as built by the COHYST program, was modified and refined, as necessary, to improve the Pumpkin Creek Model's representation of the Pumpkin Creek basin.

The Pumpkin Creek Model domain extends about 65 miles in an east-west direction, and 35 miles in a north-south direction (Attachment 1, Figure 1). The model's domain is subdivided into model cells, each measuring one-half mile on a side. There are about 2,800 active cells within the model's domain. A steady-state implementation of the model represents hydrologic conditions prior to the onset of significant well development (prior to 1950). A transient implementation of the model simulates the period from 1950 through 1997, the time of major well development. The model operates on a seasonal stress period (two per year, irrigation and non-irrigation seasons). The model's transient simulation only runs through 1997 because this is the last year with a complete well pumping data base.

The Pumpkin Creek Model represents hydrogeologic conditions within the Pumpkin Creek basin with a single layer. The physical properties of this layer (e.g., elevation of the top and bottom) and hydrologic properties of this layer (e.g., hydraulic conductivity, specific yield, etc.) vary from cell to cell.

The limits of the active portion of the model were assigned based on hydrologic features, such as where the Pumpkin Creek alluvial aquifer joins the North Platte alluvial aquifer, ground water divides, or physical limits of the ground water system.

The starting values assigned for aquifer properties, such as hydraulic conductivity, were taken from the COHYST Western Model Unit. These were subsequently modified where warranted by available data that indicated other values were more appropriate, or where necessitated during model calibration. However, values were never adjusted during calibration outside a reasonable range based on available data and our professional judgment.

Additional details on construction of the Pumpkin Creek Model are provided in Attachment 1, which contains the documentation report for the Pumpkin Creek Model. Model development may continue as additional data on historical pumping, land use, and other information becomes available.

Model Results: To demonstrate that the Pumpkin Creek Model is consistent with the available data base, the model was calibrated. The calibration process and resulting mass balance analyses are presented in the documentation report for the Pumpkin Creek Model presented in Attachment 1. A comparison of Pumpkin Creek flows simulated by the Pumpkin Creek Model to actual

Bridgeport gage records is shown in Attachment 1, Figure 8 of the documentation report. The agreement between the long-term trend of simulated surface flows and actual surface flows indicates the Pumpkin Creek Model can produce representative predictions of future conditions.

Relative to evaluating the NPNRD's ground water allocation and its effect on surface water flow, the Pumpkin Creek Model was used to simulate four separate scenarios. The scenarios that were simulated using the Pumpkin Creek Model included estimating a) native flows in Pumpkin Creek with no anthropogenic effects, b) what Pumpkin Creek flows will be in the future if 1997 levels of pumping are allowed to continue, c) how much, and in what time frame, Pumpkin Creek flows would recover if pumping was reduced to 8,000 ac-ft/yr, and d) how much, and in what time frame, Pumpkin Creek flows would recover if all pumping was eliminated. The results of these simulations are described below.

It should be noted that for all of the future predictive scenarios, the simulations were initiated in 1997. While we acknowledge that we are 11 years beyond the start of the future predictive scenarios, these model runs are designed to show the continued decline in ground water pumping that can be expected if more restrictive ground water allocations are not put in place by the NPNRD, and the relative amounts of surface flow restoration that will occur in time if more restrictive ground water allocations are imposed.

Scenario 1 used a historical period of record from 1950 to 1997, with no ground water pumping. The purpose of this simulation was to predict stream flows in Pumpkin Creek for a condition in which there was no well development over the 1950 through 1997 period. For this simulation, all pumping in the model was eliminated so that the Pumpkin Creek Model will predict time-dependent flows in Pumpkin Creek that are not influenced by ground water pumping. The results of this simulation, which show predicted stream flow in Pumpkin Creek for the period 1950 through 1997, are presented in Figure 10. The Pumpkin Creek Model predicts that stream flow in Pumpkin Creek would have been stable through this period, averaging approximately 27 cfs, in the absence of well development. When Figure 10 is compared to Figure 7 (estimated base flow), the simulation in Scenario 1 demonstrates that surface flows in Pumpkin Creek would not have declined had it not been for the dramatic increase in pumping.

