Lytle Water Solutions, LLC

ANALYSIS OF DEPLETIONS TO THE NORTH PLATTE RIVER

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INTRODUCTION AND BACKGROUND

This report summarizes the results of an investigation of factors responsible for reductions to inflows entering Lake McConaughy. This study was conducted by Lytle Water Solutions, LLC (LWS) on behalf of the Central Nebraska Public Power and Irrigation District (CNPPID). Lake McConaughy is owned and operated by CNPPID. CNPPID has the right to appropriate water for storage and other uses under priority dates of 1934. CNPPID has the right to make beneficial uses of the water for multiple purposes, including the use of natural flow and storage for irrigation, hydropower production, cooling water, underground storage, recreation, and instream flows for fish and wildlife, among other uses. The Kingsley Hydroelectric Plant generates power through the release of water stored in Lake McConaughy. Because of the multiple uses of Lake McConaughy, it is very important to CNPPID that flows into the lake are not reduced due to anthropogenic effects such as ground water pumping, which would cause a direct and substantial impact to Lake McConaughy's surface water uses.

In recent years, CNPPID has observed a reduction in inflows to Lake McConaughy. This has resulted in a reduction in levels of storage compared to levels that have been observed historically. Natural hydrologic variations are the principal cause of variation in inflows to the lake. However, these variations are not the sole cause of declining inflows. This study shows that the substantial increase in ground water pumping contributes significantly to the reduction in inflows to Lake McConaughy.

The ability of an alluvial aquifer well pumping adjacent to a river to cause a direct and substantial reduction in surface water flow is well documented. The details of this impact depends on a number of factors, including the pumping rate of the well, the stage of the river, the distance between the well and the river, the degree of hydraulic connection between the well and the river, and the extent to which a lowering of ground water levels causes changes in other sources of discharge from the ground water (e.g., sub-irrigation). Because these relationships themselves are complex, it is often useful to employ tools such as water budget analyses, analytical solutions, and numerical models to predict the impacts of wells on river discharge.

Two approaches were used in this investigation: a mass balance approach, where the amounts of all inflows and outflows to the system are identified, and a numerical model approach that uses terms from the mass balance approach and provides a more complete representation of the system.

PHYSICAL, HYDROLOGIC, AND GEOLOGIC SETTINGS

Physical Setting

There is significant agricultural development along the North Platte River corridor. Prior to about 1950, most of this agriculture was irrigated with surface water diverted from the North Platte River. Beginning about 1950, the development of ground water wells started to provide additional water for irrigation of lands within the North Platte River Basin. While there was not significant well development initially, over time, well development has proliferated until there are now almost 2,700 registered irrigation wells in the North Platte River Basin. There are two classifications of ground water wells in this area. First, there are wells serving lands that do not have access to surface water and, therefore, were not irrigated historically. The lands served by these wells are referred to herein as "ground water only" lands, indicating that their sole source of irrigation water is from ground water. However, in more recent years, there has been a proliferation of wells to supply water to lands that also receive surface water. This second type of well is used to supplement surface water supplies at times when there is a shortfall of surface water. These wells are referred to as "supplemental wells" and serve lands receiving water from both surface water and ground water. Lands irrigated with both surface water and ground water are hereinafter referred to as "comingled" lands. Virtually all of the wells in the North Platte River Basin that have been installed above Lake McConaughy obtain their water from an aquifer having direct hydrologic connection to the North Platte River.

Historically, the majority of irrigated lands within the North Platte River Basin developed along the river. These lands were irrigated with surface water diverted from the mainstem at diversion structures in Wyoming and Nebraska. There is an extensive network of canals, laterals, and drains along the North Platte River. Appendix A provides a straight-line diagram of the major canals, laterals, drains, and tributaries along the North Platte mainstem from the Nebraska-Wyoming state line to Kearney, Nebraska (Tom Hayden, NDNR, personal communication,

January 8, 2009). There are twelve canals operated by the Bureau of Reclamation (government canals). These canals serve the following irrigation districts:

- Beerline
- Browns Creek
- Central
- Chimney Rock
- Enterprise
- Farmers
- Gering
- Gering - Fort Laramie
- Mitchell
- Northport
- Pathfinder
- Ramshorn

The largest of the districts, the Pathfinder Irrigation District, serves 157,000 acres, while the smallest, the Union Irrigation District, serves 1,500 acres (Luckey and Cannia, 2006).

There has been extensive well development within the North Platte River drainage upstream of Lake McConaughy. Figure 3 shows the locations of active and non-replacement irrigation wells, based on NDNR records (2008). According to the NDNR records, there are 2,684 registered irrigation wells in the North Platte River Basin between the Wyoming-Nebraska state line and Lake McConaughy.

Hydrologic Setting

The primary source of water for Lake McConaughy is the North Platte River and its tributaries. The focus of this investigation is the area contributing water to the North Platte River between the Lewellen gage at Lake McConaughy on the east and the Nebraska-Wyoming State Line on the west (project area). The area of the basin in Nebraska is also generally defined on the north and south by the surface water drainage divide of the North Platte River and to the west by the state line. There are a few areas where the ground water divide extends beyond the surface water drainage divide. These areas do not constitute a significant fraction of the basin and for the purposes of this report are included in the area referred to as the *North Platte River Basin*. This area has been the subject of extensive study and is included within the domain of a ground water model developed under the Cooperative Hydrology Study (COHYST) program (Luckey and Cannia, 2006). The model developed under this program is known as the Western Model Unit

(WMU) and is discussed in more detail in subsequent sections of this report. The study area and domain of the WMU are shown in Figure 1.

The North Platte River Basin upstream of Lake McConaughy is predominantly rangeland, dryland, and irrigated agriculture. Average annual precipitation ranges from 14 inches to 18 inches, generally increasing from west to east. Canal losses are relatively high through the reach of the North Platte River Basin extending from the state line to Lake McConaughy. Losses are estimated to be in the range of 17 percent to 51 percent (Luckey and Cannia, 2006).

The North Platte River consistently gains water between the state line and Lake McConaughy. This is a result of the combination of the losses (recharge) from canals into the underlying alluvial ground water throughout the study area and the return flows from irrigation. The North Platte River is gaining water both directly and indirectly from these seepage losses and irrigation return flows. These flows provide base flow back to the North Platte River. Ground water currently discharges to many of the tributaries crossing the irrigated area. In a few cases, tributary discharges are large enough to allow an irrigation district to change its point of diversion of water from the mainstem to the tributary. For example, this is true in the case of the Alliance Irrigation District and the Ninemile Drain. In effect, many of the tributaries function as drains, by intercepting ground water in the irrigated areas and ultimately returning it to the North Platte River by way of the tributary channel. Many of these gains occurred in response to the onset of surface diversions and the development of irrigation along the mainstem. However, these gains are declining, as will be shown in a subsequent section of this report.

Hydrogeologic Setting

The geologic units of interest within the project area include various alluvial and colluvial sediments, dune sands and wind-blown deposits, the Ogallala Group, the Arikaree Group, and the Brule Formation (Luckey and Cannia, 2006). The distribution of these sediments is shown in Figure 2. The alluvial deposits constitute the primary aquifer along the North Platte River supporting many large capacity irrigation wells. These are generally found in the valley bottom of both the North and South Platte Rivers. The Ogallala Group is also an important aquifer and underlies, or is exposed over, much of the project area (Figure 2). The Arikaree Group underlies portions of the basin. Although not a principal source of water, the Arikaree can yield significant

quantities of water where it is fractured and saturated. Areas where such conditions exist are limited.

The Brule Formation underlies the entire North Platte River Basin in the study area. Locally, fractures may result in increased permeability of the otherwise low-permeability rocks of the Brule Formation, although the frequency of fracturing is low and the location of these fractures is unpredictable (Gottula, 1980).

The Pumpkin Creek Basin is the largest tributary to the North Platte River mainstem in the project area. There is major agricultural development within the Pumpkin Creek Basin and a large number of wells have been drilled for irrigation. The principal aquifer in the Pumpkin Creek Basin is formed by saturated alluvial sediments, or a combination of saturated alluvial sediments, and fractured Brule Formation underlying the saturated alluvial sediments. The principal aquifer is found along, or adjacent to, the present course of Pumpkin Creek and in a number of tributary valleys extending south and west from Pumpkin Creek. The vast majority of irrigation wells in the Pumpkin Creek valley penetrate the alluvial sediments, the fractured Brule sediments, or both.

CONCEPTUAL MODEL

A narrative description of the COHYST WMU conceptual model of the project area is provided by Luckey and Cannia (2006). The following is a synopsis of the conceptual model, taken in part from that report.

The major sources of inflow to the project area include surface water crossing the western boundary of the model in the mainstem of the North Platte River and in canals originating in Wyoming and crossing the state line on both the north side and south side of the mainstem to deliver water for irrigation to Nebraska inside the basin. The other major source of inflow comes from precipitation falling in the region. A portion of the precipitation falling in the region is lost to direct evaporation or evapotranspiration. The balance becomes surface runoff or enters the ground water system through deep percolation.

The two major outflows from the project area are flow in the North Platte River into Lake McConaughy and evapotranspiration (ET). Surface water outflows are measured at the Lewellen gage. Water passing the Lewellen gage travels a relatively short distance before entering Lake McConaughy. ET losses occur in the riparian corridor along the mainstem. There is also an area of significant ET in the Sand Hills area north of the mainstem. The other major outflow from the region is through consumptive use of water applied for agricultural irrigation. This water is supplied through direct diversions from the river, tributaries, and drains, and also from wells.

Subsurface inflows and outflows to the region are relatively minor when compared to the overall water budget of the system. Inflows to the project area along the Nebraska-Wyoming state line enter through the alluvial sediments of the North Platte River and through upland soils. Similarly, subsurface outflows along the eastern boundary of the project area leave primarily through the alluvial sediments of the North Platte River.

There are significant seepage losses from the canals traversing the region. These, combined with deep percolation of applied water, represent a major source of return flow to the ground water system and to the stream system.

The principal aquifer in the region of interest to this study is formed by alluvial sediments lying adjacent to, and beneath, the North Platte River. These sediments extend up to several miles north and south of the valley bottom, where they generally thin to a feather edge. The Ogallala Group (or High Plains aquifer) is an important aquifer in the northwestern portion of the region. The Arikaree Group and the Brule Formation constitute aquifers of local importance where favorable conditions exist, although they do not have a major role in ground water conditions along the North Platte River.

Table 1 summarizes the estimated water budget for the North Platte River Basin. The North Platte River Basin is defined to include those areas that contribute to the mainstem or the underlying alluvial aquifer between the Nebraska-Wyoming State Line and Lake McConaughy.

MASS BALANCE APPROACH

A mass balance, also referred to as a *water budget,* represents an accounting of all the major inflow and outflow terms for a defined system, in this case for the North Platte River Basin. The mass balance approach is based on the following equality:

Inflows - Outflows = Change in Storage

There is no evidence of widespread change in water levels since 1950 (the beginning of significant development of wells) that would indicate significant changes in storage in the North Platte River Basin, particularly in areas along the North Platte River mainstem. Ground water levels in this area fluctuate seasonally, but appear to be stable over the long term. Therefore, where the mass balance is calculated over a long period, such that changes in storage are negligible, i.e., no changes in water levels over time, the mass balance can simply be expressed as:

Inflows = Outflows

The mass balance for the North Platte River Basin, when evaluated over an extended period of time, can be used to investigate the effects of well pumping on river flow. In the case of the North Platte River Basin, the major components of inflow are:

- Surface water inflows, representing gaged inflows at the Nebraska-Wyoming state line,

- Inflows from Wyoming canals, representing inflows from canals diverting water in Wyoming and delivering water across the state line,

- Direct runoff and deep percolation, representing the combination of runoff entering the North Platte River from upland areas, and ground water discharge to tributaries and to the margins of the mainstem area, originating as deep percolation of rainfall, and

- Alluvial underflow, representing water entering the North Platte Basin as alluvial underflow at the Nebraska-Wyoming state line.

The major components of outflow are:

- Surface water outflows, representing gaged outflow at the Lewellen gage (a measure of inflow to Lake McConaughy),

- Alluvial underflow, representing water leaving the basin as subsurface flow in the area of the Lewellen gage,

- Evapotranspiration, representing evaporation and transpiration losses in areas of standing water, wetlands, areas of phreatophyte growth along the river corridor, evaporation from lakes, including a portion of the Sand Hills area north of the North Platte River mainstem, etc.,

- Consumptive use on land irrigated with ground water exclusively, representing water consumed by crops irrigated with ground water,

- Consumptive use of water on land irrigated solely with surface water, and

- Consumptive use of water on comingled lands. In the case of comingled lands, the consumptive use includes both the use associated with surface water and the use associated with ground water that supplements surface water supplies.

A mass balance analysis was prepared for the period 1950 through 2004 on a water-year basis. The purpose of the mass balance was to investigate the cause of the declining surface water flows being measured at the Lewellen gage. Figure 4 is a graph of the North Platte River gaged flows at the Wyoming-Nebraska state line (state line gage), flows at Lewellen, and the gaged flows of water carried in canals crossing the state line (Wyoming canals) added to the flows at the Wyoming-Nebraska state line. As shown on this figure, the inflows to the North Platte River at the state line (the sum of Wyoming gaged flow and the inflows from canals crossing the state line) (green line) track closely with the flows at Lewellen (pink line). This figure demonstrates

the pronounced effect of varying hydrology, as measured at the state line on flows at Lewellen. Figure 4 also suggests that either there are no sources of additional flow that would add to the North Platte River flows between these boundaries, or, that if there are significant sources, the water is removed prior to reaching the Lewellen gage. These flows represent the major surface water inflow and outflow terms in the mass balance.

Figure 5 is a graph of the cumulative flows entering the basin at the state line (state line gage plus Wyoming canals) compared with the cumulative flow leaving the region at the Lewellen gage. There is an increasing difference between the gaged inflows and gaged outflows beginning in about 1958. The average of the difference is about 103,000 acre feet per year (ac-ft/yr) over the 1958 to 2004 period. This implies that flows at the Lewellen gage have been declining over time, and the increasing separation of the lines in Figure 5 with time shows that the difference from 1997 to 2004 has increased to 149,000 ac-ft/yr. There are several possible causes for this growing difference between inflows to the region and outflows from the region, including a) reduced gains within the region; i.e., reduced canal inflows from Wyoming and/or reduced precipitation, b) changes in native ET, and/or c) increased consumption of water within the region, including the lagged effects from consumption of irrigation water prior to 1997. We have evaluated each of these potential factors.

Figure 6 is a graph of the cumulative gaged inflows of the Wyoming canals as they cross the state line (Mitchell-Gering, Fort Laramie, and Interstate Canals). There were no adjustments made to the records of flows for the Mitchell-Gering and Fort Laramie Canals as their gages are located near the state line. Recorded flows for the Interstate Canal were adjusted for estimated seepage losses of 17 percent assumed to occur between the gage and the state line, based on measured losses upstream. As can be seen in Figure 6, the fact that the cumulative flows fall in a straight line indicates that there has been no long-term progressive increase or decrease in inflows to the basin from these canals. Therefore, canal inflow changes with time are not the cause of declining flows at Lewellen.

Figure 7 is a graph showing the cumulative Division 1 precipitation (Division 1 precipitation represents multiple stations located within the panhandle region) over time for the period 1942-2004. This graph indicates that there has been no long-term change in precipitation over this

period. Accordingly, systematic changes in precipitation can be ruled out as the cause for the growing difference between basin inflows and outflows.

Data on evapotranspiration (ET) associated with native vegetation are sparse. However, there is no published evidence to our knowledge to indicate that there have been changes in native ET over this period of a magnitude sufficient to account for the increasing difference between basin inflows and outflows. Since ET in the riparian corridor is estimated to be approximately 91,000 ac-ft/yr over the period 1950-2004, ET in the riparian corridor would have to change by 113 percent over that time period to account for the measured decline in flows at Lewellen. Accordingly, changes in ET by native vegetation with time is not considered to be a significant cause for the difference between basin inflows and outflows.

Figure 8 is a graph showing the cumulative consumptive use of surface water over time, for the period 1950-2004. Surface water consumptive use was derived from several data sets and the methodology used to estimate the consumptive use of surface water is presented in Appendix C. This graph indicates there has been no long term change in the consumptive use of surface water in the region between the state line and Lewellen. Accordingly, changes in this outflow term can be ruled out as the cause for the growing difference between basin inflows and outflows.

Figure 9 is a graph of net pumping (the consumptive use of ground water) in the basin by year and the cumulative net pumping in the basin since 1950. The data used in the construction of this graph were produced by the COHYST group. Although these data are considered provisional, as they have not been formally reviewed or approved by the group, they appear to be reasonable and are believed to represent the best data currently available. Estimates of supplemental pumping agree with independent estimates by LWS. The estimates of pumping include both ground water only pumping (pumping on lands irrigated solely with ground water) and supplemental pumping (pumping on comingled lands). Figure 9 indicates that annual pumping has increased dramatically over the period 1950-2004, from approximately 10,800 ac-ft in 1950 to a maximum of 238,000 ac-ft in 2002. Cumulatively, Figure 9 shows that approximately 3,500,000 ac-ft of ground water has been pumped in the basin since 1950. Therefore, an analysis of individual factors that may be influencing flow at Lewellen indicates the principal factor apart from natural hydrologic variation is increased ground water pumping.

As shown previously in Figure 4, variations in natural hydrologic conditions, as measured at the state line, have a pronounced effect on flows measured at the Lewellen gage. Apart from these natural variations, an analysis of the major components of the water budget also shows that the only major change which has occurred over time is the large increase in ground water pumping. Since ground water pumping results in increased consumptive use of water in the reach between the Wyoming state line and Lewellen, it is the principal cause of the observed decrease in flow at Lewellen apart from natural hydrologic variation. As a test of this, Figure 10 presents a graph of the cumulative difference in flows (the difference between state line gage flows and the Lewellen gage flows) and a second graph where this difference is adjusted for net pumping. With the adjustment for net pumping, the cumulative difference lies on a straight line, indicating that, in the absence of pumping, the difference between basin inflows and outflows would have remained relatively constant over time.

Based on the accounting for major inflow and outflow factors in the reach between the state line and the Lewellen gage, it can be concluded that the consumptive use of ground water (net pumping) is the principal cause of the increasing difference between basin inflows and outflows.

The long-term average impact to North Platte River flows suggested by the water budget is about 85,000 ac-ft/yr in the period 1958 to 2004. The magnitude of the impact increases in recent years, such that the average impact to North Platte River flows is approximately 157,000 ac-ft/yr between 1997 and 2004. This increase is caused in part by the increase in supplemental pumping in response to the most recent drought, beginning in 2002. The well impacts described above are a direct measure of the reduction in inflows to Lake McConaughy. Accordingly, the long-term reduction in inflows to Lake McConaughy (as indicated by the water budget analyses) are estimated to average approximately 85,000 ac-ft/yr from 1958 to 2004 and approximately 157,000 ac-ft/yr during the period 1997 to 2004 (Figure 10).

The findings of the mass balance analysis are consistent with basic principles relating to the effects of wells on a hydrologic system. C. V. Theis, in a well-known paper on the source of water derived from wells (Theis, 1940), opined that

> "[u]nder natural conditions, therefore, previous to development by wells, aquifers are in a state of approximate dynamic equilibrium. Discharge by wells is thus a

> new discharge superimposed upon a previously stable system, and it must be balanced by an increase in the recharge of the aquifer, or by a decrease in the old natural discharge, or by loss of storage in the aquifer, or by a combination of these."

In effect, Theis was stating that water pumped from ground water wells either has to come from a change in storage in the aquifer system or changes in recharge or discharge from the aquifer. In this case, the increasing use of water supplied by wells has resulted in a proportional decrease in stream flows. Theis' opinion is reiterated by the NDNR in its February 2004 report, which states that "where there is a hydrological connection between surface water flow and ground water aquifers, a consumptive use of one depletes the supply in the other." (Nebraska Department of Natural Resources, 2004).

NUMERICAL MODEL APPROACH

Background

The North Platte River Basin is a relatively complex hydrologic system, having multiple sources of inflow and outflow, hydraulic properties that vary from one location to another, and stresses that vary both in location and time. The North Platte River system is further complicated by the interaction that occurs between surface water and the underlying ground water. For purposes of this investigation, a numerical ground water model was developed by LWS and used to evaluate hydrologic processes within the North Platte River Basin.

The area of interest in this study (generally the area extending from Lake McConaughy to the Nebraska-Wyoming state line) has been modeled by others using a numerical model. The COHYST group has developed a ground water model of this area, known as the WMU Model using MODFLOW, a three-dimensional ground water flow model developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988). The WMU Model includes the drainage areas of both the North Platte River and the South Platte River (Figure 1). The WMU Model extends approximately 130 miles in an east-west direction and 90 miles in a north-south direction, encompassing an area of about 11,300 square miles. At the time of the publication of the WMU Model documentation report (Luckey and Cannia, 2006) the model was considered

complete. However, since then, a number of limitations have been identified that warrant additional work on the model (Bleed, 2008). In light of this, CNPPID commissioned LWS to modify the WMU Model consistent with current information on irrigated land areas, refined estimates of pumping, improved information on areas subject to native ET, revised estimates of natural recharge and recharge associated with canal leakage and irrigation return flows. In addition, LWS modified the way in which the mainstem of the North Platte River was represented in the model. These modifications are discussed in more detail in the following section and in the appendices to this report.

Model Modifications

Modifications to the WMU Model were completed by LWS and the resulting model was used to investigate the impact of wells on surface water flows. For purposes of this study, LWS' model is referred to as the "North Platte Depletions Model". LWS' North Platte Depletions Model incorporates changes to the WMU Model that were considered to be of major importance relative to providing representative model simulation results and as needed to address the objectives of this investigation.

The WMU Model represented evapotranspiration (ET) using constant values over time. LWS changed this such that ET is adjusted by stress period and by year for the entire simulation period of 1950 to 2004. In addition, the WMU assigned native ET to an area approximately 2 miles wide and extending the length of the North Platte River. LWS modified the area over which native ET may occur based on published mapping by the U.S. Fish and Wildlife Service (1994) supplemented with inspection of satellite imagery. Appendix B describes changes made in the representation of ET in more detail.

In the WMU Model, surface water return flows (herein defined to include canal leakage and return flows from applied irrigation water) were treated as constant in space over time. This approach was modified in the North Platte Depletions Model to more closely reflect the timing and spatial distribution of return flows. Appendix C describes the methodology for estimating canal leakage and the values assigned to specific canals. This information is used in estimating the rate of recharge supplied to the model.

Another significant limitation of the COHYST WMU Model was that it did not include supplemental pumping in its representation of the pumping component. While ground water pumping for irrigation represents a large component of the water budget, the WMU Model only simulated ground water pumping on lands that had ground water as their sole source of water. Where wells were used to supplement irrigation water on lands historically supplied by surface water, the COHYST WMU Model ignored this ground water pumping. Since the time that the original WMU Model was developed, COHYST has developed revised estimates of ground water pumping, inclusive of supplemental pumping. These estimates are considered to be provisional, as they have not been formally adopted by COHYST and may be subject to further revision. Nonetheless, they appear to be reasonable and are believed to represent the best estimates currently available. The procedure used to develop these ground water pumping estimates is summarized in Appendix D.

Review of major inflow and outflow components of the basin's water budget suggested that the recharge from precipitation used in the WMU Model may have been underestimated. During calibration of the original WMU Model, the COHYST group agreed that it was necessary to introduce additional recharge on lands converted from rangeland to cultivated land (Luckey and Cannia, 2006), further evidence that recharge from precipitation may have been underestimated. Therefore, estimates of recharge from precipitation were revised for use in the North Platte Depletions Model, based on a review of several independent sources of information on rainfall/recharge relationships. The procedure for developing the values used in the North Platte Depletions Model are presented in Appendix E.

In the WMU Model, the North Platte River was represented using the river package whereas the tributaries were represented using the stream package. The North Platte Depletions Model represents both the mainstem and the tributaries using the stream package, since this package provides greater flexibility and a more robust simulation of the interaction between water in the stream and the adjacent ground water. The procedure for developing the stream package for both the North Platte River mainstem and its tributaries is presented in Appendix F.

The WMU Model contained two simulation periods, one representing the period from 1950 through 1997, and a second representing the period from 1998 through 2004. The North Platte Depletions Model combines these into a single simulation representing the period from 1950

through 2004. The process of combining the simulation periods required that some of the model's input files, e.g. recharge from canal losses, be reconstructed. Descriptions of changes to the model input files are included in the appendices to this report.

Model Calibration

The North Platte Depletions Model was calibrated to observed flows in the North Plate River, as well as tributary flows. Calibration targets included five gages on the North Platte River mainstem, and ten gages on tributaries to the mainstem. Model-predicted flows at the Lewellen gage are in excellent agreement with observed flows (Appendix G, Figure G-1). Model predictions at other mainstem gages are also considered to be in reasonable agreement with observed flows (Appendix G, Figures G-2 through G-5). Calibration to tributary flows is also reasonable (Appendix G, Figures G-6 through G-16). The model was also calibrated to alluvial ground water levels. Model predictions of alluvial ground water levels are also in reasonable agreement with observed levels (Appendix G, Figures G-20 through G-25). The results of the North Platte Depletions Model calibration are also presented in Appendix G.

The North Platte Depletions Model has benefitted from improved information on pumping, recharge, ET, and an improved representation of the North Platte River mainstem. Calibration of the model to gaged flows on both the mainstem and the major tributaries provides a more complete representation of the hydrologic system than that contained in the WMU Model. This approach to calibration is considered to be more rigorous than that employed in the WMU Model, thereby providing greater confidence in the model as a predictive tool. Additionally, the North Platte Depletions Model is calibrated to actual water level elevations, as opposed to changes in water levels, as was done in the WMU Model. This provides better representation of the hydrologic system.

Calibration of the model indicates that the model is capable of providing reliable predictions of the relative impacts of well pumping on flows in the North Platte River for the area between the Nebraska-Wyoming state line and the Lewellen gage. The Lewellen gage provides a direct measure of inflows to Lake McConaughy.

Results

Following calibration, the North Platte Depletions Model was used to investigate the impact of well pumping on North Platte River flows at Lewellen. This location is considered a measure of the North Platte River inflows to Lake McConaughy. The evaluation was based on conditions beginning with the irrigation season of 1950 (May 1950 through September 1950) and ending with the non-irrigation season of 2005 (October 2004 through April 2005, end of 2004 water year).

The evaluation of historic impacts involved a comparison of two simulations. The first run simulated conditions as they occurred historically from 1950 to 2004, including the time-related increase in ground water pumping. The second run simulated hydrologic conditions as they occurred historically, but assumed that no ground water pumping occurred. The difference in predicted flow of the North Platte River at Lewellen between these two cases represents the impact of pumping during the period 1950 to 2004. The results of this historical analysis are shown on the left portion of Figure 11 (to 2005). Figure 11 indicates that the depletions had increased to approximately 79,000 ac-ft/yr by 1997 and to approximately 125,000 ac-ft/yr by 2004, the end of the historic simulation. Figure 11 also shows the significant increase in the rate of depletion to river flows beginning in 2002, in response to the drought conditions at that time.

The right side of Figure 11 is a projection of future depletions to flow of the North Platte River, beginning in 2005 and continuing for 50 years into the future. Because it is difficult to accurately predict future pumping, depletions were evaluated for three levels of pumping projected into the future. Pumping amounts of 170,000 ac-ft/yr, 120,000 ac-ft/yr, and 90,000 ac-ft/yr were simulated. These amounts correspond approximately with average annual pumping in 2004, 1998, and 1997. They also potentially correspond to scenarios in which drought conditions continue and future pumping is unconstrained at approximately 2004 levels (170,000 ac-ft/yr), pumping returns to a level experienced during “average” hydrologic conditions (120,000 ac-ft/yr), and pumping returns to 1997 levels (90,000 ac-ft/yr), consistent with prior investigations of “post-1997" depletions (Luckey, 2008). Hydrologic conditions for 1998 were selected for this purpose as being representative of average hydrologic conditions in the basin over approximately the past 25 years.

All simulations used historic hydrology for the period 1950 through 2004. The forecasting period (2005 through 2055) used hydrologic conditions from 1998, i.e hydrologic conditions observed in 1998 were repeated for each year of the 50-year forecast. Depletions to flow at Lewellen were then predicted for several varying levels of future pumping (170,000 ac-ft/yr, 120,000 ac-ft/yr, and 90,000 ac-ft/yr). These simulations contained historic pumping for 1950 through 2004, followed by continuous future pumping at either 170,000 ac-ft/yr, 120,000 ac-ft/yr, or 90,000 ac-ft/yr. Depletions were calculated as the difference between predicted flow at Lewellen for the particular level of pumping, and the predicted flow at Lewellen if all ground water pumping is eliminated from the simulation (i.e. no pumping from 1950 through 2055). These results provide an estimate of the historic depletions, followed by the projected future depletions to flows if pumping is continued at some future level of pumping. Figure 11 indicates that future depletions will be approximately 148,000 ac-ft/yr by the end of the 50-year forecast period if pumping continues at 2004 levels (170,000 ac-ft/yr), 108,000 ac-ft/yr if future pumping is at a rate of 120,000 ac-ft/yr, and that future depletions will be approximately 85,000 ac-ft/yr at the end of the 50-year forecast period if pumping is at a rate of 90,000 ac-ft/yr.

The North Platte Depletions Model was also used the predict the recovery of flows that would occur with the curtailment of ground water pumping for several scenarios (Figures 12, 13, and 14). In all cases, recovery of flows at Lewellen is calculated as the difference in flow at Lewellen for a future level of pumping compared with the flow at Lewellen if pumping is reduced. As in the case of the depletions analysis described above, future pumping cannot be precisely estimated. Accordingly, simulations were made for each of several future levels of pumping and four levels of reduction in pumping (25, 50, 75, and 100 percent). Scenarios based on future pumping at 170,000 ac-ft/yr are shown in Figure 12, while scenarios based on future pumping at 120,000 ac-ft/yr are shown in Figure 13, and scenarios based on future pumping at 90,000 ac-ft/yr are shown in Figure 14. These scenarios all clearly demonstrate the direct and substantial impact of ground water pumping on surface water flows, and the rapid recovery of surface water flows in response to a reduction in pumping. Obviously, surface flow recovery increases as the percent reduction in ground water pumping increases. However, the general shape of the recovery curve with time remains the same, regardless of the change in pumping rate, and indicates that the largest recovery of flow occurs in the initial 5- to 10-year period following a reduction in pumping. The shape of the recovery curve remains the same because the stream and aquifer characteristics related to the hydraulic connection between the steams and associated

alluvial aquifers remains unchanged. Results of these simulations are tabulated in Appendix H. Results are presented as flow recovery at 5 years, 10 years, and 50 years following reduction in pumping at varying projected net pumping rates.

Figures 15 through 17 reflect the composite results of the relationship between flow recovery at Lewellen and several projected future levels of pumping for four levels of reduction in pumping i.e., 25, 50, 75, and 100 percent reduction at varying times after pumping has been reduced or eliminated; i.e., at 5, 10, and 50 years. These figures indicate that the recovery of flow is directly proportional to level of pumping assumed for future conditions (as indicated by the linear relationship between flow recovery and future pumping at all levels of pumping reduction). Therefore, these figures can be used to estimate flow recovery for a range of future pumping conditions or a range in the levels of reduction in pumping at varying time frames into the future.

SUMMARY AND CONCLUSIONS

There has been significant growth in the number of irrigation wells in the North Platte Basin beginning around 1950. In 1950, there were 26 registered wells in the basin between Lake McConaughy and the state line, according to the NDNR data base. By 2001, the year in which a moratorium was instituted on the construction of new wells, there were 2,684 registered irrigation wells in this same reach. Irrigation pumping in 1950 is estimated by the COHYST group to have been approximately 10,800 ac-ft/yr, whereas by 2004, irrigation pumping is estimated to have grown to approximately 173,000 ac-ft/yr, based on metered records. In 2002, irrigation pumping peaked at approximately 238,000 ac-ft/yr, in response to drought conditions in the basin. It should be noted that the peak in ground water pumping occurred <u>after</u> the moratorium on wells was put in place by the NPNRD. Therefore, the moratorium itself is ineffective in protecting surface water users from direct and substantial impacts on surface water flows due to ground water pumping.

The irrigation wells constructed since 1950 are used either to irrigate lands that do not have access to surface water (ground water only lands) or are used to supplement irrigation supplies on lands irrigated with surface water at times when surface water supplies fall short of the need for water. Both of these conditions have led to a significant expansion in the consumption of the basin's water resources.

A water budget was developed for the North Platte River Basin summarizing the major inflows and outflows to the basin. The terms of the water budget represent estimated average flows over the period 1950 through 2004. There is no evidence to indicate long-term gains or losses of ground water storage during this period. In such a case, inflows and outflows will be equal. Further, there is no evidence of a systematic or long-term change in inflow (such as a change in surface water inflows to the basin, ET, or precipitation falling within the basin). The water budget does show that the long-term growth in irrigation pumping over this period corresponds with a reduction in outflows, as measured at the Lewellen gage. The impact of well development becomes apparent beginning in about 1958. The long-term average impact to North Platte River flows suggested by the water budget is about 85,000 ac-ft/yr in the period 1958 to 2004. The magnitude of the impact increases in recent years, such that the average impact to North Platte River flows is approximately 157,000 ac-ft/yr between 1997 and 2004. This increase is caused in part by the increase in supplemental pumping in response to the most recent drought, beginning in 2002. The well impacts described above are a direct measure of the reduction in inflows to Lake McConaughy. Accordingly, the long-term reduction in inflows to Lake McConaughy (as indicated by the water budget analyses) are estimated to average approximately 85,000 ac-ft/yr from 1958 to 2004 and approximately 157,000 ac-ft/yr during the period 1997 to 2004 (Figure 10).

The North Platte Depletions Model was also used to investigate the impact of irrigation wells on inflows to Lake McConaughy. The North Platte Depletions Model relies in part on data that have not been formally reviewed or adopted by the COHYST group, and is, therefore, subject to change. However, the information incorporated in the North Platte Depletions Model is believed to represent the best, and most current, information available at this time. There are two areas of data that may be most susceptible to change; estimates of irrigated lands within the model domain and estimates of ground water pumping (both for ground water only lands and supplemental pumping). The COHYST group is continuing to work to resolve estimates for these extremely important areas of data.

Once the improvements to the North Platte Depletions Model were completed, the model was re-calibrated. The emphasis of the calibration process was on the prediction of flows of the North Platte River at each of the mainstem gages. The model was also calibrated to gaged flows on

tributaries to the mainstem and to ground water levels. We judge that the North Platte Depletions Model provides reliable estimates of the impact of ground water pumping on North Platte River flows.

The North Platte Depletions Model was run over the development period (1950-2004), first with pumping that was estimated to have occurred over the period, and second with the pumping eliminated. The results of these two simulations were compared in terms of the model's predictions of North Platte River flow at the Lewellen gage. The difference in flow at the Lewellen gage between these two simulations provides a measure of the impact of irrigation pumping on flows at Lewellen and, therefore, inflows to Lake McConaughy. The results of this analysis indicate that irrigation pumping has had a direct and substantial impact on inflows to Lake McConaughy. The magnitude of this impact has grown in proportion to the growth in annual pumping. By the year 1997, the model results suggest this impact has reached about 79,000 ac-ft/yr. By the end of water year 2004, following several years of drought, the impact is estimated to have reached about 125,000 ac-ft/yr. This is a 46,000 ac-ft/yr increase in surface water depletion over an 8-year period (including 4 years in which a new well moratorium was in place). When these values are compared to the mass balance estimates from the water budget analyses, the results are shown to be very similar.

The numerical model was also used to simulate estimated future depletions for several levels of future pumping over a 50-year simulation period. These simulations indicate that depletions to surface flows into Lake McConaughy could reach 148,000 ac-ft/yr if ground water pumping continues at 2004 levels, while depletions are estimated to reach 108,000 ac-ft/yr if future pumping is at a level of pumping estimated to have occurred in 1998 (120,000 ac-ft/yr). Depletions are estimated to reach 85,000 ac-ft/yr if future pumping is at a level of pumping estimated to have occurred in 1997 (79,000 ac-ft/yr)(Figure 11). The scenario with future pumping at 90,000 ac-ft/yr is closest to achieving the "1997 levels" mandated by LB962, because it establishes a steady-state pumping volume consistent with pumping levels estimated for 1997. However, this represents a decrease of 80,000 ac-ft/yr of pumping from 2004 levels (a substantial decrease in ground water pumping).

The North Platte Depletions Model was also used to forecast the recovery of flows at Lewellen for several levels of future pumping (170,000, 120,000, and 90,000 ac-ft/yr), in response to

several levels of reduction in pumping (25, 50, 75, and 100 percent). These results are shown in Figures 12, 13, and 14 and tabulated in Appendix H. The model indicates that for all cases, substantial flow recovery at Lake McConaughy can be achieved in a relatively short period of time. For the scenario comparing the recovery of flow in response to a full cessation of pumping to pumping continuing at 2004 levels, recovery is estimated to be approximately 96,000 ac-ft/yr (133 cubic feet per second (cfs)) after 5 years, 110,000 ac-ft/yr (152 cfs) after 10 years, and 139,000 ac-ft/yr (192 cfs) by the end of a 50-year period (Figures 15 through 17). The model further indicates that the recovery of flow at Lewellen is directly proportional to the level of pumping assumed to occur in the future, and that it is possible to estimate recovery over a range of assumed future levels of pumping.

In all cases, the analyses indicate that ground water pumping has a direct and substantial impact on surface water flows. These results also suggest that it is possible to recover substantial amounts of water quickly, as might be needed in times of a shortfall in the natural supply of water.

RECOMMENDATIONS

The North Platte Depletions Model provides reliable estimates of the impact of irrigation wells on flows in the North Platte River. However, at this time, the model relies on data and estimates that have not been formally adopted and are subject to continuing updates as the COHYST group continues with its work. There is an ongoing process by COHYST to update and refine the WMU Model. The COHYST group recognizes that some of the data on which the WMU Model relies (e.g., irrigated acreages, ground water only pumping, supplemental pumping, areas and rates of ET, etc.) require additional investigation and work before they can be formally adopted by COHYST. This information, as it is formally developed, should be evaluated for possible inclusion into the North Platte Depletions Model.

There are several areas in which the WMU Model can be refined. The COHYST group is continuing to move forward in their efforts to refine the WMU Model. As a part of this process, COHYST is likely to develop improved estimates of some of the critical inputs to the model. These include estimates of irrigated land and changes in irrigated land over time, estimates of pumping, and mapping of the distributions of phreatophytes and wetlands in the riparian

corridor. We understand there are ongoing programs (COHYST, Great Plains GIS Partnership) that may provide more reliable and higher resolution mapping of land cover along the riparian corridor than is presently available. It may be useful to incorporate updates of information on irrigated lands, pumping, ET, etc. in the North Platte Depletions Model if the updated information differs significantly from what is currently used in the model.

In light of the foregoing, it is recommended that the COHYST process be monitored. As COHYST updates their basic data, such as irrigated acreages and/or estimates of key input data such as supplemental pumping estimates, these updates can be evaluated in terms of their impact on the North Platte Depletions Model. Where appropriate, these updates should be incorporated into the North Platte Depletions Model. Toward this end, it is recommended that CNPPID continue to participate in the COHYST process, to guide the continuing changes and further development of the WMU Model.

ACKNOWLEDGMENTS

Hayden R. Strickland, E.I., Senior Engineer of LWS was responsible for the current development of the North Platte Depletions Model, under the supervision of the undersigned.

The analyses described herein are being refined as additional data are acquired. Accordingly, the results of these analyses may be revised in the future as deemed appropriate and/or necessary.

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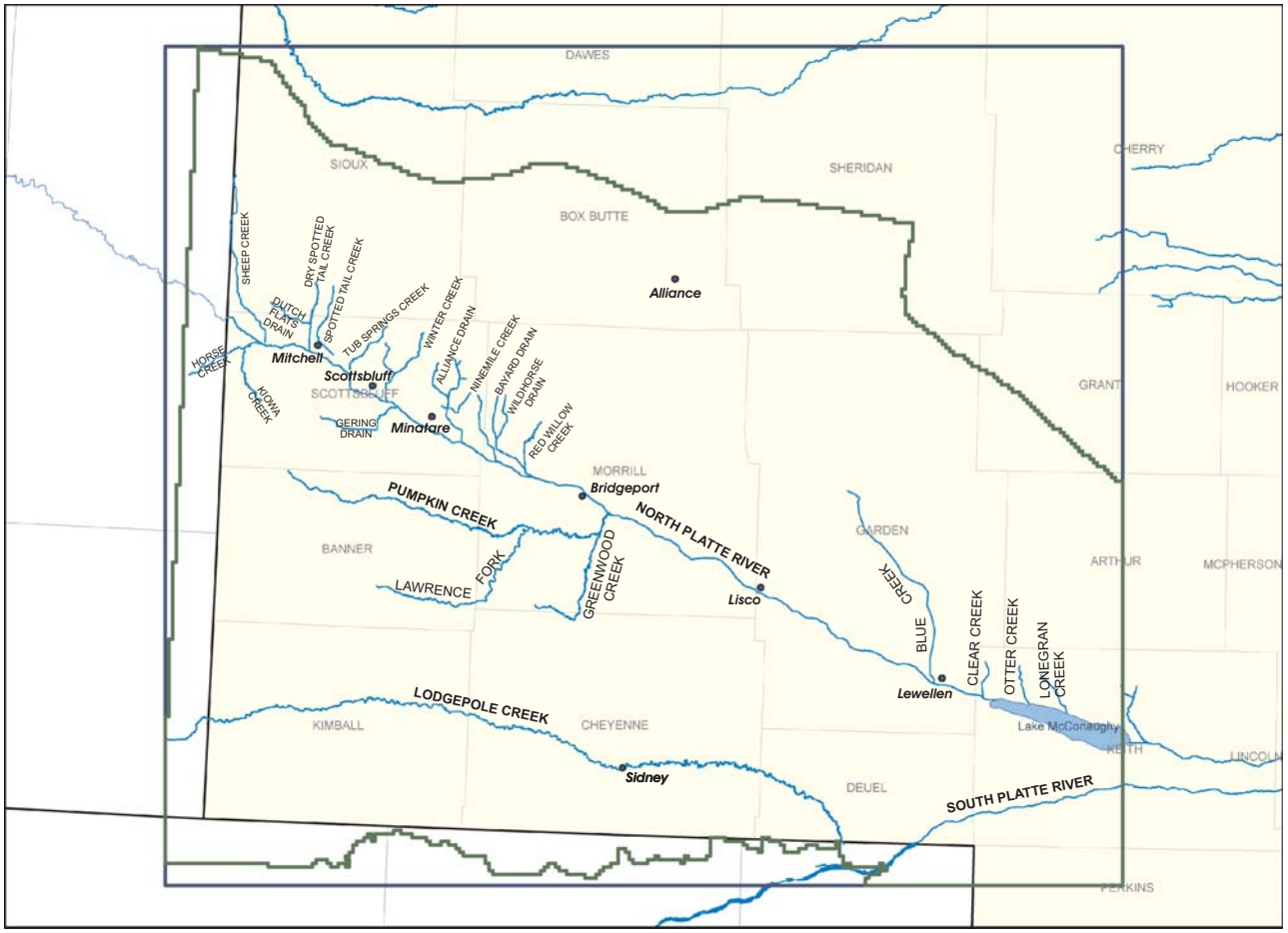
LYTLE WATER SOLUTIONS, LLC



N

0 17 34 miles

LEGEND

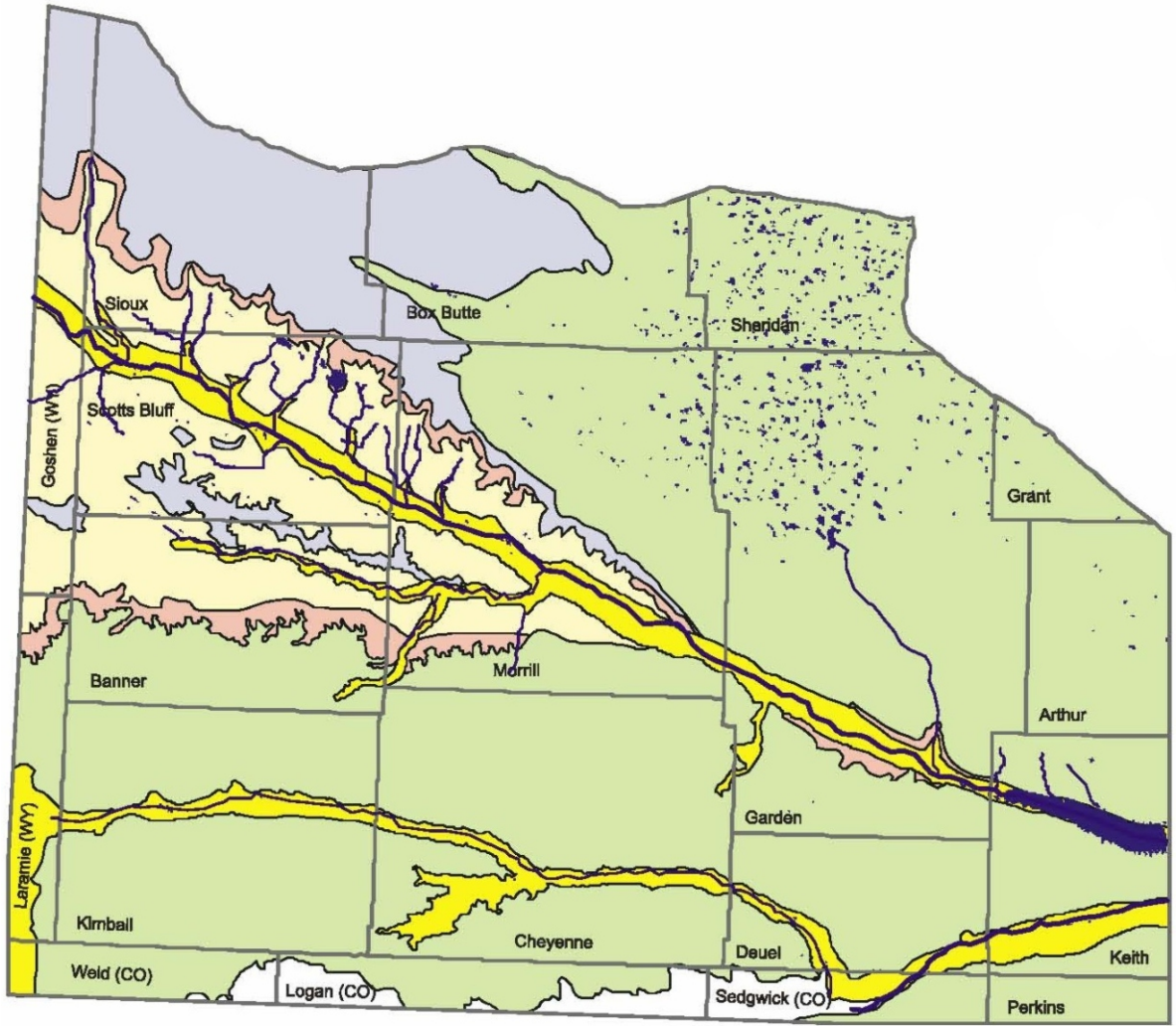
- *Sidney* CITIES
- COUNTIES
- STREAMS
- ACTIVE CELL OUTLINE
- MODEL DOMAIN OUTLINE

Notes:
1) Coordinate System: Nebraska State Plane FIPS 2600 (feet).
2) Projection: Lambert Conformal Conic.
3) Horizontal Datum: NAD 1983.