Scenario 2 simulates 40 years of future pumping at 1997 pumping levels. Adequate records are not presently available to extend the Pumpkin Creek Model beyond 1997, the ending year for the COHYST Western Model Unit. Accordingly, for purposes of this investigation, the level and geographic distribution of pumping that existed in 1997 was adopted for an analysis that looked at continuing pumping at or near "present" levels of pumping. It is important to note in the WMU model that "[f]or both calibrations, Pumpkin Creek was simulated as nearly dry by 1998" (Luckey and Cannia, 2006). As such, the WMU model would predict no flow for any future prediction at similar pumping rates. Therefore, the WMU could not be expected to produce results other than continuing dry stream conditions.

While 1997 ground water pumping is well below the permissible pumping limit under a 14-inch allocation (56,092 ac-ft), actual use, as shown in Table 2, is considerably less than the permissible limit. Therefore, we believe that this scenario adequately represents how Pumpkin Creek flows will continue to be affected by ground water pumping if more limits on the ground water allocation by NPNRD are not imposed.

The purpose of this simulation was to predict stream flows in Pumpkin Creek for the period 1997 forward for 40 years for the case where pumping is maintained at 1997 levels (about 24,000 ac-ft/yr of net pumping, based on results from the COHYST Western Model Unit). This scenario was constructed by simulating the period 1950 through 1997 using estimates of historical pumping levels, then extending the simulation an additional 40 years and repeating the estimate of pumping that occurred in 1997 for each of those years. The 1997 pumping level (about 24,000 ac-ft/yr net pumping, or 30,000 ac-ft/yr gross pumping) is estimated to be equivalent to an allocation of approximately 7.7 inches (using the NPNRD's 2006 certified acres (37,383 acres)). The results of this simulation are shown in Figure 11 for the historical period and the future period. The Pumpkin Creek Model predicts a continued decline in stream flow in Pumpkin Creek, stabilizing at an average annual flow of about 3 cfs. This is equivalent to an annual flow of 2,168 ac-ft, which is similar to the reduced flow observed at the Bridgeport gage (1,208 ac-ft) (Figure 4). These results indicate that at an allocation of approximately 7.7 inches, stream flow in Pumpkin Creek will continue to decline, and may be expected to stabilize at approximately 3 cfs.

Scenario 3 simulates 40 years of future pumping at 8,000 ac-ft/yr. The purpose of this simulation is to investigate the timing and magnitude of recovery of stream flow in Pumpkin

Creek that might be expected if levels of pumping are reduced to about 8,000 ac-ft per year. A value of 8,000 ac-ft per year of pumping was selected for testing for a number of reasons. Given that historic levels of use prior to about 1950 were of the same order of magnitude, it was reasoned that pumping at this level might be sustainable without significant reductions in stream flow (LWS, September 10, 2008). Further, even if it was determined that this level of pumping would not restore stream flow in a timely manner, it might provide insight as to the magnitude and timing of recovery of stream flow that might be expected. This scenario was constructed by simulating the period 1950 through 1997 using estimates of historical pumping levels, then extending the simulation an additional 40 years with pumping reduced to 8,000 ac-ft per year for each of those years. A pumping level of 8,000 ac-ft/yr is estimated to be equivalent to an allocation of approximately 2.5 inches. Alternatively, 8,000 ac-ft of pumping could have a higher per-acre allocation if the number of certified acres is reduced. For example, at the current use range (Table 2), if the allocation remained consistent with use, a 7.95-inch allocation would allow 12,075 acres of irrigation and an 11.6-inch allocation would allow 8,275 acres of irrigation.

The results of this simulation are shown in Figure 12 for both the historical period and the future period. The Pumpkin Creek Model predicts a recovery in stream flow to about 18 cfs by the end of the 40-year simulation. Given that pre-development stream flow was 27 cfs, Figure 12 shows that stream flow has not fully recovered to pre-ground water development levels after 40 years of reduced pumping. What is evident from Figure 12 is the direct and immediate recovery of surface water flows once pumping is reduced from 1997 levels. Surface water flow recovered 32 percent in the first year after pumping was reduced and 45 percent in the first five years after pumping was reduced (Figure 12).

Scenario 4 simulates future conditions with all ground water pumping eliminated. The purpose of this simulation is to investigate the timing and magnitude of recovery of stream flow in Pumpkin Creek that might be expected if pumping is eliminated altogether. This scenario was constructed by simulating the period 1950 through 1997 using estimates of historical pumping levels, then extending the simulation an additional 40 years with no pumping for each of those years. The results of this simulation are shown in Figure 13 for both the historical period and the future period and indicate flow recovery to 25 cfs by the end of the 40-year simulation. As Figure 13 shows, there is more complete recovery of surface water flows than in the 8,000 ac-ft/yr pumping scenario, yet pre-ground water development surface flows have not totally recovered after 40 years of no pumping (25 cfs versus 27 cfs). However, the stream flow recovery is quicker than in the 8,000 ac-ft/yr pumping scenario, with stream flows recovering 37 percent in the first year and 63 percent within five years (Figure 13).