CENTRAL NEBRASKA PPID

MODIFIED WESTERN MODEL UNIT OVERVIEW

File Name: ModelOverview.cdr		Date: 01/27/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 1



N

0 21.5 miles

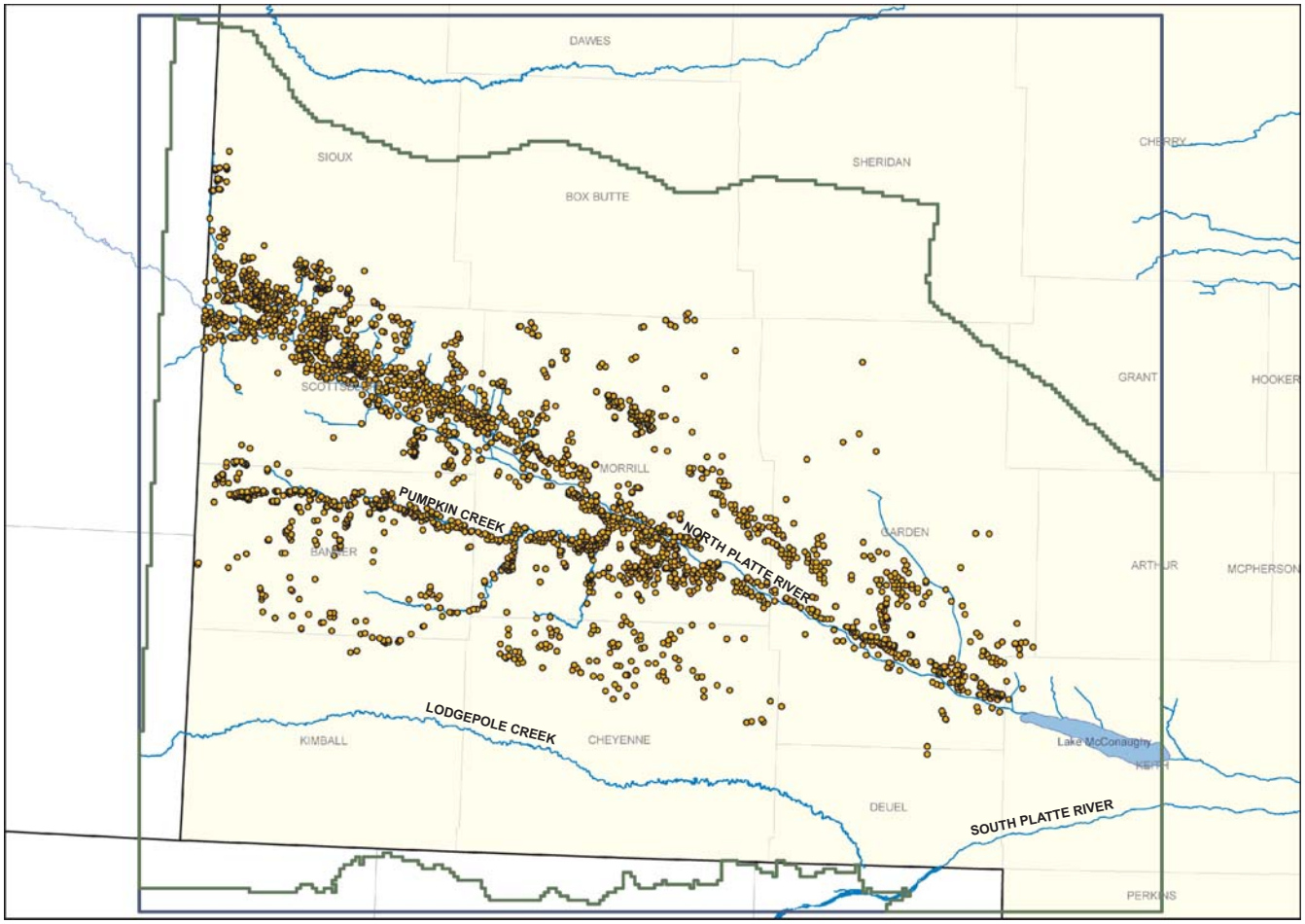
LEGEND

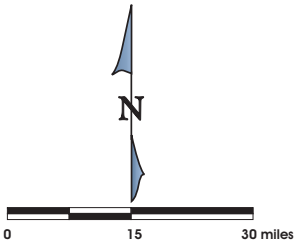
- ALLUVIUM
- ALLUVIUM AND COLLUVIUM
- OGALLALA GROUP
- ARIKAREE GROUP
- BRULE FORMATION

Note:
Reproduced from the Western Model Unit documentation report (Luckey and Cannia, 2006).

CENTRAL NEBRASKA PPID		
GEOLOGIC MAP		
File Name: GeologicMap.cdr		Date: 02/11/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 2

LYTLE WATER SOLUTIONS, LLC





LEGEND

- NDNR REGISTERED IRRIGATION WELLS
- COUNTIES
- STREAMS
- ACTIVE CELL OUTLINE
- MODEL DOMAIN OUTLINE

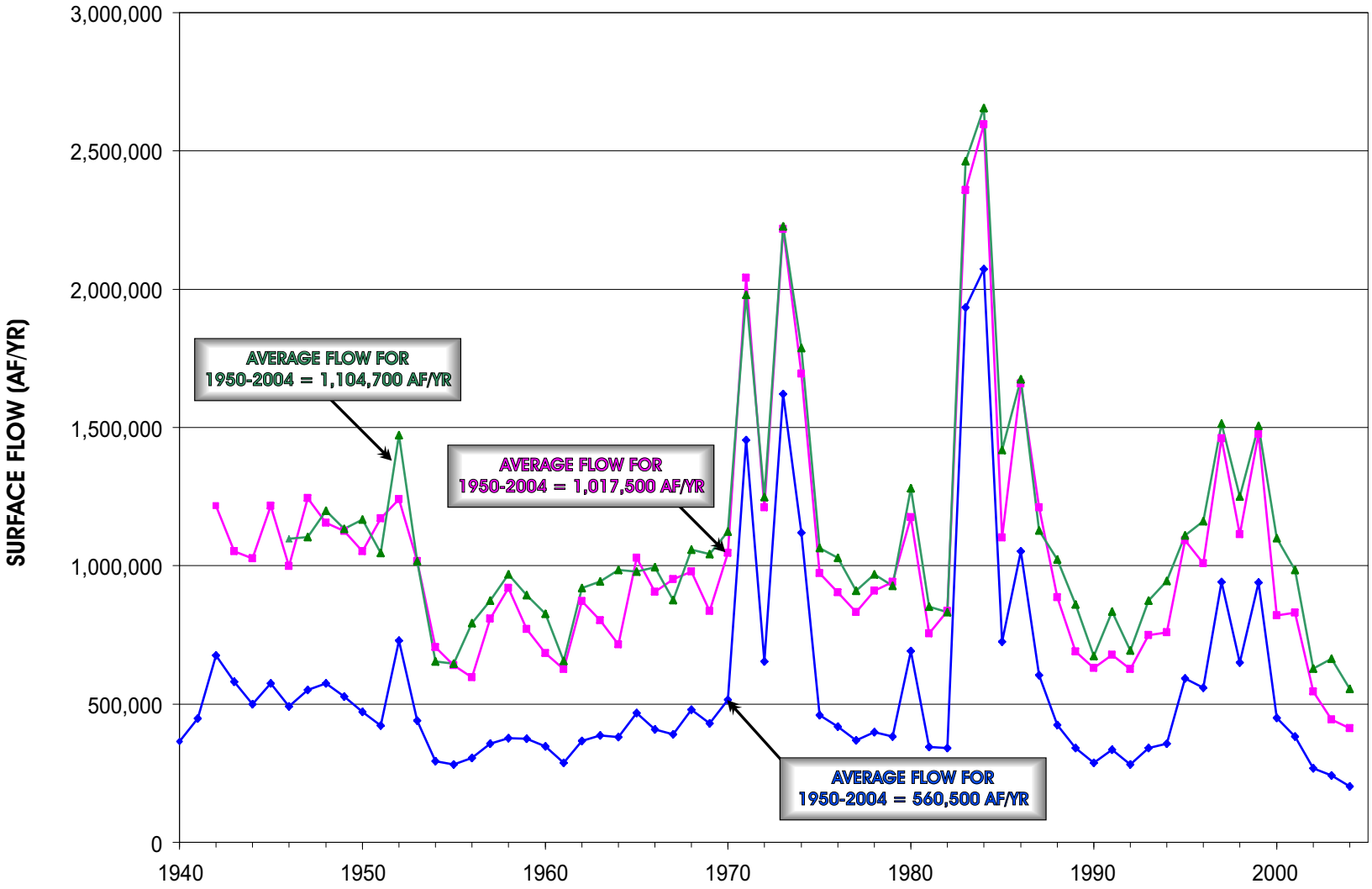
Notes:
1) Only active and non-replacement irrigation wells displayed.
2) There are currently 2,684 total irrigation wells in the NDNR data base for the North Platte River Basin above Lake McConaughy.

CENTRAL NEBRASKA PPID

REGISTERED GROUND WATER IRRIGATION WELLS IN THE NORTH PLATTE BASIN UPSTREAM OF LAKE McCONAUGHY

File Name: GWwells.cdr		Date: 02/16/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 3

LYTLE WATER SOLUTIONS, LLC



LEGEND

- WYOMING LINE GAGED FLOW
- LEWELLEN GAGED FLOW
- WYOMING LINE GAGED FLOW PLUS WYOMING CANALS

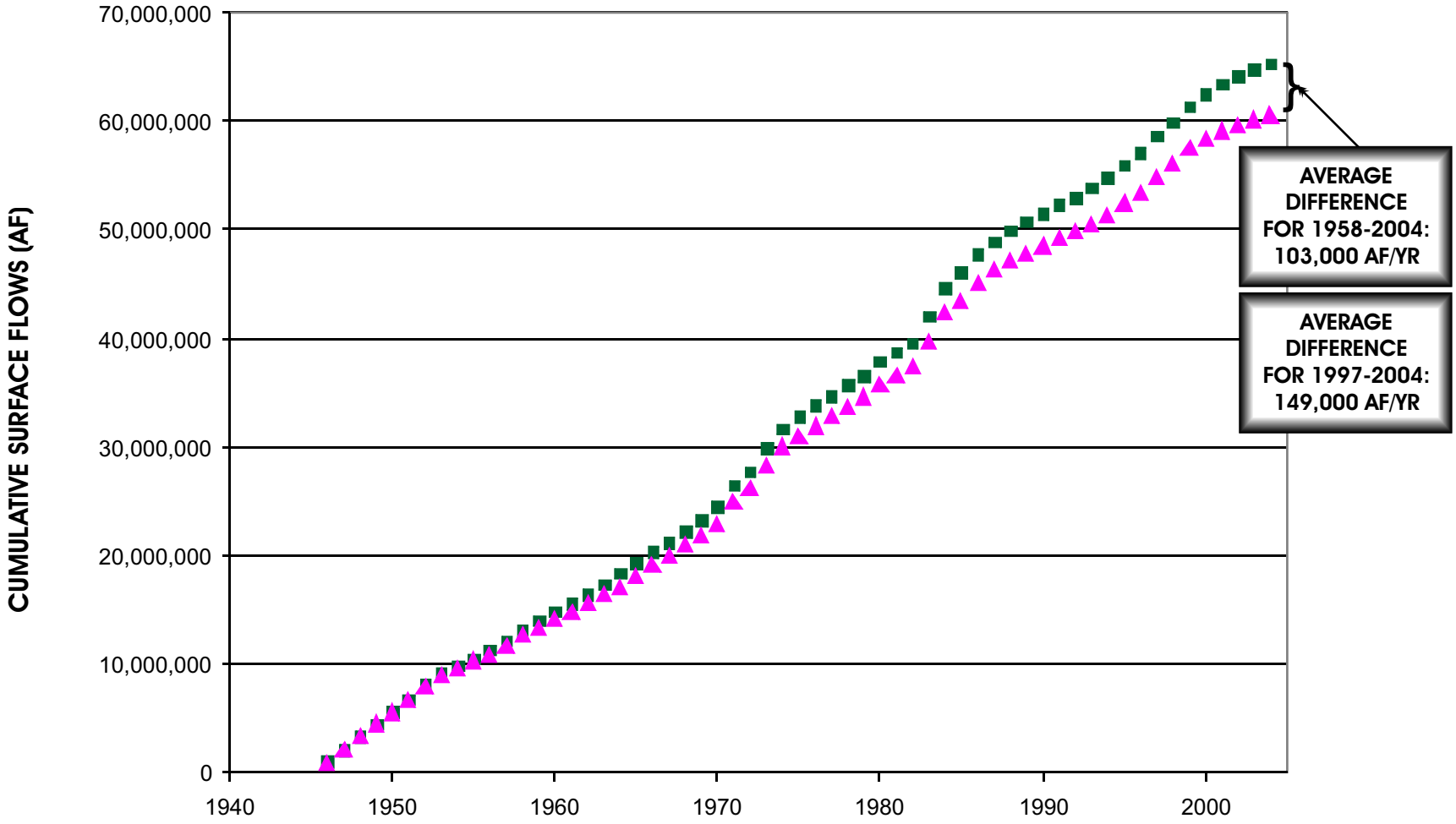
Note:
Wyoming canals include Fort Laramie and Interstate canals (adjusted for amounts crossing over the Wyoming line) and Gering-Mitchell canal.

CENTRAL NEBRASKA PPID

COMPARISON OF NORTH PLATTE RIVER GAGED FLOWS

File Name: N.Platte-GagedFlows.cdr		Date: 02/03/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 4

LYTLE WATER SOLUTIONS, LLC



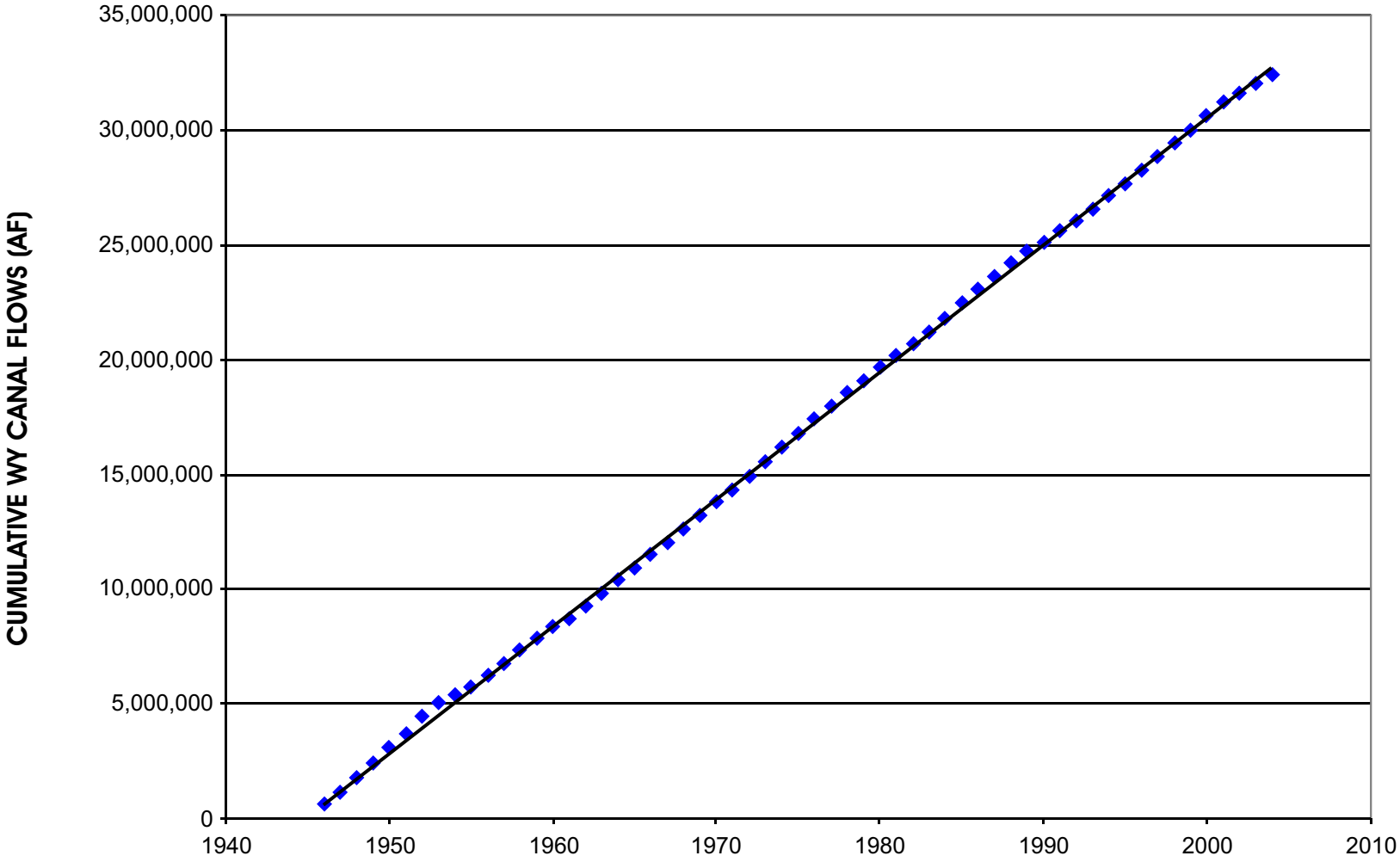
LEGEND

- ■ WYOMING-LINE GAGE PLUS WYOMING CANALS
- ▲ LEWELLEN GAGE

Note:
Wyoming canals include Fort Laramie and Interstate canals (adjusted for amounts crossing over the Wyoming line) and Gering-Mitchell canal.

CENTRAL NEBRASKA PPID		
COMPARISON OF UPSTREAM AND DOWNSTREAM SURFACE FLOWS		
File Name: SurfaceComparison.cdr		Date: 02/16/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 5

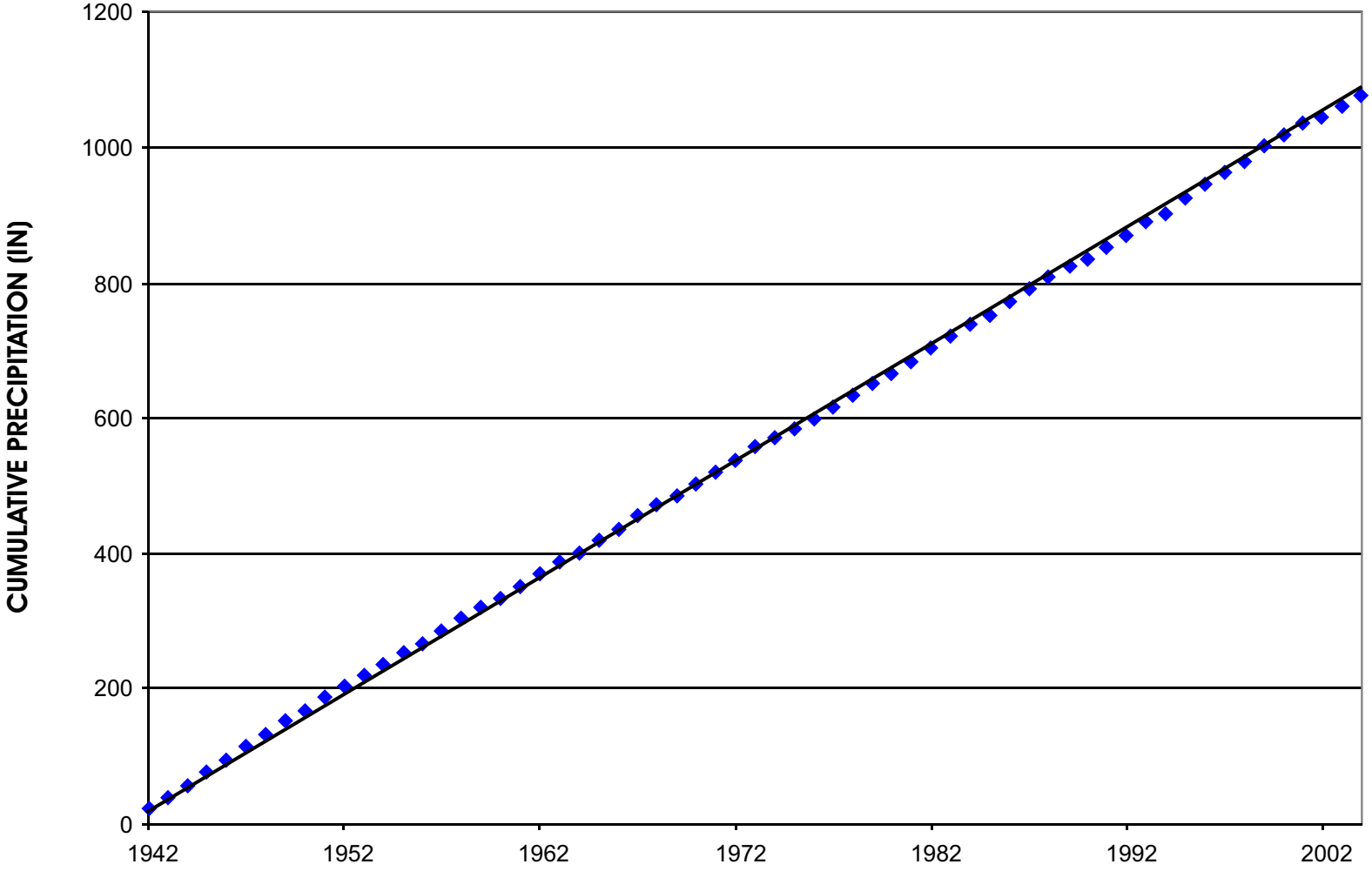
LYTLE WATER SOLUTIONS, LLC



Note: Wyoming canals include Fort Laramie and Interstate canals (adjusted for amounts crossing over the Wyoming line) and Gering-Mitchell canal.

CENTRAL NEBRASKA PPID		
CUMULATIVE WYOMING CANAL FLOWS		
File Name: CanalFlows.cdr		Date: 02/11/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 6

LYTLE WATER SOLUTIONS, LLC



CENTRAL NEBRASKA PPID		
CUMULATIVE DIVISION 1 PRECIPITATION		
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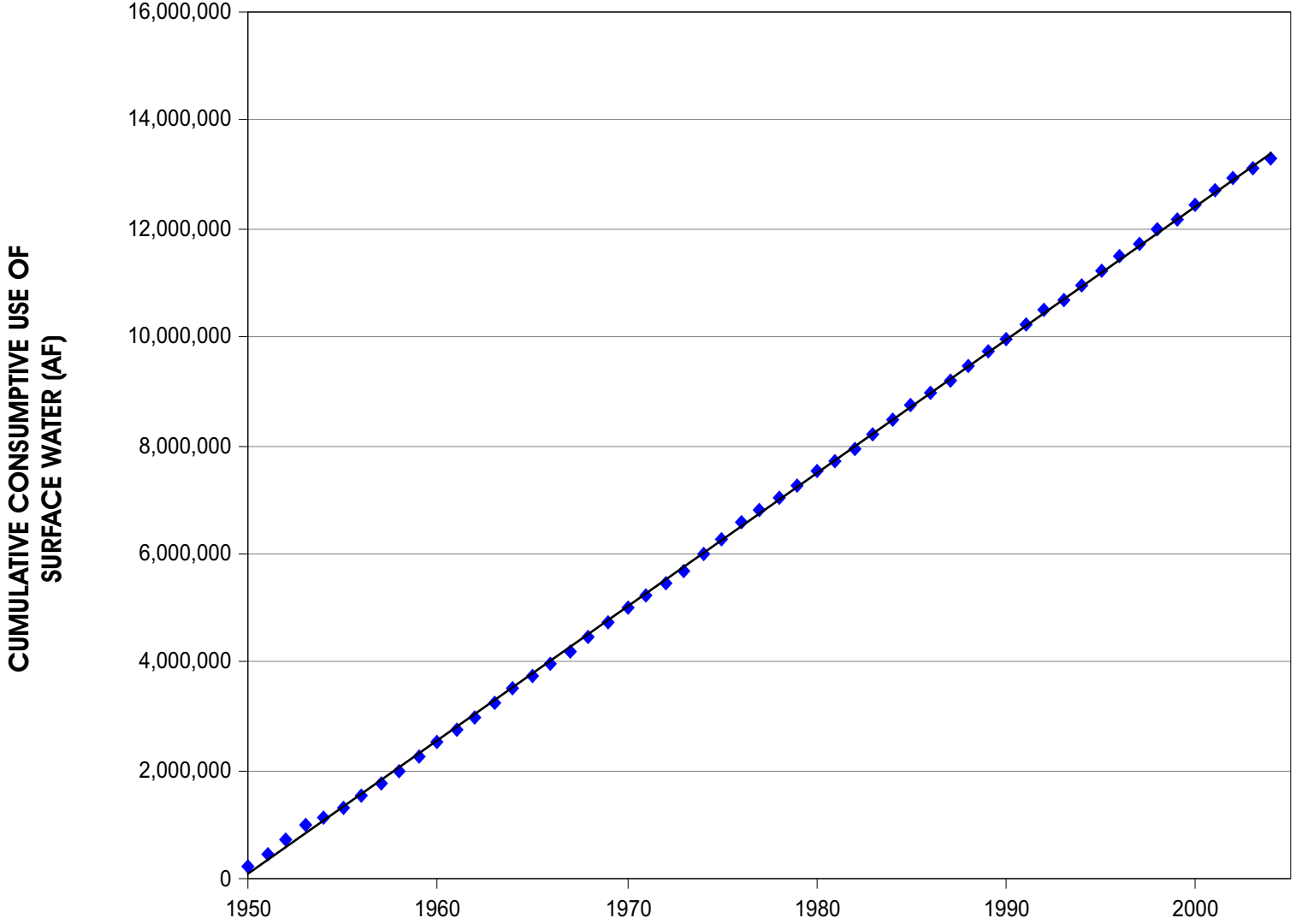
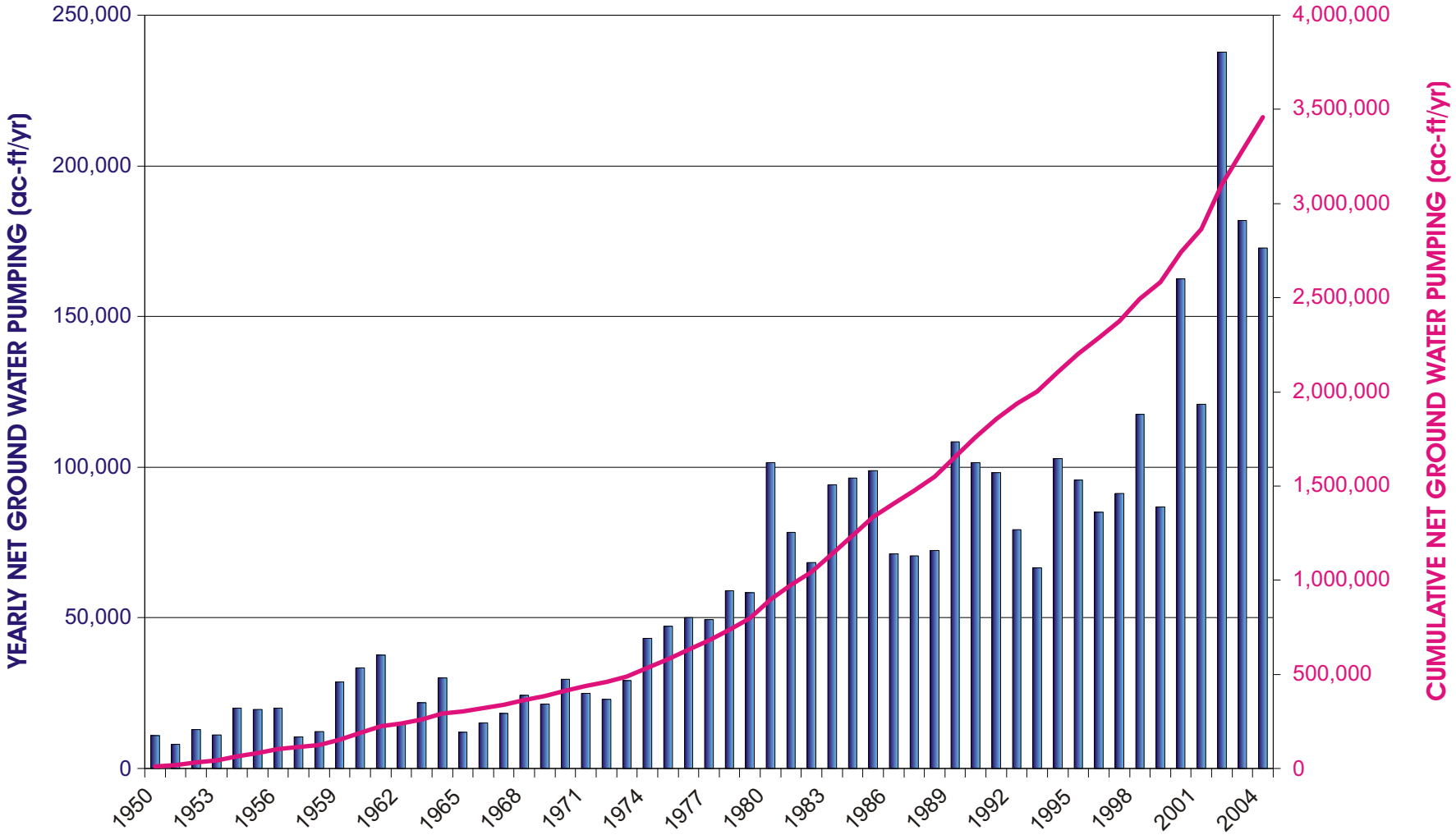
LYTLE WATER SOLUTIONS, LLC



Note: The methodology used for estimates of cumulative consumptive use of surface water are described in Appendix C.

CENTRAL NEBRASKA PPID		
CUMULATIVE CONSUMPTIVE USE OF SURFACE WATER		
File Name: ConsumptiveUse.cdr		Date: 02/11/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 8

LYTLE WATER SOLUTIONS, LLC



LEGEND

YEARLY NET GROUND WATER PUMPING

CUMULATIVE NET GROUND WATER PUMPING

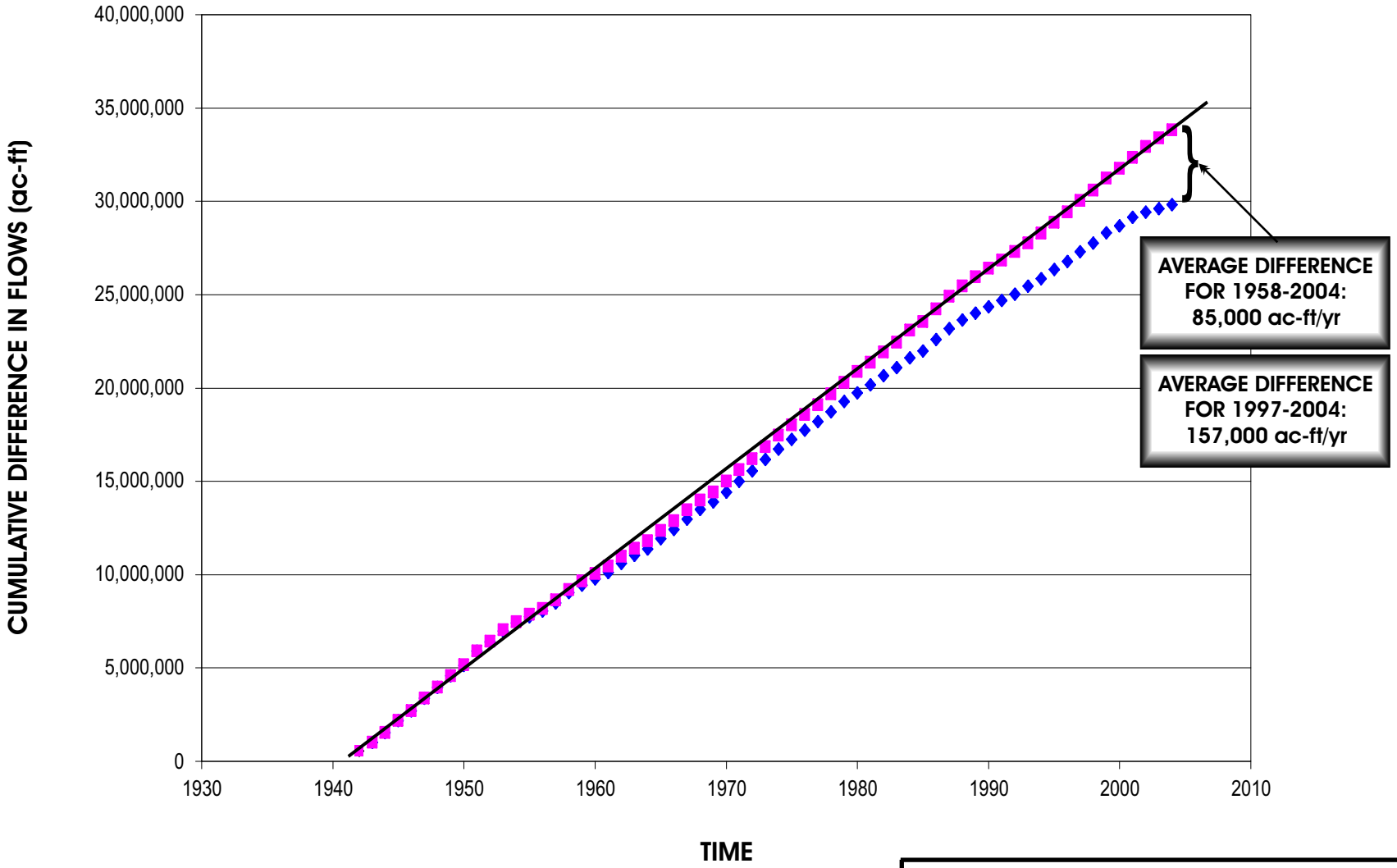
Notes:

1) Net pumping includes pumping from lands irrigated with ground water only and supplemental pumping from lands irrigated with surface water.

2) Pumping estimates developed by COHYST group.

CENTRAL NEBRASKA PPID		
ESTIMATED NET PUMPING IN THE NORTH PLATTE RIVER BASIN ABOVE LAKE McCONAUGHY		
File Name: NetPumping_NoPlatte.cdr		Date: 06/10/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 9

LYTLE WATER SOLUTIONS, LLC

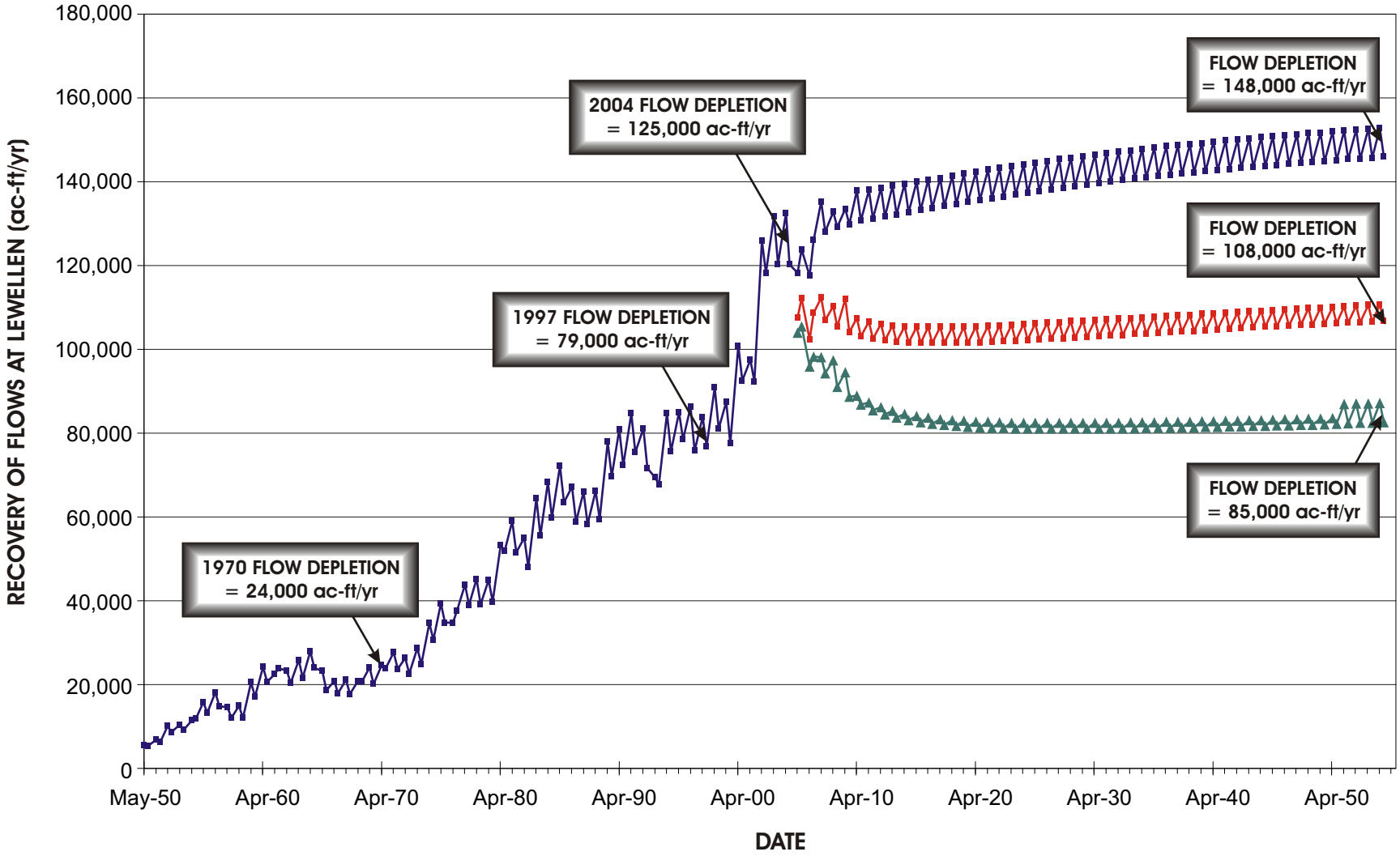


LEGEND

- ◆ CUMULATIVE DIFFERENCE IN SURFACE FLOWS (LEWELLEN - WY-LINE GAGE)
- ■ CUMULATIVE DIFFERENCE IN SURFACE FLOWS PLUS NET PUMPING

CENTRAL NEBRASKA PPID		
COMPARISON OF CHANGES IN SURFACE FLOW WITH AND WITHOUT GROUND WATER PUMPING		
File Name: SurfaceFlows.cdr		Date: 02/11/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 10

LYTLE WATER SOLUTIONS, LLC



LEGEND

- PROJECTED NET PUMPING RATE OF 170,000 AC-FT/YR
- PROJECTED NET PUMPING RATE OF 120,000 AC-FT/YR
- PROJECTED NET PUMPING RATE OF 90,000 AC-FT/YR

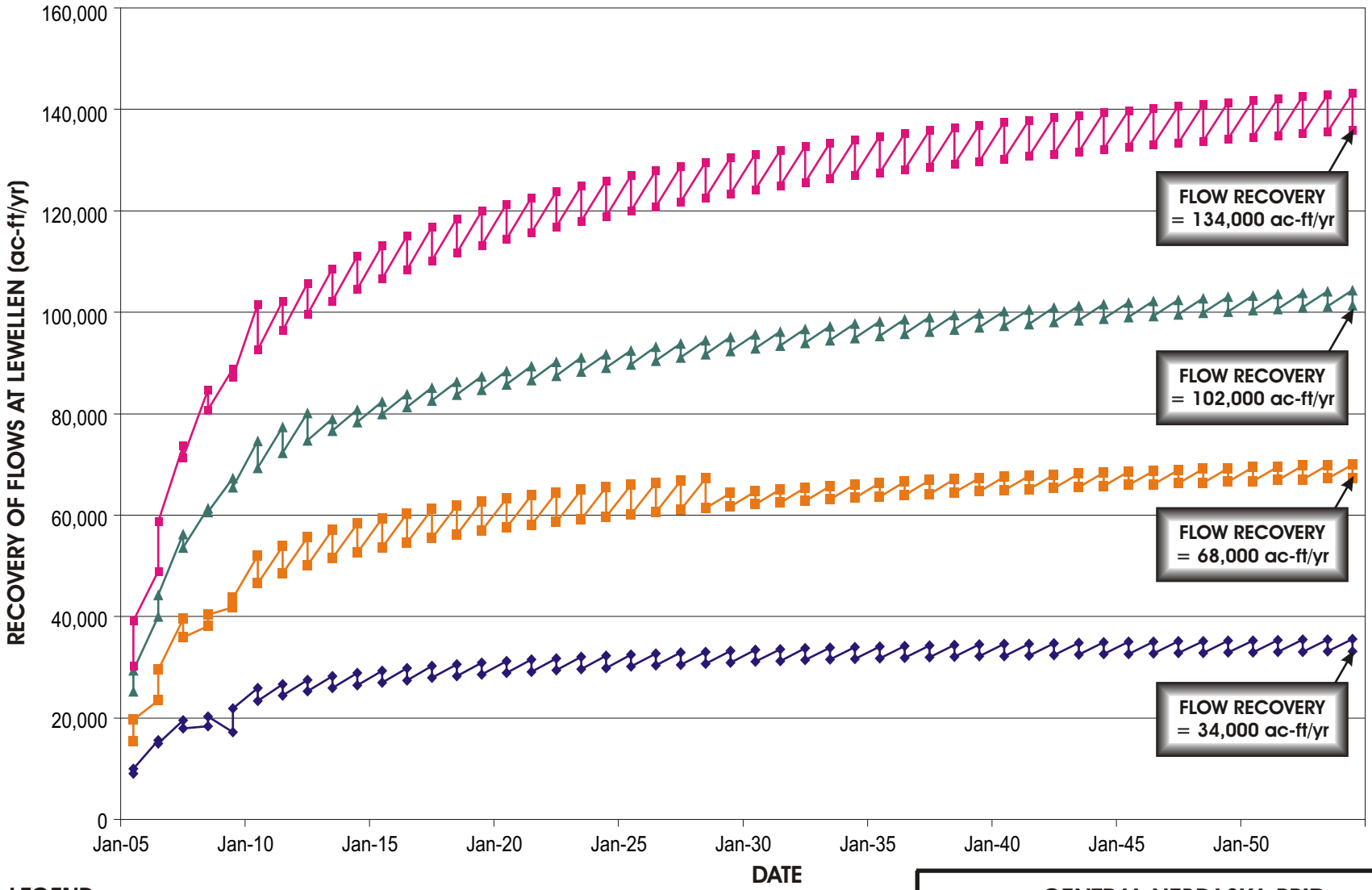
Notes:
1) Historic hydrologic values used for years 1950 - 2004. Values from 1998 used for years 2005-2055.
2) Historic estimates used (blue line on left side of graph) from 1950-2004.

CENTRAL NEBRASKA PPID

HISTORIC AND FUTURE FLOW DEPLETIONS AT LEWELLEN DUE TO PUMPING

File Name: FlowDepletions.cdr		Date: 06/10/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 11

LYTLE WATER SOLUTIONS, LLC



LEGEND

- 25% NET PUMPING REDUCTION
- 50% NET PUMPING REDUCTION
- 75% NET PUMPING REDUCTION
- 100% NET PUMPING REDUCTION

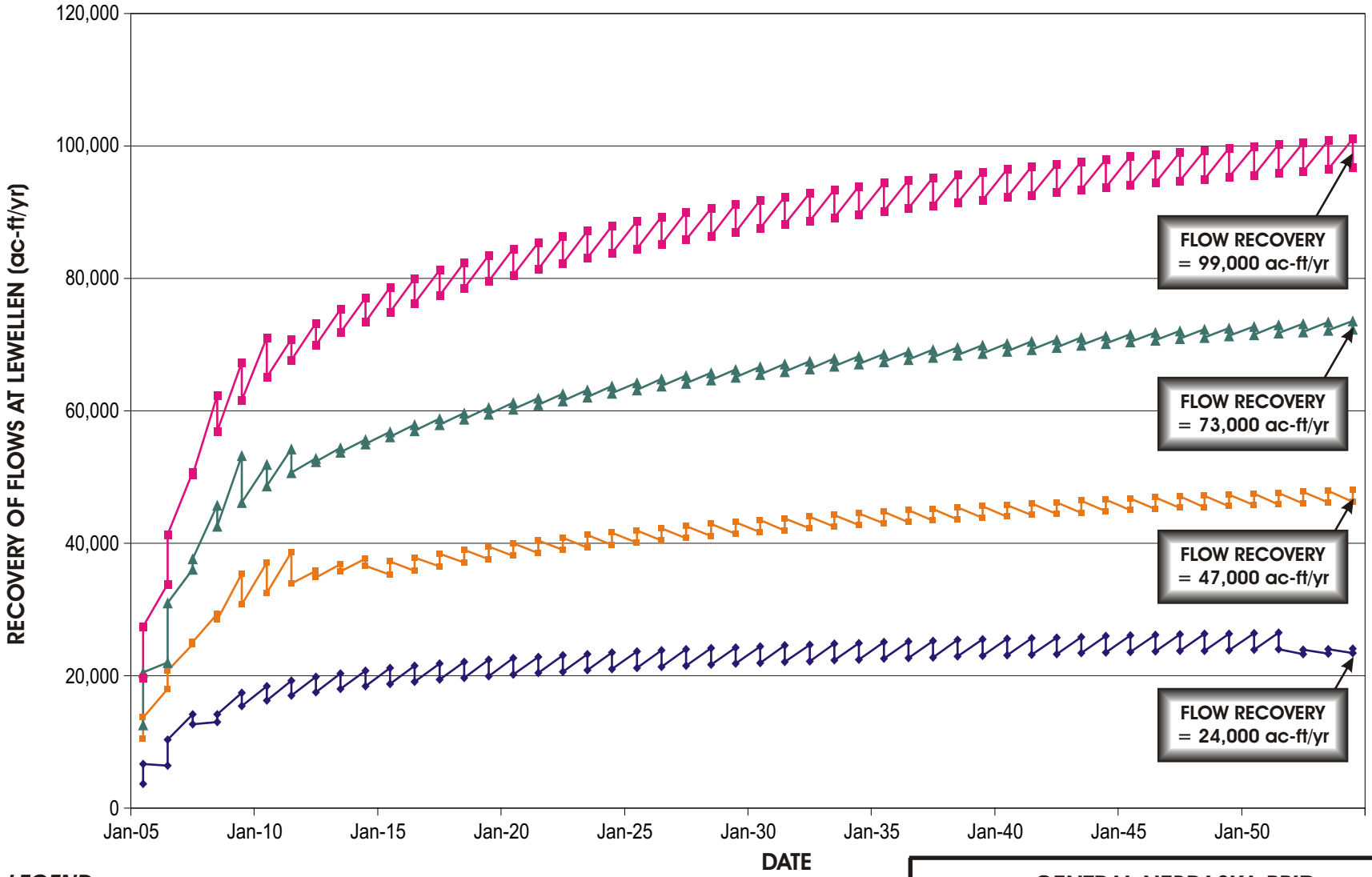
Notes:
1) Hydrologic values from 1998 extended from 2005 to 2055.