Summary of Numerical Modeling Results. The numerical model simulates the principal aquifer and the principal components of the water budget within the Pumpkin Creek basin. Calibration of the model provides assurance that these representations are reasonable. As such, the numerical model provides an independent means to investigate the cause and effect relationship between pumping and stream flow within the Pumpkin Creek basin. The numerical model confirms the findings of the analytical investigation. In particular, the model confirms that reduced stream flow in Pumpkin Creek is directly related to an increase in pumping over the same period. Likewise, when ground water pumping is decreased or eliminated, surface water flows in Pumpkin Creek recover (Figures 12 and 13). Furthermore, the NPNRD ground water allocation is clearly not based on the hydrology of the Pumpkin Creek watershed. Allowable ground water pumping (56,092 ac-ft) is more than double the basin outflow on an average annual basis, and even when half this volume of pumping is simulated (Scenario 2), surface flows stabilize at approximately 10 percent of the native basin outflow. Therefore, the numerical model clearly shows that the NPNRD ground water allocation is flawed.

In comparing model predictions to actual surface water flow recovery, it is necessary to understand the actual hydrology versus the simulated hydrology. If the actual hydrology differs from the future predicted hydrology, the Pumpkin Creek Model may need to be modified and re-run to more closely match actual conditions.

ANALYSIS OF THE PUMPKIN CREEK ALLOCATION

It is clear from both the analytical and numerical methods that ground water pumping is the principal reason for declining surface water flows. The proposed 12-inch allocation will not recover surface water flows, as demonstrated by the Scenario 2 results, where even a 7.7-inch allocation results in a near-depletion of Pumpkin Creek flows (Figure 11). The following describes our analysis of the ground water allocation.

The NPNRD states that allowable ground water pumping under the 14-inch allocation is 56,092 ac-ft. This volume exceeds the total estimated annual in-basin base flow plus the storm runoff, and far exceeds the volume of pumping that may be possible without significant impacts to surface water flows. Scenario 2 of the numerical model clearly demonstrates how ongoing pumping (even at a level below current pumping) will continue to deplete virtually all native surface flows. In addition, the current NPNRD allocation also exceeds actual use for the period 2003–2006. NPNRD records indicate actual water use ranged from 26,740 to 36,145 ac-ft/yr from 2003–2006, which is equivalent to an allocation of 7.95 to 11.60 inches per acre (Table 2). Therefore, it is clear that there is not enough water being recharged in the basin on an annual basis to support a 14-inch allocation. In addition, a reduction in allocation to a range of 7.95–11.60 inches per acre (based on recent use) would have no measurable effect on actual ground water pumping because, given the current number of irrigated acres, the current volume of pumping may be limited by the physical supply in the basin. Therefore, an allocation in the range of 7.95–11.60 inches per acre, or greater, would not address the declines in surface water flows that have been observed since 1970. To address this issue, it is necessary to reduce the allocation below these levels.

While analytical methods in the LWS September 10 report indicated that 8,000 ac-ft/yr of ground water pumping might allow recovery of surface water flows, the numerical model indicates that an allocation which allows for up to 8,000 ac-ft/yr pumping is not low enough to restore stream flow to 1950 levels within 40 years (Figure 12). Elimination of all ground water pumping also takes a significant time to recover surface water flows (Figure 13). However, both simulations indicate a direct and immediate response to a significant reduction in pumping. This clearly shows the benefit of acting immediately to reduce ground water pumping so that surface water flows can begin to be restored. Since the numerical model is simply a predictive tool, actual confirmation of model results is also necessary. Therefore, since the Pumpkin Creek Model indicates that initial surface water flow recovery is relatively fast (48 percent recovery in 5 years at pumping of 8,000 ac-ft/yr), an initial reduction in the ground water allocation to 8,000 ac-ft for the next 2 years, accompanied by basin flow monitoring to assess how flows actually recover compared to how the model predicts their recovery, could evaluate the benefit of reducing the ground water allocation. Thereafter, the ground water allocation can be adjusted, as necessary, to fully restore pre-ground water development surface flows.