CENTRAL NEBRASKA PPID

FLOW RECOVERY AT LEWELLEN ASSUMING A REDUCTION FROM A PROJECTED NET PUMPING RATE OF 170,000 AC-FT/YR

File Name: FlowRecovery_170K.cdr		Date: 06/10/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 12

LYTLE WATER SOLUTIONS, LLC



LEGEND

- 25% NET PUMPING REDUCTION
- 50% NET PUMPING REDUCTION
- 75% NET PUMPING REDUCTION
- 100% NET PUMPING REDUCTION

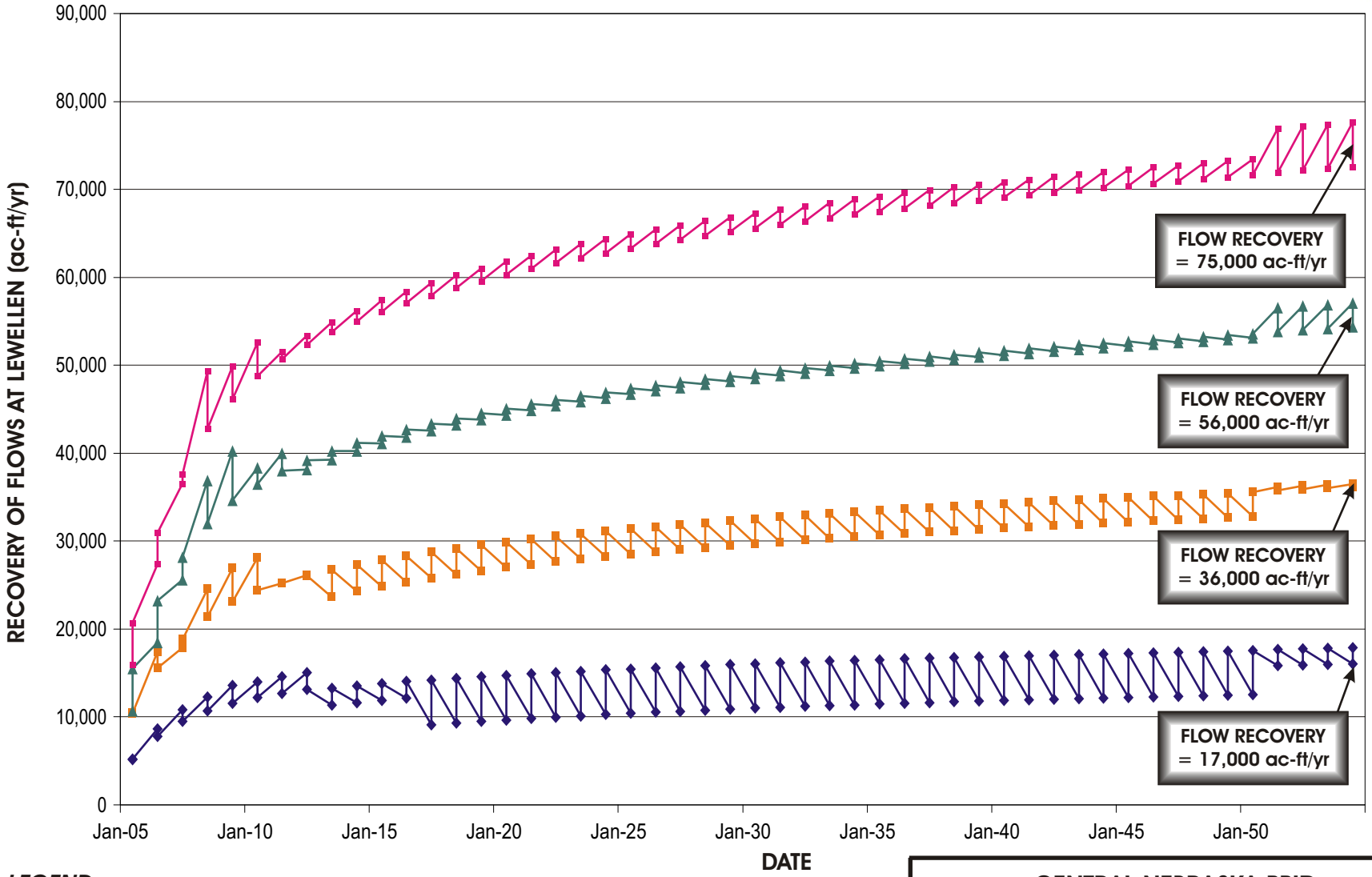
Notes:
1) Hydrologic values from 1998 extended from 2005 to 2055.

CENTRAL NEBRASKA PPID

FLOW RECOVERY AT LEWELLEN ASSUMING A REDUCTION FROM A PROJECTED NET PUMPING RATE OF 120,000 AC-FT/YR

File Name: FlowRecovery_120K.cdr		Date: 06/10/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 13

LYTLE WATER SOLUTIONS, LLC



LEGEND

- 25% NET PUMPING REDUCTION
- 50% NET PUMPING REDUCTION
- 75% NET PUMPING REDUCTION
- 100% NET PUMPING REDUCTION

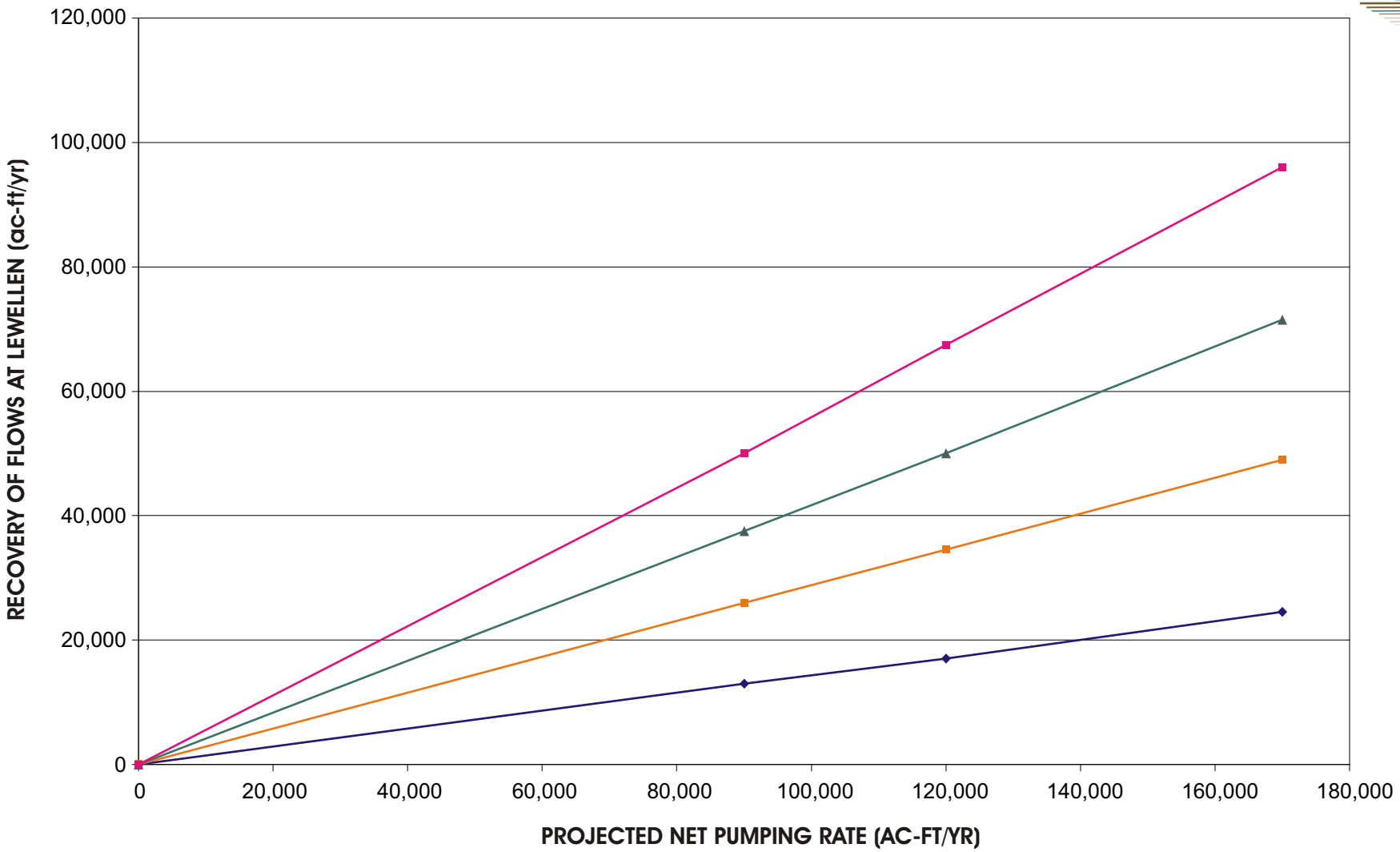
Notes:
1) Hydrologic values from 1998 extended from 2005 to 2055.

CENTRAL NEBRASKA PPID

FLOW RECOVERY AT LEWELLEN ASSUMING A REDUCTION FROM A PROJECTED NET PUMPING RATE OF 90,000 AC-FT/YR

File Name: FlowRecovery_90K.cdr		Date: 06/10/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 14

LYTLE WATER SOLUTIONS, LLC



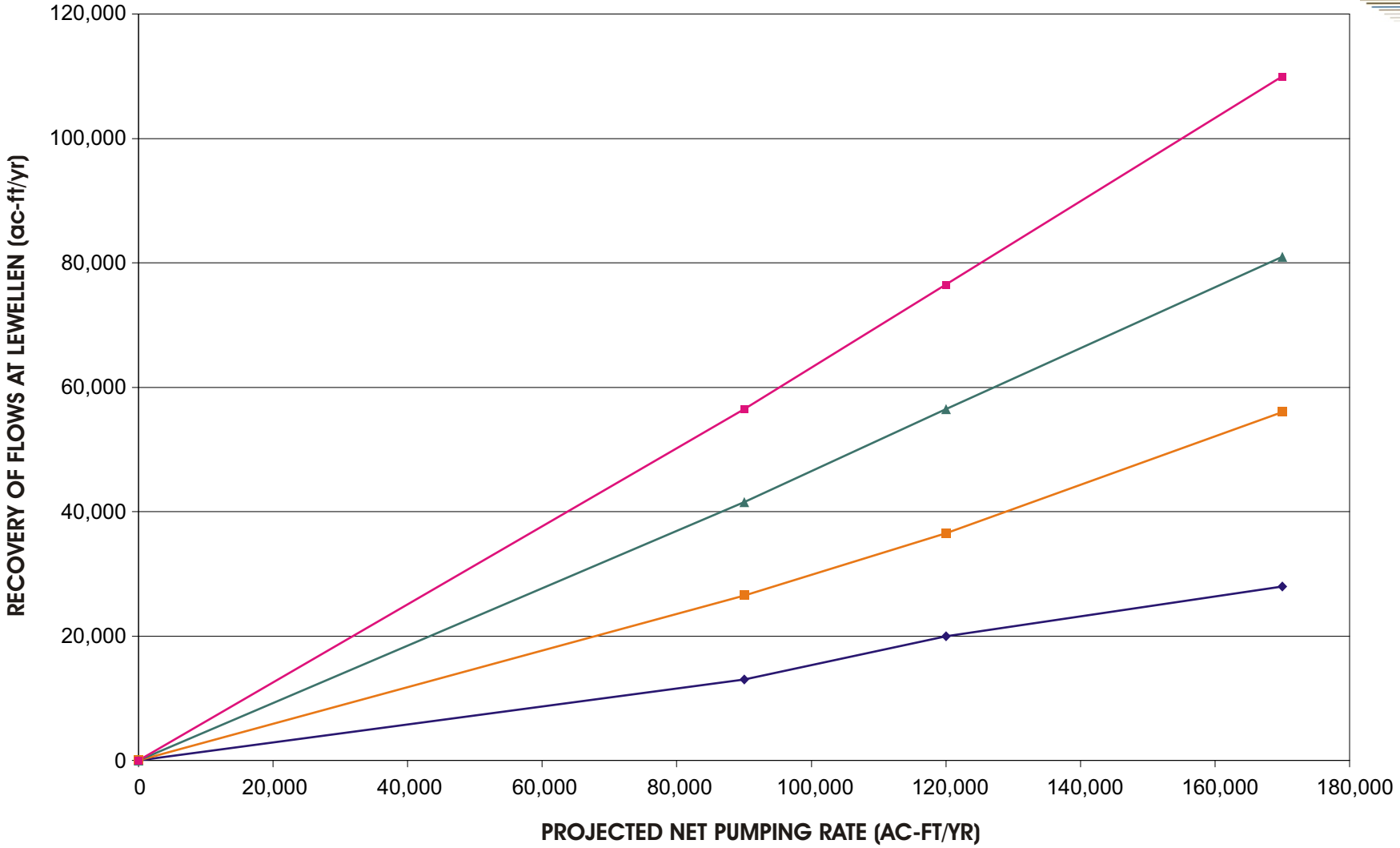
LEGEND

- 25% NET PUMPING REDUCTION
- 50% NET PUMPING REDUCTION
- 75% NET PUMPING REDUCTION
- 100% NET PUMPING REDUCTION

Notes:
1) Hydrologic values from 1998 were used for all future simulations.
2) All values of recovery taken from 5 years after pumping reduction.

CENTRAL NEBRASKA PPID		
FLOW RECOVERY AT LEWELLEN AFTER 5 YEARS FOR VARYING PROJECTED NET PUMPING RATES		
File Name: FlowRecovery_5yrs.cdr		Date: 06/10/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 15

LYTLE WATER SOLUTIONS, LLC



LEGEND

- 25% NET PUMPING REDUCTION
- 50% NET PUMPING REDUCTION
- 75% NET PUMPING REDUCTION
- 100% NET PUMPING REDUCTION

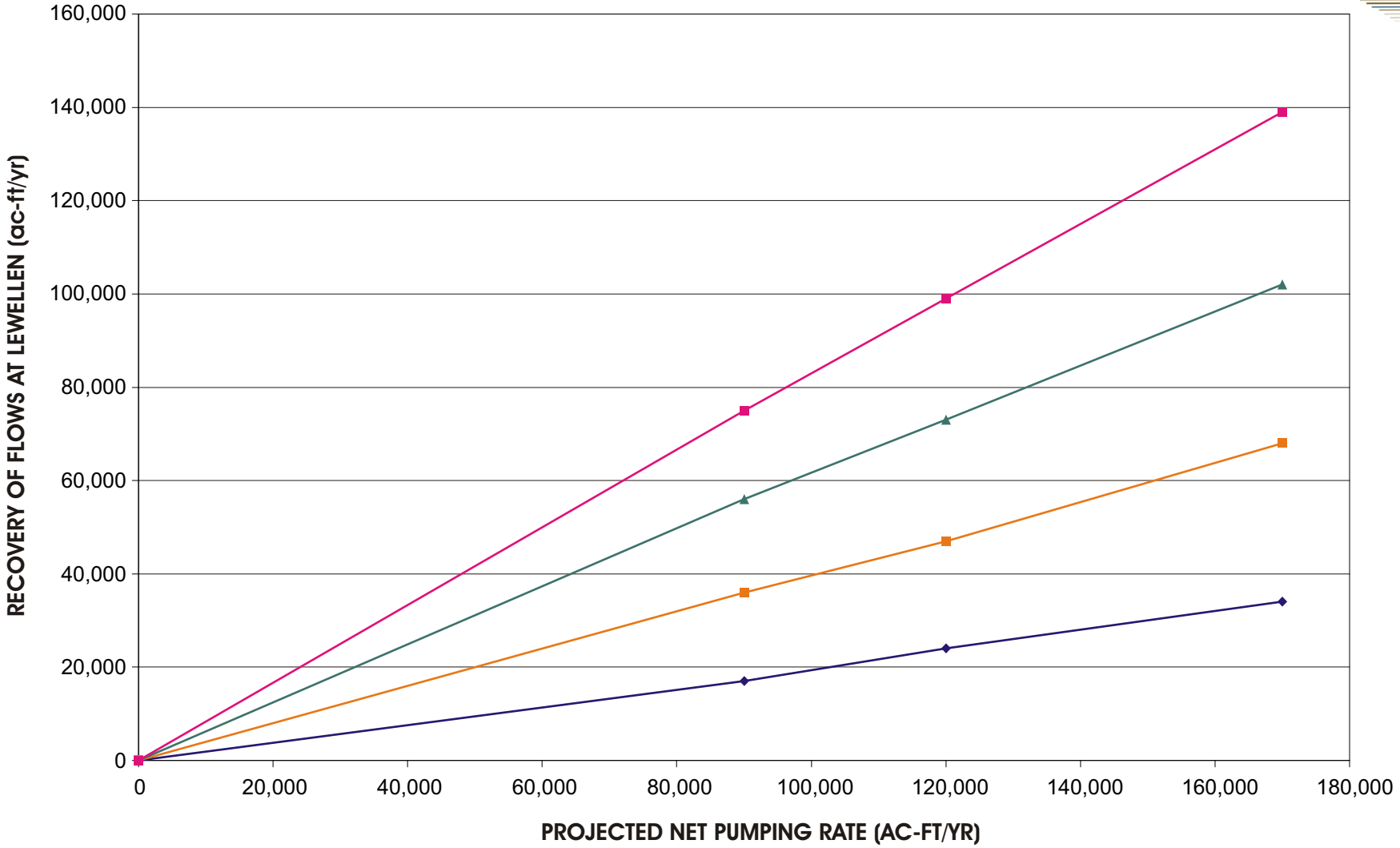
Notes:
1) Hydrologic values from 1998 were used for all future simulations.
2) All values of recovery taken from 10 years after pumping reduction.

CENTRAL NEBRASKA PPID

FLOW RECOVERY AT LEWELLEN AFTER 10 YEARS FOR VARYING PROJECTED NET PUMPING RATES

File Name: FlowRecovery_10yrs.cdr		Date: 06/10/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 16

LYTLE WATER SOLUTIONS, LLC



LEGEND

- 25% NET PUMPING REDUCTION
- 50% NET PUMPING REDUCTION
- 75% NET PUMPING REDUCTION
- 100% NET PUMPING REDUCTION

Notes:
1) Hydrologic values from 1998 were used for all future simulations.
2) All values of recovery taken from 50 years after pumping reduction.

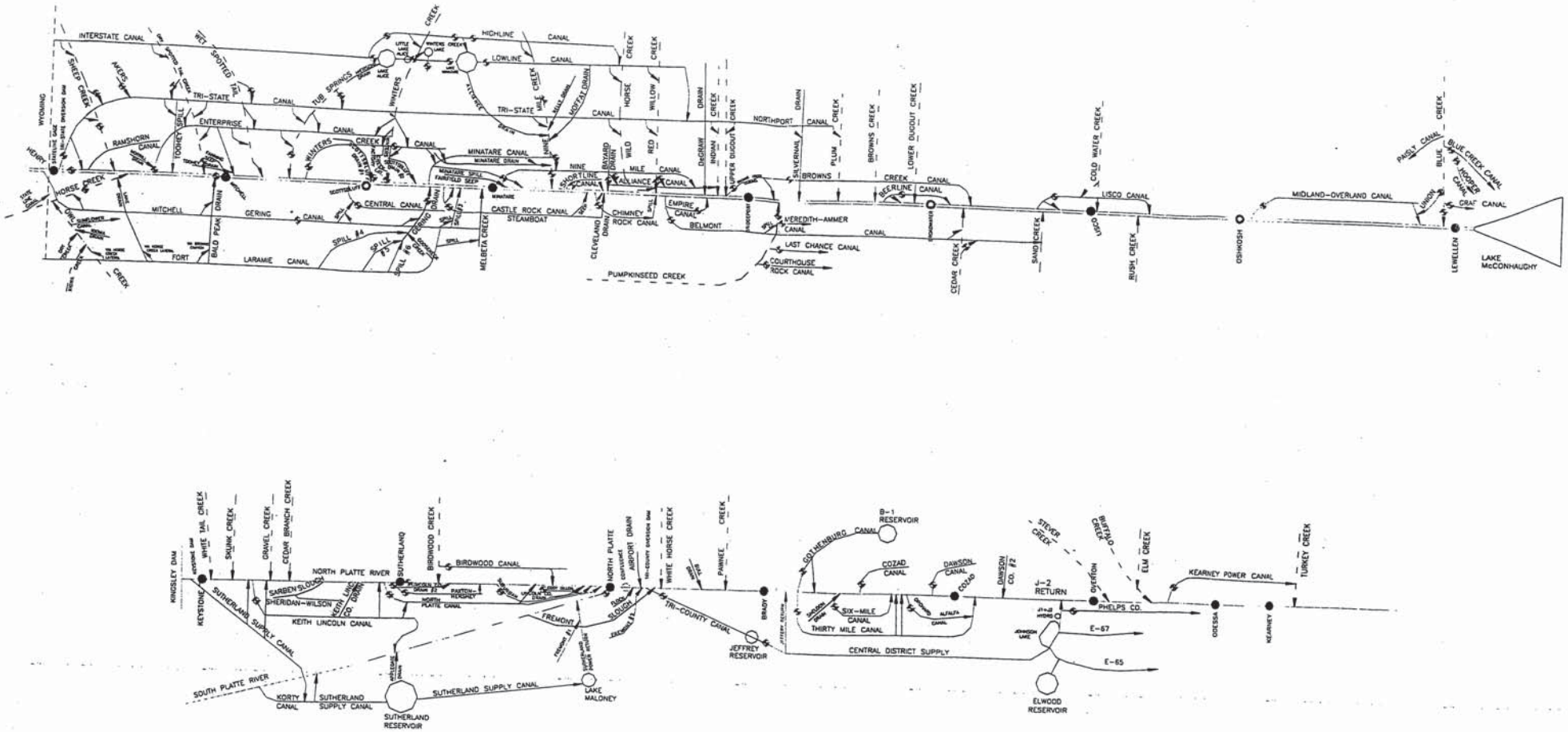
CENTRAL NEBRASKA PPID		
FLOW RECOVERY AT LEWELLEN AFTER 50 YEARS FOR VARYING PROJECTED NET PUMPING RATES		
File Name: FlowRecovery_50yrs.cdr		Date: 06/10/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: 17

TABLE 1
ESTIMATED AVERAGE WATER BUDGET
1950–2004

Flux Term		**Average Flux (ac-ft/yr)**
Inflows:		
Surface Flow (State Line Gage)		559,000
Wyoming Canal Flows		546,000
Runoff and Deep Percolation		391,000
Alluvial Underflow at State Line		4,000
	TOTAL:	**1,500,000**
Outflows:		
Surface Flow (Lewellen Gage)		1,018,000
Alluvial Underflow at Lewellen Gage		2,200
Evapotranspiration		184,000
Consumptive Use (Ground Water)		63,000
Consumptive Use (Surface Water)		232,800
	TOTAL:	**1,500,000**

APPENDIX A

NORTH PLATTE STRAIGHT LINE DIAGRAM



NOTE:

- ALL CANALS HAVE A GAGING STATION
- RAMSHORN CANAL WAS CANCELLED

NOT TO SCALE

LEGEND

- GAGING STATION
- CITIES
- CITIES/GAGING STATION
- RESERVOIR
- CANAL
- CREEK
- DRAIN

APPENDIX B
EVAPOTRANSPIRATION

EVAPOTRANSPIRATION

BACKGROUND

Evapotranspiration (ET) from open water, riparian areas, and wetlands is simulated in the WMU Model based on an inferred relationship between the rate at which ET occurs and the model's prediction of ground water levels in the areas where ET is expected. This relationship requires that information be supplied for the following: a) spatial distribution of lands where ET occurs, b) elevation of the ET surface (the point at which ET is at a maximum, usually coinciding with an elevation approximating ground surface elevation), c) extinction depth (the depth below the ET surface where the ET rate is zero), and d) the maximum ET rate. The elevation of the ET surface and extinction depth in the WMU Model were found to be reasonable and were, therefore, adopted. However, the maximum ET rate and the spatial distribution used in the WMU Model were modified to better represent ET losses. The parameters related to ET in the WMU Model and reasons for changing the ET rate and distribution are described below.

The maximum ET rate in the WMU Model was 16 inches per year in the western half of the model and 15 inches per year in the eastern half of the model (defined as areas east of the western half) (Luckey and Cannia, 2006). No specific reason was provided in the WMU Model documentation as to why the maximum ET rate was different in the eastern portion of the model versus the western portion of the model. The maximum ET rate occurs when the simulated water level is at, or above, the ET surface. The ET surface was estimated as halfway between the mean land surface in a 160-acre grid (model cell) and the minimum land surface in the grid (Luckey and Cannia, 2006). The maximum ET rate decreases linearly to zero as the water level reaches the extinction depth and is then held constant throughout time in the WMU Model. The distribution of lands in the WMU Model where ET occurs was approximately one to two miles wide along the riparian corridor of the river (Luckey and Cannia, 2006).

Evapotranspiration along the riparian corridor of the North Platte River plays a critical role in the exchange between ground water and surface water, and in the water balance. The ET rate varies seasonally, with lower ET rates in the winter than in the summer. The WMU

documentation also recognizes this variability and the need for better representation of ET by stating that "[t]he representation of evapotranspiration in the model, as well as evapotranspiration parameters, also needs further research and refinement"(pg. 6). We agree with this statement and, therefore, have investigated the means to develop a representative time-variant ET rate.

The WMU documentation describes that the source and justification for the use of the constant ET rate is that "[t]hese estimates were based on the difference between lake evaporation and precipitation, and a factor based on riparian woodland evapotranspiration studies near Gothenburg and Odessa, Nebraska (M.K. Landon, USGS, oral commun., July 2004), accounting for the fact that vegetation evapotranspiration rates are less than open-water rates"(pg. 38). The study conducted by M.K. Landon may provide the best source for adjusting lake evaporation rates for riparian woodlands by calculating the difference between lake evaporation and precipitation, but this method potentially limits the true maximum ET rate, which means that the WMU Model underestimates the maximum ET rate. Eagle Resources, in its peer review of the WMU Model, had a similar assessment and stated that "[t]he use of maximum ET rates that are the difference between lake evaporation and precipitation is not correct. ET from gw [ground water] is driven by atmospheric demand, not by the difference between this demand and precipitation. The method used assumes that no precipitation becomes runoff. Recharge was apparently also applied where ET from groundwater was simulated" (pg. 184, comments 82 and 83). The comments from Eagle Resources support the need to change the ET rate to better represent the true maximum ET rate. Both of these concerns, combined with a dynamic water table affected by both ground water pumping and surface water irrigation practices, are reasons for further investigation into representative time-varying ET rates.

APPROACH

CropSim was used to develop crop irrigation requirements (CIRs) in the WMU Model, which were then used to define ground water pumping in the WMU Model. The CropSim methodology uses daily precipitation, temperature, soil moisture conditions, and crop coefficients to estimate ET rates. The methodology calculates these daily ET rates on a year-round basis. The underlying data that were used in the calculation of CIRs for both crops and riparian vegetation were provided by NDNR personnel (NDNR, 2009). Monthly ET values (produced by CropSim) for

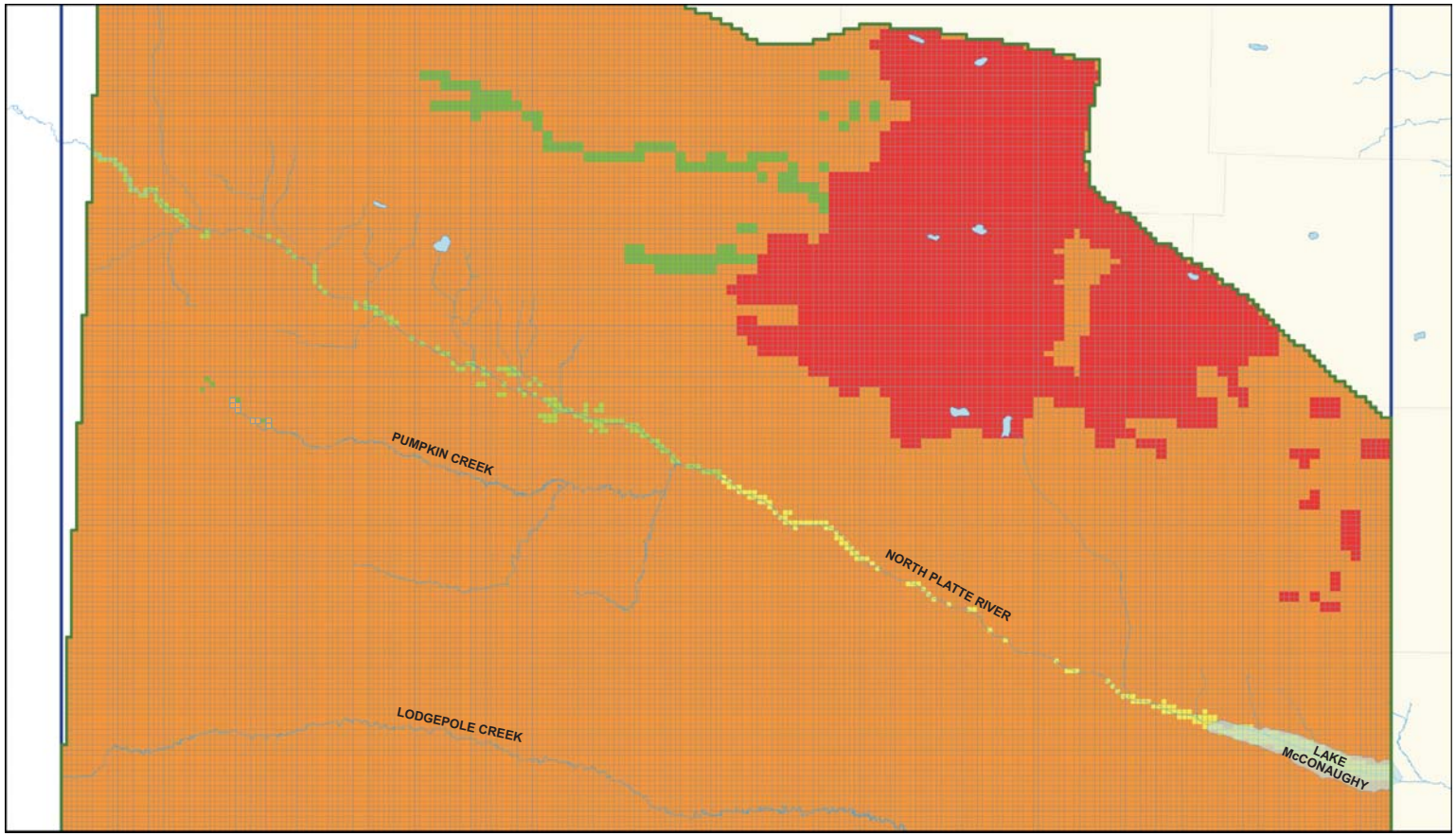
four of the environments (shallow open water, riparian woodlands, reed-swamp mixed wetlands, and cattail and bulrush wetlands) for Scottsbluff County were averaged over the period 1950 to 2005. This resulted in an average ET rate by month representative of the environment found in the riparian corridor of the North Platte River.

To produce ET rates that correspond to the stress periods in the development period model, the average monthly ET rates from CropSim were summed over the irrigation and non-irrigation seasons, resulting in 72.3 percent of the ET occurring during the irrigation season stress period and 27.7 percent of the ET occurring during the non-irrigation season stress period.

The distribution of areas subject to ET as represented in the WMU Model, generally a corridor 1 to 2 miles wide along the North Platte River mainstem (Luckey and Cannia, 2006), was compared with satellite imagery of the same area and with National Wetlands Inventory mapping created by the U.S. Fish and Wildlife Service (1994). The area identified in the WMU Model as having the potential for ET was found to be significantly larger than the area identified on the imagery or the area mapped as part of the wetlands inventory. Areas of the mainstem that would be subject to ET in the WMU Model were, therefore, redefined for use in the North Platte Depletions Model, based on National Wetlands Inventory mapping. Areas subject to ET in the Sand Hills area appeared reasonable, and were adopted without change. The area subject to ET in the Pumpkin Creek basin was reduced somewhat, based on inspection of topographic mapping and satellite imagery for this area.

Maximum ET rates in the range of approximately 33 to 36 inches were adopted for use in the North Platte Depletions Model. These rates were determined based on a review of estimates of ET produced by the CropSim Model, basin-wide estimates of ET developed during the assembly of the water budget, and refined during the model calibration process. The spatial distribution of ET rates is shown in Figure B-1.

LYTLE WATER SOLUTIONS, LLC



LEGEND

- STREAMS
- ACTIVE CELL OUTLINE
- MODEL DOMAIN OUTLINE

Evapotranspiration Zones

- Zone 1, 0 in/yr Ext. Depth = 0 ft
- Zone 2, 35.5 in/yr Ext. Depth = 5 ft
- Zone 3, 33.5 in/yr Ext. Depth = 5 ft
- Zone 4, 33.5 in/yr Ext. Depth = 7 ft
- Zone 5, 35.5 in/yr Ext. Depth = 7 ft

Notes:
1) The spatial distribution of ET cells along the North Platte River and Pumpkin Creek was modified from the WMU Model based on wetlands delineation mapped by the U.S. Fish and Wildlife Service.
2) See Figure 1 for Model Domain.
3) The ET rates listed in the legend represent the maximum rates in the Pre-Ground Water Development Model.

N

0 11.2 miles

CENTRAL NEBRASKA PPID

SPATIAL DISTRIBUTION OF EVAPOTRANSPIRATION ZONES IN THE NORTH PLATTE RIVER BASIN

File Name: ETzones.cdr		Date: 02/17/2009
Project No.: 1165-08	Drawn By:VAL	Fig. No.: B-1

APPENDIX C

CANAL LEAKAGE AND IRRIGATION RETURN FLOWS

CANAL LEAKAGE AND IRRIGATION RETURN FLOWS

INTRODUCTION

The WMU Model simulated ground water recharge from several sources, including direct infiltration of precipitation, canal leakage and surface water irrigation return flows (SWIRFs). There was no contribution from ground water irrigation return flows because the WMU Model used a net pumping value for ground water pumping, i.e., total pumping minus return flows. This appendix discusses modifications that LWS believes are necessary to the canal leakage and SWIRF portions of the total recharge to provide representative leakage and return flow values. The combined canal leakage and SWIRFs are referred to herein collectively as *surface water return flows*.

In the WMU Model, surface water return flows did not vary over time; rather, an average value from 1950 to 1997 was used. LWS believed that a more dynamic representation is needed. In constructing the North Platte Depletions Model, the recharge from surface water return flows was recalculated by LWS for each year of the simulation (1950 through 2004). Additionally, a new spatial distribution of surface water irrigated acreage for each district has been developed by the COHYST group since the WMU Model documentation report was published. Therefore, we have modified both the rate of recharge and the location of this recharge to provide a more representative set of surface water return flows.

DISCUSSION OF AVAILABLE DATA SETS

In general, we followed a similar process, and used the same available data sets, in determining the surface water return flows as was described in the WMU Model documentation (Luckey and Cannia, 2006). Many of the data sets used in this analysis were created by COHYST personnel, but have not been formally adopted by the COHYST group. LWS believes that these data sets represent an improvement from previous data sets and, therefore, they have been used in the analysis of annual return flow estimates instead of using one average historic value. The following sections describe the available data sets, their reliability and how they were used to develop year-to-year return flow values.

Diversion Records

Diversion records measure the amount of water diverted from the North Platte River for each district. LWS used the two available sources for diversion records. The first source is the United States Bureau of Reclamation (USBR) diversion records. These records were compiled by COHYST personnel into one data set (Central Platte Natural Resources District (CPNRD), 2008). The second source is the Nebraska Department of Natural Resources (NDNR) diversion records. These records were also compiled by COHYST personnel into a second separate data set (CPNRD, 2008). The USBR diversion records provide historical annual diversions, while the NDNR records provide historical monthly diversions. Table C-1 shows the period of record for both data sets. Both sets of data are considered reliable, as they are based on gaged flows for each canal.

Delivery Records

Delivery records measure the amount of water delivered to the edge of the farm for each district, and were only available for districts with USBR diversions records (CPNRD, 2008) and were only available on an annual basis. These records were considered reliable. These data were used to calculate canal leakage directly, i.e., diversion volume from the river minus the delivery volume at the farm. For districts with NDNR diversion records only, no delivery values were available. Instead, delivery values were calculated by subtracting canal loss from diversions. A canal leakage of 43 percent of the diversions was assumed. LWS reviewed several other sources to evaluate the representativeness of this value. These sources included: a) the COHYST WMU Model documentation, which reported an average value of 36 percent, b) a report prepared for the North Valley Water Coalition (Bishop Brogden Associates, Inc. 2002), which reported an average value of 39 percent, c) the USBR diversion and delivery records (43 percent), and d) new estimates by COHYST personnel (43 percent). Based on this review, the value of 43 percent was judged to be representative of canal leakage and was used for districts with NDNR diversion data. Table C-1 summarizes the diversion and delivery data available.

Crop Irrigation Requirement

The COHYST modeling effort used CropSim to calculate Crop Irrigation Requirement (CIR) values. CIR values vary from year to year depending on hydrology, however, they also vary

spatially. LWS cannot generate spatial and temporal distributions of CIRs, as we do not have access to the multiple data bases required to create these distributions.

There were two sets of CIR records available to LWS for the North Platte Depletions Model. The first set of data was provided by COHYST personnel and included historic monthly values which changed throughout time, but were averaged spatially over Scottsbluff County (Nebraska Department of Natural Resources, 2009). The second set was taken from the NDNR website and included values averaged over time (1950-2005) which varied spatially for different regions of Nebraska (2009).

In an effort to determine which set was more representative, LWS compared the average change in CIRs of each data set. Table C-2 includes the maximum and minimum CIR value from 1950 to 2005, for each crop commonly irrigated in the WMU Model. Averaging the maximum values for all of the crops in the WMU Model over the time period 1950-2005 resulted in a CIR of 19.2 inches. Averaging the minimum values for all of the crops in the WMU Model resulted in a value of 8.7 inches, a difference of 10.4 inches. This indicates a significant variation in CIRs temporally.

Table C-3 compares the average (1950-2005) CIR values taken from the NDNR website for western Scottsbluff County versus eastern Scottsbluff County. Table C-4 compares the average (1950-2005) CIR values for the western edge of the WMU Model versus the eastern edge of the WMU Model. These tables allow an assessment of spatial variations in CIRs. For crops commonly irrigated in the WMU Model, the average change in CIR values due to spatial variation across Scottsbluff County was 0.7 inches, with a maximum change of 1.4 inches. Across the entire WMU Model, the average change in CIR values due to spatial variation was 3.7 inches, with a maximum change of 5.2 inches.

In the absence of the data bases needed to create a rigorous spatial and temporal distribution, LWS chose to use the time-varying historic monthly values. LWS believes that this provides a reasonable representation of CIR, given the data sources available.

Supplemental Pumping

Supplemental pumping is defined as the net ground water pumping used in addition to surface water supplies to irrigate crops. The original WMU Model did not include any estimates of

supplemental pumping. However, since the completion of the WMU Model, COHYST personnel have produced an estimate of supplemental pumping using the same 1-mile cell distribution used in the CIR calculations as previously described (CPNRD, 2008). These data have not been adopted by the COHYST group and lack documentation. We have adopted COHYST's supplemental pumping rates, as LWS believes that these provisional data represent the most current and reliable estimate of supplemental pumping and is the best data set available.

Areal Distribution of Surface Water Return Flows

The original WMU Model documentation report prepared by the COHYST group describes how surface water return flows were distributed spatially by district. The distribution of return flows should also vary yearly as irrigated acreage increases or decreases, however, such a temporal data set is not currently available. Since the completion of the WMU Model, COHYST personnel have developed an estimate of the spatial distribution of acres irrigated with surface water within each district (CPNRD, 2008). It is our understanding that this new estimate is based on legal water rights records from 1997 only. Because this data set is a snapshot in time, it provides spatial distribution, but not temporal distribution, of surface water return flows.

The lack of time-varying data may affect localized water levels in the model and potentially the volume of recharge entering the model. However, LWS feels that this COHYST data set represents the best available data and has chosen to use it to distribute surface water return flows.

Acres Irrigated With Surface Water

Estimates for the number of acres irrigated with surface water used in the WMU Model have been deemed incorrect by the COHYST group. As such, COHYST personnel have created a new estimate of acres irrigated with surface water. This estimate includes historic annual values of acreage and a historic distribution of crop type for each 1-mile cell, as was used in the CIR analysis (COHYST acreage) (NDNR, 2008).

In addition to this data set, a second data set estimates the number of acres irrigated with surface water based on USBR records for districts served by USBR diversions and NDNR water rights records for those with NDNR diversion records (USBR acreage). This data set has also been

compiled by COHYST personnel but has not yet been adopted by the COHYST group (CPNRD, 2008). These records include historic yearly irrigated acreage for each district, but do not include any crop type distribution information.

Table C-5 summarizes the average acreage irrigated by surface water for each district, for both data sets. This table indicates an average of approximately 250,000 acres irrigated by surface water using the COHYST acreage data set versus approximately 333,000 acres using the USBR acreage data set. Due to a lack of documentation, LWS was unable to verify either set of data; however, we believe that both sets of data have value, depending upon their use.

Initially, both the COHYST acreage and the USBR acreage were used to calculate the total potential consumptive use of surface water. These values were used with a mass balance approach of the entire WMU Model in an effort to determine the amount of precipitation that becomes runoff or directly infiltrates into the ground water. When the COHYST acreage was used, approximately 6.6 percent of the total precipitation was required to balance the inflows and outflows. When the USBR acreage was used, approximately 8.2 percent was required to balance the inflows and outflows. Szilagyi, et. al estimated the total recharge from precipitation in western Nebraska to be 7 percent (2005). Based on these findings and our professional judgment, LWS believes that the value of 6.6 percent is more representative of the amount of precipitation that becomes runoff or directly infiltrates. Therefore, the COHYST acreage was used when calculating a surface water consumptive use.

Both acreage data sets were also initially used to evaluate the rate of water supplied to the edge of each farm. This value was calculated by dividing the delivery data by the irrigated acreage to yield a unit delivery, i.e., per acre. Using the COHYST acreage resulted in an average unit delivery of 40 inches per acre, with a maximum of 1,040 inches per acre. Additionally, the COHYST acreage resulted in unit deliveries greater than 80 inches for 5 percent of the data set. Conversely, using the USBR acreage resulted in an average unit delivery of 18 inches, and a maximum of 86 inches. Less than 0.1 percent of the records were greater than 80 inches when the USBR acreage was used. Based on these results, LWS believes that the USBR acreage data set provides the most reliable estimate of supply rates. Therefore, this acreage set was used when determining the unit deliveries.

APPROACH

We were able to develop a reasonable representation of time-varying surface water return flows by first calculating the time-varying consumptive use of surface water for each district. Once the consumptive use of surface water was known, the surface water return flows could be determined by subtracting the surface water consumptive use from the diversions. The surface water return flows were then grouped into irrigation and non-irrigation seasons. This section discusses the specific process used to develop an estimate of consumptive use of surface water and, subsequently, surface water return flows.

The North Platte Depletions Model has two stress periods, an irrigation season stress period and a non-irrigation season stress period. The irrigation season stress period represents May through September for any given year, while the non-irrigation season stress period represents October of the previous year through April of the current year. For example, the non-irrigation stress period for 1951 is October 1950 through April 1951. We reviewed the available historic monthly diversion records to determine how much of the water was diverted outside of the irrigation season. Table C-1 shows the average non-irrigation season diversions and the percent of these diversions to the total diversions. The majority of the districts divert water in the irrigation season only. Those that divert outside of this season divert the balance of the irrigation supply generally in April and October. Additionally, LWS believes that there is an insignificant time lag associated with when crops receive water and when surface water return flows accrue to the ground water system because there are only two stress periods per year in the model. Therefore, we made the simplifying assumption that all the surface water return flows would occur during the irrigation season stress periods.

The calculation of surface water return flows is closely tied to consumptive use of surface water. Because the consumptive use of surface water equals the diversions minus the surface water return flows, LWS first estimated the consumptive use of surface water for the North Platte Depletions Model and then used this relationship to determine surface water return flows.

The first step in this process was to convert all the data sets from volumes to unit rates, i.e., ac-ft/yr to in/ac/yr. This was accomplished by dividing the volume data sets by the USBR acreage, as the USBR acreage data set was judged to be more representative for this task (See "Acres Irrigated With Surface Water" section). Next, unit deliveries were compared with the CIR

values. The results of this comparison, along with the supplemental pumping data developed by COHYST personnel, were used to determine which years crops received a full supply of surface water.