Had the NPNRD developed a comprehensive integrated water management plan, the impact of ground water pumping on surface flows in the Pumpkin Creek basin would be apparent. The proposed reduction in ground water allocation presented herein could be a first step to this integrated water management plan.

CONCLUSIONS AND SUMMARY OF PROFESSIONAL OPINIONS

Based on our analysis of available hydrologic, hydrogeologic, pumping and irrigation records, and using an analytical and numerical approach to evaluating the Pumpkin Creek basin, we offer the following professional opinions regarding the NPNRD's ground water allocation process in the Pumpkin Creek watershed:

(1) Pumping of ground water within the Pumpkin Creek basin causes a direct and substantial impact on surface flow in Pumpkin Creek. This is demonstrated by both analytical methods and through the use of the Pumpkin Creek numerical ground water flow model.

(2) The pumping of ground water within the Pumpkin Creek watershed from wells completed adjacent to the primary stream channels in the basin directly impacts surface flows within the basin by inducing additional recharge into the ground from surface flows. Our analyses indicate that the direct impact of ground water pumping on surface water outflows is 20,800 ac-ft.

(3) An allocation of 12 to 14 inches per year is not sustainable within the Pumpkin Creek watershed and will not result in restoration of stream flows. In recent years, actual use has been in the range of 7.95–11.60 inches per acre. This level of use is probably limited by the physical availability of water in the basin and not by the amount of the allocation.

(4) To restore historic surface water flow conditions, it is necessary to reduce the ground water allocation significantly below the actual use values. The Pumpkin Creek Model predicts that even with the elimination of all ground water pumping, it could take over 40 years to fully restore surface water flows.

(5) The first step for a functional integrated water management plan would be to initially reduce the ground water allocation to 8,000 ac-ft/yr and setting up basin

flow monitoring to assess whether actual flow recovery matches the predicted flow recovery. It is predicted that there will be 38 percent recovery of surface flows in two years and 48 percent recovery of flow will occur in five years (13 cfs). With this as a guide, if actual surface flow recovery is different from simulated flow recovery, the ground water allocation can be adjusted, as necessary.

(6) Setting a pumping limit at 8,000 ac-ft can either result in a lower application rate for current certified acres (approximately 2.5 inches) or certified acres could be reduced to allow current application rates (7.95 to 11.6 inches) to continue. This would result in 12,075 acres to 8,275 acres to continue to be irrigated.

(7) The analyses presented herein can serve as the initial steps in the comprehensive integrated water management plan that the NPNRD is required to develop to minimize conflicts between surface water users and ground water users in over-appropriated basins.

The analyses presented herein are based on available data bases and our professional opinions are based on these analyses. Loring P. Watkins, E.I., Staff Engineer of LWS was responsible for the current development of the Pumpkin Creek Model, assisted by Hayden R. Strickland, E.I., Senior Engineer of LWS, under the supervision of the undersigned. Ms. Watkins also assisted in the drafting of this report under the supervision of the undersigned. The numerical model is being refined as additional data are acquired. Accordingly, the results of the analyses using the numerical model may be revised.

Bruce

Bruce A. Lytle, P.E.
President

PROFESSIONAL CIVIL ENGINEER
BRUCE A. LYTLE
E-12433
STATE OF NEBRASKA

W. H

William F. Hahn, P.G.
Principal Hydrogeologist

STATE OF NEBRASKA
William F
Hahn
G-0325
PROFESSIONAL GEOLOGIST

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TABLE 1
SUMMARY OF MEAN ANNUAL PRECIPITATION AT PUMPKIN CREEK GAGES

Gage	NDNR Station Index No.	Period of Record	Mean Annual Precipitation (in)
Harrisburg	3605	1949-1999	15.0
Bridgeport	1145	1932-1998	15.7
Kimball	4440	1895-1999	17.4

TABLE 2
PUMPKIN CREEK BASIN WATER USE COMPARISON [1]

Year	Certified Irrigated Acres (ac)	Total Allocation (ac-ft)	Total Water Used (ac-ft)	Inches Applied Per Acre
2003	40,597	51,173	30,240	8.94
2004	40,466	47,767	32,621	9.67
2005	40,358	47,618	26,740	7.95
2006	37,383	44,012	36,145	11.60

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1) From data prepared by the NPNRD.

APPENDIX A

RAINFALL GAGE DATA

ATTACHMENT 1

DOCUMENTATION FOR THE FLOW PROCESSES MODEL OF PUMPKIN CREEK