In years when a full supply of surface water was available, LWS assumed that the full crop demand was met entirely with surface water supplies. In this case, unit consumptive use of surface water was set equal to the crop demand. In years when a full supply of surface water was not available, LWS assumed that supplemental pumping was used in addition to surface water supplies to provide a full supply to crops. The COHYST supplemental pumping file identified specific locations where supplemental ground water pumping can occur. However, based on the COHYST supplemental pumping file, not every farm had access to ground water supplies. Therefore, LWS assumed that the farms that did not have access to ground water supplies were unable meet the full crop demand and the crops were shorted water. In this case, the consumptive use of surface water was less than the crop demand and it was not possible to equate the two data sets. Therefore, two separate unit rate terms, canal leakage and SWIRF were independently calculated, and then subtracted from the unit diversions to determine the unit consumptive use of surface water.

The unit canal leakage was calculated by subtracting the unit diversions from the unit delivery data for districts with delivery records. For districts without delivery data, a canal leakage percentage (43 percent) was applied to the unit diversion data to determine the unit canal leakage.

Unit SWIRFs were calculated by applying a maximum farm efficiency to the unit delivery data. LWS assumed a maximum farm efficiency of 67 percent (33 percent return flows). This value of maximum farm efficiency was the same value used by COHYST personnel to develop their provisional supplemental pumping data set. It also compares well to values used in conjunction with the South Platte Decision Support System model being developed for the Colorado Division of Water Resources, which reported a maximum efficiency of 60 percent for flood irrigation and 80 percent for sprinkler irrigation (Leonard Rice Engineers, 2008).

The last step in calculating surface water return flow was to convert the unit consumptive use of surface water from in/ac/yr to ac-ft/yr by multiplying by the COHYST acreage data set, as the COHYST acreage data set was judged to be more representative for this task (See "Acres

Irrigated With Surface Water" section). The time-varying volumes of consumptive use of surface water data set were subtracted from the diversions records to produce a final estimate of time-varying surface water return flows in acre-feet per year.

Once the total amount of surface water return flows were estimated for each year, they were grouped into the appropriate irrigation season stress periods. These volumes were then distributed over the areal extent of irrigated acreage as previously described. Figure C-1 shows the final areal extent of recharge for each district.

SUMMARY

Based on our analysis we have the following conclusions.

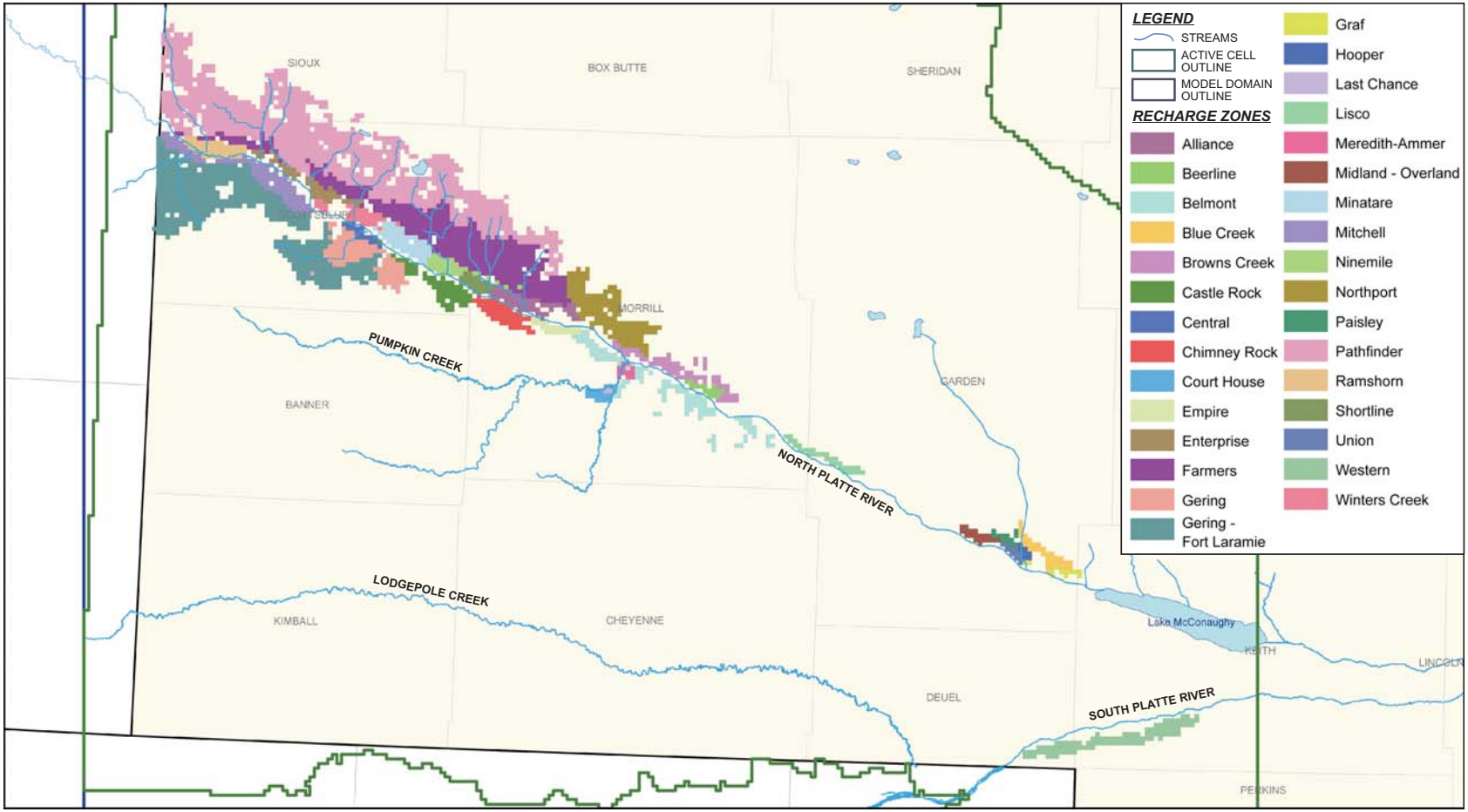
(1) Surface water return flow volumes were modeled by COHYST as being constant over time and as having an unchanging spatial distribution.

(2) LWS developed estimates of the volume of return flows for each year of the simulation using available data sets.

(3) LWS used a new distribution of irrigated acreages developed by COHYST to estimate the distribution of return flows spatially. The distribution of acreage did not vary with time but, rather, reflected the distribution of irrigated lands in 1997. Therefore, the return flows were treated as having a uniform spatial distribution over time.

(4) The process that was used provides a representative estimate of the time-varying surface water return flows and adequately distributes them in the North Platte Depletions Model.

LYTLE WATER SOLUTIONS, LLC



Notes:
1) Coordinate System: Nebraska State Plane FIPS 2600 (feet).
2) Projection: Lambert Conformal Conic.
3) Horizontal Datum: NAD 1983.
4) See Figure 1 for Model Domain.
5) Recharge zones represent irrigation districts in which recharge occurs in model cells.

N

0 11.7 23.4 miles

CENTRAL NEBRASKA PPID		
AREAL EXTENT OF RECHARGE ZONES		
File Name: RechargeZones.cdr		Date: 01/27/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: C-1

TABLE C-1
SUMMARY OF DATA SETS REPRESENTING DIVERSIONS AND DELIVERIES

Canal Name	USBR Diversions [1)]	USBR Delivery	USBR Period of Record	USBR Avg Canal Loss % [2)]	NDNR Diversions [3)]	NDNR Period of Record	NDNR Diversion Records Monthly?	Mean Non-Irrigation Diversions (ac-ft/yr) [4)]	% of Tot. Div. Outside of the Irr. Season.
Alliance	No	No	n/a		Yes	1946-2004	Yes	1165	7
Beerline	Yes	Yes	1946-2005	41	Yes	1946-2004	Yes	78	4
Belmont	No	No	n/a		Yes	1946-2004	Yes	1272	4
Bridgeport	Yes	Yes	1946-2005	38	No	n/a	n/a	n/a	n/a
Blue Creek	No	No	n/a		Yes	1945-1997	Yes	584	8
Blue+Hooper	No	No	n/a		Yes	1998-2002	Yes	n/a	n/a
Blue+Hooper+Graf	No	No	n/a		Yes	10/2002-2004	Yes	n/a	n/a
Browns Creek	Yes	Yes	1946-2005	42	Yes	1946-2004	Yes	449	3
Castle Rock	No	No	n/a		Yes	1946-2004	Yes	1287	6
Central	Yes	Yes	1946-2005	42	Yes	1946-2004	Yes	67	1
Chimney Rock	Yes	Yes	1946-2005	42	Yes	1946-2004	Yes	943	6
Court House	No	No	n/a		Yes	1946-2004	Yes	196	9
Empire	No	No	n/a		Yes	1957-2004	Yes	106	2
Enterprise	Yes	Yes	1946-2005	42	Yes	1946-2004	Yes	549	2
Farmers	Yes	Yes	1950-2005	49	No	n/a	n/a	n/a	n/a
Gering	Yes	Yes	1946-2005	44	No	n/a	n/a	n/a	n/a
Gering-Fort Laramie	Yes	Yes	1946-2005	42	No	n/a	n/a	n/a	n/a
Graf	No	No	n/a		Yes	1946-2002	Yes	199	7
Hooper	No	No	n/a		Yes	1943-2004	Yes	264	11
Last Chance	No	No	n/a		Yes	1946-2004	Yes	90	10
Lisco	No	No	n/a		Yes	1946-2004	Yes	677	8
Meredith-Ammer	No	No	n/a		Yes	1946-2004	Yes	11	1
Midland-Overland	No	No	n/a		Yes	1946-2004	Yes	158	8
Minatare	No	No	n/a		Yes	1946-2004	Yes	1181	6
Mitchell	Yes	Yes	1946-2005	27	No	n/a	n/a	n/a	n/a
Ninemile	No	No	n/a		Yes	1947-2004	Yes	1487	11
Northport	Yes	Yes	1946-2005	53	Yes	1946-2004	Yes	101	0.2
Paisley	No	No	n/a		Yes	1945-2004	Yes	602	20
Pathfinder	Yes	Yes	1946-2005	55	No	n/a	n/a	n/a	n/a
Ramshorn	No	No	n/a		Yes	1946-1992	Yes	81	4
Shortline	No	No	n/a		Yes	1946-2004	Yes	382	6
Union	No	No	n/a		Yes	1946-2004	Yes	119	5
Western	No	No	n/a		Yes	1946-2004	Yes	4732	19
Winters Creek	No	No	n/a		Yes	1946-2004	Yes	115	0.8

1) Based on records provided by NDNR staff. Filename: npdiv-del.xls
2) Canal loss percentage represents the percentage of diversions lost during transport.
3) Based on records provided by NDNR staff. Filename: PlatteCnls1-3-08.xls
4) Irrigation season is May-September.

TABLE C-2

SUMMARY OF CHANGES IN CIR VALUES OVER TIME FOR SCOTTSBLUFF COUNTY

	Crop Irrigation Requirement [1)]		
Crop Type	Max	Min	Difference
Irrigated Spring Small Grains	18.1	8.5	9.6
Irrgated Edible Beans	22	11.8	10.2
Irrgated Soybeans	20	9.8	10.2
Irrgated Potatoes	19.7	10.6	9.1
Irrgated Sugar Beets	13.6	6	7.6
Irrgated Sorghum (MILO)	17.6	8.3	9.3
Irrgated Winter Wheat	28.1	12	16.1
Irrgated Corn	18.6	5	13.6
Irrgated Sunflowers	15.2	6.9	8.3
Average	19.2	8.8	10.4

1) Based on a period of record 1950-2005.

TABLE C-3
COMPARISON OF AVERAGE (1950-2005) CROPSIM RESULTS FOR WESTERN AND EASTERN SCOTTSBLUFF COUNTY

(All values are in inches)	Average Values for Western Scottsbluff County, 1950 - 2005				Average Values for Eastern Scottsbluff County, 1950 - 2005				Change in Values (Western - Eastern)			
Crop	ET	Eff. Rain	CIR	Recharge	ET	Eff. Rain	CIR	Recharge	ET	Eff. Rain	CIR	Recharge
Irrigated Corn	28.1	14.6	14.4	1	27	15	13	1	1.1	-0.4	1.4	0
Irrigated Sugar Beets	30.9	14.5	17.7	1.5	30.9	14.3	17.2	0.5	0	0.2	0.5	1
Irrigated Soybeans	25.8	14.6	14.9	3.8	25.9	14.8	14.1	3	-0.1	-0.2	0.8	0.8
Irrigated Sorghum (Milo, Sudan)	27.4	14.6	14.8	2.1	27.5	15	14.1	1.6	-0.1	-0.4	0.7	0.5
Irrigated Dry Edible Beans	21.1	14.4	9.9	3.4	20.7	14.2	9.5	3	0.4	0.2	0.4	0.4
Irrigated Potatoes	26.5	14.4	15	3	26.5	14.1	14.5	2.2	0	0.3	0.5	0.8
Irrigated Alfalfa	37.3	14.8	22.5	0	37.2	15.3	21.9	0	0.1	-0.5	0.6	0
Irrigated Small Grains	24.6	14.8	10.3	0.6	23.8	15.4	9	0.7	0.8	-0.6	1.3	-0.1
Range/Pasture/Grass (Brome, Hay, CRP)	14.7	14.8	0	0.2	15.1	15.3	0	0.1	-0.4	-0.5	0	0.1
Urban Land	35.4	14.8	0	0	35.6	15.5	0	0	-0.2	-0.7	0	0
Open Water	31.9	14.8	0	0	31.9	15.7	0	0	0	-0.9	0	0
Riparian Forest and Woodlands	46.2	14.8	0	0	46.7	15.5	0	0	-0.5	-0.7	0	0
Wetlands	53.6	14.8	0	0	53.9	15.6	0	0	-0.3	-0.8	0	0
Other Agricultural Lands (Farmsteads, Feedlots, etc.)	14.7	14.8	0	0.3	15	15.2	0	0.2	-0.3	-0.4	0	0.1
Irrigated Sunflower	23.3	14.5	11.3	2.5	22.6	14.7	10.6	2.6	0.7	-0.2	0.7	-0.1
Summer Fallow	0	0	0	0	0	0	0	0	0	0	0	0
Roads	14.7	14.8	0	0.3	15	15.2	0	0.2	-0.3	-0.4	0	0.1
Dryland Corn	14.1	14.4	0	0.4	14.1	14.4	0	0.3	0	0	0	0.1
Dryland Soybeans	13.3	14.4	0	1.3	13.4	14.3	0	0.9	-0.1	0.1	0	0.4
Dryland Sorghum	13.9	14.5	0	0.6	14.1	14.6	0	0.4	-0.2	-0.1	0	0.2
Dryland Dry Edible Beans	13	14.4	0	1.5	12.9	14	0	1.1	0.1	0.4	0	0.4
Dryland Alfalfa	14.9	14.8	0	0	15.3	15.3	0	0	-0.4	-0.5	0	0
Dryland Small Grains	12.3	14.6	0	2.3	12.4	15.1	0	2.6	-0.1	-0.5	0	-0.3
Dryland Sunflower	13.7	14.4	0	0.7	13.7	14.3	0	0.6	0	0.1	0	0.1
Dryland Sugar Beets	0	0	0	0	0	0	0	0	0	0	0	0
Dryland Potatoes	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated Hay	31.7	14.8	17.6	1	31.8	15.5	17.2	0.8	-0.1	-0.7	0.4	0.2
Irrigated Rotation Pasture	32.6	14.8	18.2	0.6	32.6	15.5	17.6	0.5	0	-0.7	0.6	0.1
Average of All Values	21.99	13.07	5.95	0.97	21.99	13.35	5.67	0.80	0.00	-0.28	0.28	0.17
Average of irrigated crops in the WMU only.	27.22	14.58	14.53	1.99	26.90	14.76	13.77	1.62	0.32	-0.18	0.77	0.37

Green Cells represent crops commonly irrigated in the WMU.
Values taken from http://dnrmap2.dnr.state.ne.us/CIR/

TABLE C-4
COMPARISON OF AVERAGE (1950-2005) CROPSIM RESULTS FOR THE WESTERN AND EASTERN EDGES OF THE WMU MODEL

(All values are in inches)	Average Values for the Western Edge of the WMU, 1950 - 2005				Average Values for the Eastern Edge of the WMU, 1950 - 2005				Change in Values (Western - Eastern)			
Crop	ET	Eff. Rain	CIR	Recharge	ET	Eff. Rain	CIR	Recharge	ET	Eff. Rain	CIR	Recharge
Irrigated Corn	28.1	14.6	14.4	1	24.1	16.6	9.2	2.2	4	-2	5.2	-1.2
Irrigated Sugar Beets	30.9	14.5	17.7	1.5	29	16.8	13.6	0.4	1.9	-2.3	4.1	1.1
Irrigated Soybeans	25.8	14.6	14.9	3.8	24	16.6	10.2	1.4	1.8	-2	4.7	2.4
Irrigated Sorghum (Milo, Sudan)	27.4	14.6	14.8	2.1	25.7	16.6	10.1	1.6	1.7	-2	4.7	0.5
Irrigated Dry Edible Beans	21.1	14.4	9.9	3.4	18.7	16.6	6.1	4.1	2.4	-2.2	3.8	-0.7
Irrigated Potatoes	26.5	14.4	15	3	24.6	16.6	12.4	3.8	1.9	-2.2	2.6	-0.8
Irrigated Alfalfa	37.3	14.8	22.5	0	36.2	16.8	19.3	0	1.1	-2	3.2	0
Irrigated Small Grains	24.6	14.8	10.3	0.6	24.6	16.7	8.8	1	0	-1.9	1.5	-0.4
Range/Pasture/Grass (Brome, Hay, CRP)	14.7	14.8	0	0.2	17.8	16.8	0	0	-3.1	-2	0	0.2
Urban Land	35.4	14.8	0	0	34.2	16.8	0	0	1.2	-2	0	0
Open Water	31.9	14.8	0	0	30.4	16.8	0	0	1.5	-2	0	0
Riparian Forest and Woodlands	46.2	14.8	0	0	45.3	16.8	0	0	0.9	-2	0	0
Wetlands	53.6	14.8	0	0	51.9	16.8	0	0	1.7	-2	0	0
Other Agricultural Lands (Farmsteads, Feedlots, etc.)	14.7	14.8	0	0.3	16.2	16.8	0	0	-1.5	-2	0	0.3
Irrigated Sunflower	23.3	14.5	11.3	2.5	19.9	16.6	7.4	4.2	3.4	-2.1	3.9	-1.7
Summer Fallow	0	0	0	0	0	0	0	0	0	0	0	0
Roads	14.7	14.8	0	0.3	16.2	16.8	0	0	-1.5	-2	0	0.3
Dryland Corn	14.1	14.4	0	0.4	15.8	16.6	0	1.6	-1.7	-2.2	0	-1.2
Dryland Soybeans	13.3	14.4	0	1.3	15.3	16.6	0	0.5	-2	-2.2	0	0.8
Dryland Sorghum	13.9	14.5	0	0.6	15.7	16.6	0	0.4	-1.8	-2.1	0	0.2
Dryland Dry Edible Beans	13	14.4	0	1.5	14.4	16.6	0	2.7	-1.4	-2.2	0	-1.2
Dryland Alfalfa	14.9	14.8	0	0	16.9	16.8	0	0	-2	-2	0	0
Dryland Small Grains	12.3	14.6	0	2.3	10.6	16.5	0	8	1.7	-1.9	0	-5.7
Dryland Sunflower	13.7	14.4	0	0.7	14.6	16.6	0	2.7	-0.9	-2.2	0	-2
Dryland Sugar Beets	0	0	0	0	0	0	0	0	0	0	0	0
Dryland Potatoes	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated Hay	31.7	14.8	17.6	1	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
Irrigated Rotation Pasture	32.6	14.8	18.2	0.6	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
Average of All Values	21.99	13.07	5.95	0.97	20.85	14.76	3.73	1.33	0.36	-1.83	1.30	-0.35
Average of irrigated crops in the WMU only.	27.22	14.58	14.53	1.99	25.20	16.66	10.79	2.08	2.02	-2.08	3.74	-0.09

Green Cells represent crops commonly irrigated in the WMU.
Values taken from http://dnrmap2.dnr.state.ne.us/CIR/

TABLE C-5
COMPARISON OF AVERAGE (1950-2004) ACREAGE FOR THE USBR AND COHYST DATA SETS

District Name	USBR Acreage [1)]	COHYST Acreage [2)]
Alliance	6,197	2,862
Beerline	961	995
Belmont/Bridgeport	8,108	6,223
Blue Creek	2,865	94
Browns Creek	5,227	4,035
Castle Rock	6,244	4,950
Central	1,772	1,407
Chimney Rock	5,113	2,015
Empire	2,112	728
Enterprise	6,834	3,795
Farmers	61,114	46,979
Gering	12,286	9,483
Gering-Fort Laramie	52,422	43,884
Graf	795	145
Lisco	3,525	1,739
Midland-Overland	2,017	633
Minatare	9,174	4,798
Mitchell	12,588	9,472
Ninemile	6,098	2,884
Northport	14,105	11,211
Pathfinder	94,363	75,532
Shortline	2,828	1,002
Western	10,297	11,591
Winters Creek	5,676	3,564
Total	**332,721**	**250,021**

1) USBR acreage is based on USBR reported acreages for districts with USBR diversion records and NDNR water rights for those with NDNR diversion records. Filename: npdel-div.xls
2) COHYST acreage is based on estimate of acreage irrigated by surface water developed by COHYST personnel. Filename: Acres 1950-2005.zip

APPENDIX D

GROUND WATER PUMPING

GROUND WATER PUMPING

INTRODUCTION

Ground water pumping for irrigation represents an important component of the water budget in the North Platte River basin upstream of Lake McConaughy. Historically, surface water was the major source of water for irrigation of lands along the North Platte River. Significant well drilling for irrigation began around 1950 and ground water pumping for irrigation has continued to the present time. In some cases, wells are used to irrigate lands whose sole source of water for irrigation was ground water, which is referred to as "ground water only" pumping. In other cases, the wells are used to supplement irrigation supplies on lands historically supplied by surface water. This pumping is referred to as "supplemental pumping" serving lands that are also irrigated with surface water. These lands are also referred to as "comingled lands." In 2001, a moratorium was instituted by the North Platte Natural Resources District prohibiting further development of wells in the area along the North Platte River between the Nebraska-Wyoming state line and Lake McConaughy, designated by the NDNR as over-appropriated with respect to ground water.

There were several issues identified by the COHYST Technical Committee in their assessment of the WMU Model with respect to irrigation pumping and the manner in which it was represented in the model. For purposes of this report, the original WMU Model is the version documented in a report by Luckey and Cannia (2006). The original WMU Model overestimated ground water only irrigated land area and underestimated surface water irrigated land area (Bleed, 2008). COHYST has since revised their estimated distribution between ground water only irrigated lands and surface water lands, and developed revised estimates of ground water only irrigation pumping over the period from 1950 to 2005. These estimates are considered provisional, as they have not been formally reviewed nor have they been formally adopted by the COHYST group. However, these estimates appear to be reasonable and are believed to represent the best available estimates of irrigation pumping available at present. Further, the estimates of supplemental pumping agree well with independent estimates of supplemental pumping developed by LWS.

The original WMU Model also did not include any estimates of supplemental pumping. COHYST has since developed estimates for supplemental pumping. As with the estimates of pumping for ground water only irrigated lands, these estimates have not been formally adopted by the COHYST group. As such, they are considered to be provisional and subject to change.

Nonetheless, these estimates of supplemental pumping are believed to represent the best available estimates of supplemental pumping available at this time.

DISCUSSION

Irrigation pumping is typically expressed in one of two ways: as *total pumping* or as *net pumping*. Total pumping represents the full amount of water pumped from a well. A portion of that water is consumed through evapotranspiration, while the remaining portion becomes return flow. Net pumping represents only the portion of the total pumping that is consumed through evapotranspiration. Estimates of pumping supplied through the COHYST group represent net pumping amounts. As with the previous estimates of pumping, the current estimates are determined using CropSim (Luckey and Cannia, 2006). In the case of pumping for ground water only lands, the amount of pumping is estimated as that required for a full supply. In the case of supplemental pumping, the amount of pumping is estimated as that required for a full supply on areas that have wells in close proximity to the irrigated lands after first accounting for surface water deliveries.

The estimates of pumping that have been received from the COHYST group are based on a one square mile grid. This grid is coincident with the area used by both the WMU Model and the North Platte Depletions Model being developed by LWS as part of this work. However, the model cells themselves are 1/4 square mile in area. Therefore, it is necessary to distribute the pumping estimates from the one-mile grid to a 1/4 square mile area. This was done using a program called "Split Pump" that was developed by, and is available through, COHYST.

SUMMARY

Revised estimates of net pumping for irrigation of ground water only lands for the period 1950 through 2005 were provided through the COHYST group and were incorporated in the North Platte Depletions Model. Supplemental pumping was not included in the original WMU Model. However, estimates of supplemental pumping for the period 1950 through 2005 were subsequently provided through the COHYST group and have been incorporated into the North Platte Depletions Model.

APPENDIX E

RECHARGE FROM PRECIPITATION

RECHARGE FROM PRECIPITATION

INTRODUCTION

A portion of the precipitation falling in the basin infiltrates the ground surface and percolates to the water table, resulting in recharge to the ground water system. The WMU Model assigned values for recharge from precipitation based on soil types and topography (Luckey and Cannia, 2006). These values ranged from 0.15 inches per year (in/yr) to 2.30 in/yr. A majority of the area contributing both surface runoff and recharge to ground water in the WMU Model was assigned a value of 0.18 in/yr. According to the WMU Model documentation, these recharge rates provided "[t]he best fit between simulated and observed water levels and ground water discharge to streams" during calibration of the pre-ground water development model (Luckey and Cannia, 2006). We have completed an analysis of these values to assess whether they are representative.

DISCUSSION

There were two issues identified during the course of a review of the WMU Model suggesting that recharge from precipitation may have been underestimated.

First, calibration of the development period WMU Model required an additional amount of recharge on dryland and irrigated land ("recharge bump") to achieve reasonable agreement between predicted and observed water levels throughout much of the model area. The recharge bump entailed adding recharge in areas that were converted from rangeland to cultivated land during the development period. While invoking an adjustment such as this is not unprecedented (a similar adjustment was employed in a model of the Republican River Basin (McKusick, 2003)), the magnitude of the adjustment in the WMU Model appeared to be abnormally high (e.g., an increase of up to 4.6 inches per year was added in some portions of the model). The need for such an adjustment, particularly of the magnitude employed in the WMU Model, suggested the possibility that recharge may have been underestimated in the original configuration of the model.

Second, in the course of assembling a basin-wide preliminary water budget for the development period (1950 - 2004) , use of the original recharge value assigned over much of the WMU Model (0.18 in/yr) resulted in an imbalance in the development period water budget when combined with estimates of the remaining terms of the water budget.

The estimated water budget for the development period reflects estimated inflow and outflow terms for the *contributing* portion of the modeled area, defined herein as the area contributing either surface runoff, ground water recharge, or both, to the North Platte River mainstem area. For example, the water budget does not reflect water conditions in portions of Box Butte County, as this area does not contribute or interact in any significant way with water conditions in the mainstem area.

SUMMARY

The estimated water budget for the contributing area within the WMU Model area combined with testing over a range of plausible recharge values during the model calibration process suggested a value of 0.44 in/yr for deep percolation, or about 2.6 percent of total rainfall. This value is higher than the value assigned over most of the WMU Model domain (0.18 in/yr), consistent with earlier conclusions that recharge was underestimated. This value has been incorporated into the North Platte Depletions Model.

APPENDIX F
STREAM PACKAGE TO MODEL THE NORTH PLATTE RIVER

STREAM PACKAGE TO MODEL THE NORTH PLATTE RIVER

INTRODUCTION

One of the primary goals of the North Platte Depletions Model is to accurately account for flows and changes in flows with time in the North Platte River between the Wyoming state line and Lewellen. In the WMU Model, the North Platte and South Platte Rivers are represented using the river package and tributaries are represented using the stream package. The river package in the WMU Model does not vary river stage with time and also does not track the amount of total flow in the North Platte River. Since flows in the North Platte River fluctuate greatly (both temporally and spatially) based on irrigation practices and climatic variation, it will improve the reliability of the model to predict river flows if the model has the ability to account for the dynamics of the North Platte River. The stream package has the ability to track the amount of flow in the stream, calculate the stream stage based on the parameters of the stream and stream discharge, and is capable of modeling the variation in flow and stage and allows for calibration to observed stream flows. Therefore, the river package was replaced with the stream package in the North Platte Depletions Model for the North and South Platte Rivers.

APPROACH

Many of the parameters in the stream package for both the North and South Platte Rivers were adopted from the river package, however, additional inputs that are required by the stream package (and not defined in the river package) were estimated and are described herein. The elevation of the streambed and the conductance of the streambed were unchanged from the WMU Model. The elevations of the streambed were estimated at points from 1:24,000 scale topographic maps where 100-ft contours crossed the streams, and Ground Water Modeling System (GMS) software performed linear interpolations between points (Luckey and Cannia, 2006). In the river package, the width of the river is carried in the conductance term. The WMU Model used a stream "conductance" (defined in Luckey and Cannia, 2006, as a term that accounts for the hydraulic conductivity, streambed thickness, and stream width) of 22.5 feet per day (ft/day) per unit length. The value of conductance was unchanged, however, the terms comprising the conductance needed to be estimated to accommodate inputs required by the stream package.

In the stream package, the stream widths have to be defined because the stream stage is calculated based on the width of the stream. For the North Platte River in the North Platte Depletions Model, a width of 265 ft was used. This width was estimated from aerial photography using a mean of widths of the North Platte River at the gages at the Wyoming-line, Mitchell, Minatare, Bridgeport, Lisco, and Lewellen. Using a streambed thickness of 1 ft, a width of 265 ft, and a streambed conductance of 22.5 ft/day, the initial vertical hydraulic conductivity is calculated as 0.085 ft/day.

The stream package tracks the total amount of flow in the North Platte River. This includes diversion segments identifying areas where there are canal diversions, and a specified flow entering the North Platte River at the Wyoming state line. These flows were included in the stream package. A specified flow was input at the upstream end of the North Platte River, where the North Platte River crosses the Wyoming line, and values were set based on the Wyoming-line gage. All measured diversions and spills from tributaries were also included in the North Platte Depletions Model (Table F-1). For the pre-development model, an average of measured diversions from 1946 to 1950 was used. For canals that do not have records from 1946 to 1950, but were known to divert during that time period, an average of the available record was used (Table F-1). For the development period in the North Platte Depletions Model, only recorded diversions were used. Records for all the major canals were complete for the development period. Records for some of the smaller canals were incomplete prior to about 1960 but complete thereafter. Because the diversions were considered to be small relative to the total water balance in the system, available records were considered representative.

The stream package used to simulate the North Platte River is limited in the way in which it is able to simulate diversions from the river. Diversions are typically specified at various locations along the river. Where there is sufficient flow in the river (as determined by the stream package) the diversion is made, and the flow is adjusted accordingly. Where the flow is less than the specified diversion, no diversion takes place. The effects of this are minor, but may be seen in some of the forecasting model run results. This type of model behavior is more likely to occur when simulating future conditions where depletions are increased and available flows reduced over those predicted historically.

Recent improvements to the stream package have modified this methodology, such that a diversion would still occur, up to the amount of flow in the river. Incorporating this new package would require significant changes to model input files. Because the effects of this limitation are minor, no attempt was made to incorporate the newer package.

SUMMARY

Using the stream package to model flows in the North Platte River (in the North Platte Depletions Model) has advantages over using the river package to model flows in the North Platte River (as used in the WMU Model). Those refinements include calibration to observed flows, and the ability to model the dynamics of North Platte River stage and flows. All of these refinements are important to include when predicting the reduction in surface water flows due to ground water pumping.

TABLE F-1
DIVERSION AMOUNTS

Name of Diversion Structure	Pre-Ground Water Development Period Diverted Amount (ac-ft/yr)	Development Period Diverted Amount (ac-ft/yr)
Alliance from Bayard Creek	4,198	6,459
Alliance from Red Willow Creek	8,910	10,442
Beerline from North Platte River	1,575	2,072
Bellmont Spill into Pumpkinseed Creek (1)(2)	2,246	2,246
Belmont from North Platte River	23,833	28,776
Blue Creek From Blue Creek and Crescent Lake	7,408	7,052
Browns from North Platte River	8,775	13,511
Castle Rock from North Platte River	18,831	20,540
Central from North Platte River	4,759	5,482
Chimney Rock from North Platte River	11,113	15,090
Court House from Pumpkin Creek	3,925	2,185
Empire from North Platte River (1)(2)	5,155	5,155
Enterprise from Dry Spotted Tail (1)(2)	1,254	1,254
Enterprise from North Platte River	12,311	20,679
Enterprise from Tub Springs Creek	5,318	2,202
Enterprise from Winters Creek (1)(2)	372	372
Farmers from Alliance Creek (1)(2)	816	816
Farmers from Dry Spotted Creek (1)(2)	3,472	3,472
Farmers from North Platte River	190,502	194,312
Farmers from Sheep Creek (1)(2)	17,670	17,670
Farmers from Tub Springs (1)(2)	6,663	6,663
Graf from Blue Creek	3,767	2,309
Hooper from Blue Creek	3,048	2,412
Last Chance from Pumpkin Creek	1,405	864
Lisco from North Platte River	4,899	8,542
Meridith-Ammer from Pumpkin Creek	1,077	807
Midland-Overland from North Platte River	2,204	1,959
Minatare from North Platte River	14,176	18,923
Ninemile from Ninemile Drain (3)	15,988	11,387
Ninemile from North Platte River	16,525	14,055
Paisley from Blue Creek	2,732	3,009
Ramshorn from North Platte River	2,857	2,173
Shortline from North Platte River	3,421	6,887
Union from Blue Creek	2,181	2,403
Western from South Platte River	27,692	25,393
Winters Creek Canal from Winters Creek	10,115	8,868
Winters Creek Factory Lateral from Winters Creek	2,558	1,469
Winters Creek from North Platte River	5,002	5,102

(1) No data for 1946 – 1950, available record data used.

(2) Entire period of record (1950 - 2004) unavailable, available records used.

(3) Partial record (1947-1950) available.

APPENDIX G
CALIBRATION RESULTS

CALIBRATION RESULTS

INTRODUCTION

Since one of the primary goal of the North Platte Depletions Model is to evaluate sources of impacts on surface water flows, it is important to develop and calibrate the North Platte Depletions Model to flows in the North Platte River. Alluvial ground water pumping is likely a significant contributor to diminished surface water flows. In the development period of the WMU Model, where significant growth in ground water irrigation has occurred, a quantitative base flow (surface water gains from ground water sources) calibration was not performed (Lucky and Cannia, 2006). Without base flow calibration, the WMU Model's reliability to predict changes in base flow is limited. Moreover, the impact of well pumping on flow in the North Platte River may not be limited to base flow, but may also extend to flows associated with storm runoff.

A significant change from the WMU Model to the North Platte Depletions Model is the calibration to observed flows in the North Platte River. In the pre-ground water development period and development period of the North Platte Depletions Model, the primary calibration targets were both North Platte River flows and tributary flows to the North Platte River. Secondarily, calibration to alluvial ground water levels in both periods of the North Platte Depletions Model was performed.

APPROACH

Stream gages for the North Platte River and its tributaries (operated by both the USGS and the NDNR) were used for calibration targets. There are five gages located along the North Platte River that were used for calibration, the Mitchell, Minatare, Bridgeport, Lisco, and Lewellen gages. Ten tributaries (Sheep Creek, Horse Creek, Dry Spotted Tail Creek, Tub Springs Drain, Winters Creek, Ninemile Creek, Bayard Drain, Pumpkin Creek, Blue Creek, and Red Willow Creek) in the North Platte Depletions Model were calibrated to observed flows. In the pre-ground water development period North Platte Depletions Model, averages of flows at the above-named gages from 1946 to 1950 were used as calibration targets (Table G-1). For the development period North Platte Depletions Model, observed flows were averaged over irrigation and non-irrigation season stress periods and varied by year. Calibration to water levels in USGS monitoring wells was limited because of the limited number of available wells having an extended record of water level measurements.

SUMMARY

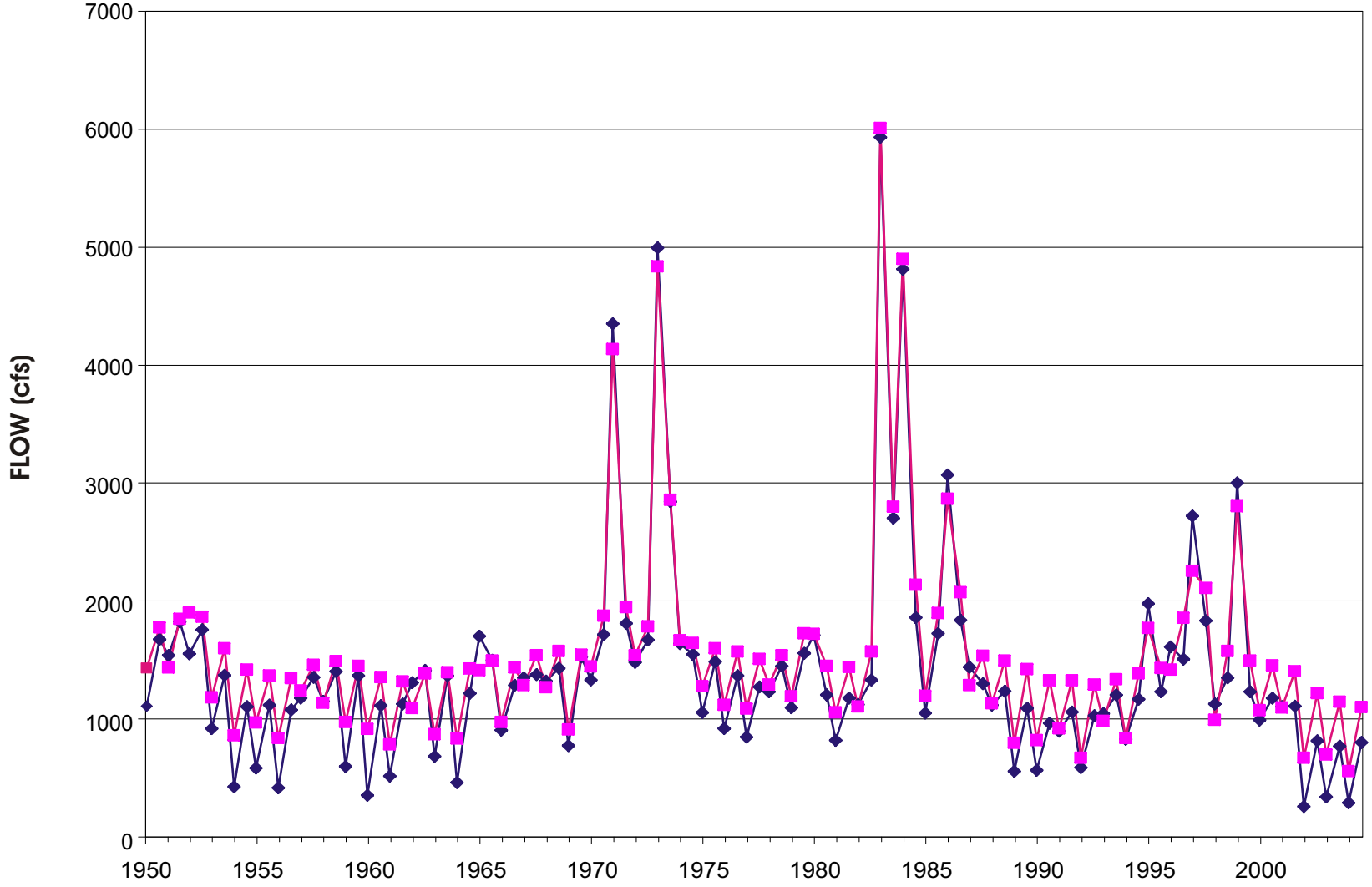
Calibration of North Platte River flows and flows of tributaries to the North Platte River during the development period of the North Platte Depletions Model provided good correlation to observed flows. For example, hydrographs of flows predicted by the North Platte Depletions Model at the Lewellen gage are in excellent agreement with observed flows at this location (Figure G-1). Model predictions at the other mainstem gages are also in reasonable agreement with observed flows (Figures G-2 thru G-5). Flows for tributaries to the North Platte River match reasonably well to observed flows (Figures G-6 thru G-16). In general, both seasonal and long-term trends are reflected in the model predictions. Where the model predictions differ from observed flows, these differences are generally less than 50 cfs (e.g., Red Willow Creek gage, Figure G-14). Given the complexity of the delivery and drain systems, the multiple cross-connections which exist, and the many places where there are opportunities to spill water from one canal/tributary/drain to another, calibration of the tributaries is considered reasonable. Observed flows at the Lewellen gage were plotted versus the North Platte Depletions Model simulated flows to show if there is a bias in the simulated flows (Figure G-17). Linear correlation with an R-squared of 0.93 and a slope of 1.04 suggests that the North Platte Depletions Model simulated flows are not biased relative to observed flows.

Simulated water levels are also in good agreement overall with observed water levels. The locations of water level targets in the pre-ground water development and development period models are shown in Figure G-18 and G-19, respectively. A scatter plot (Figure G-20) of observed water levels versus simulated water levels for the pre-ground water development period shows no bias in simulated water levels. The linear correlation of these data show excellent correlation (0.99) and the slope of the line (0.99) suggests no bias in the observed versus the simulated water levels. For the development period model, time series of simulated and observed water levels are shown in Figures G-21 through G-25. In general, model-predicted water levels are in good agreement with observed water levels. Differences are typically less than 10 feet, with the exception of Well No. 420355102564001 (Figure G-24). At this location, water levels differ by 20 to 25 feet. These differences could be related to the well's proximity to pumping wells, the depth to which the well was drilled, the well's construction, or other factors. Resolving these differences would require additional investigation of these factors.

The simulated water level surface at the end of water year 2004 is shown in Figure G-26. The shape of this surface is consistent with the conceptual model of the North Platte River Basin. Ground water gradients are generally toward the river and to the east, in the direction of Lake McConaughy. In light of these calibration conditions, the model is considered to be well calibrated.

The calibrated model contains several cells that dry out during the simulation. Many of these cells lie along the margins of the North Platte River mainstem area where the aquifer thins to a few feet in saturated thickness. In these instances, the emergence of dry cells during a simulation is not unexpected, nor does this have a significant effect on simulation results. There are other areas, such as in the Pumpkin Creek Basin, where cells dry up in the course of a simulation. In some cases, this condition has been traced to the fact that the aquifer is thin at these locations, and that as dewatering associated with pumping progresses, the model cell is unable to sustain continued extraction of water. As in the case of the mainstem cells, these occurrences do not significantly affect the model's predictions of changes to North Platte River flow related to pumping.

LYTLE WATER SOLUTIONS, LLC



LEGEND

OBSERVED

SIMULATED

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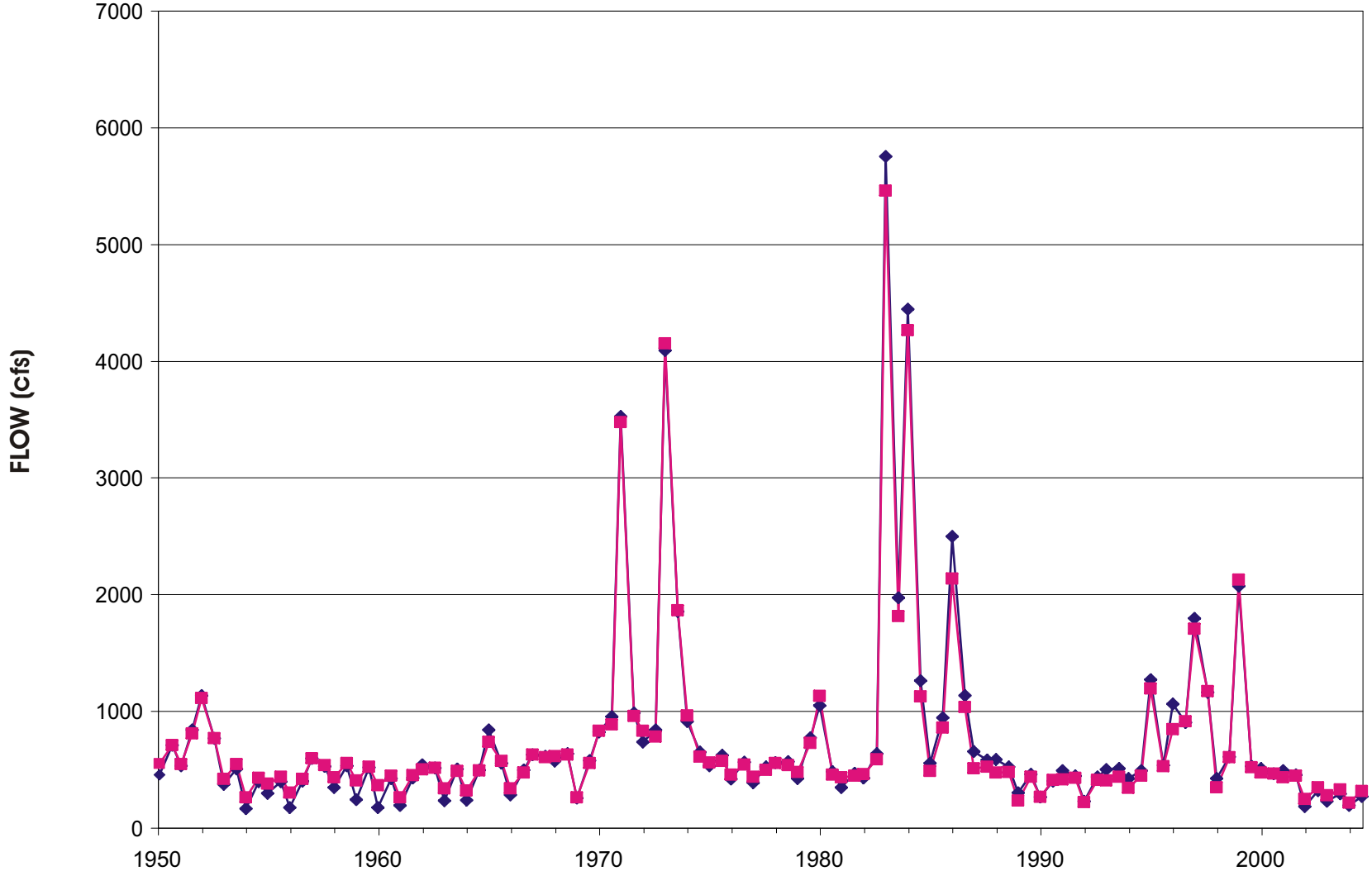
NORTH PLATTE AT LEWELLEN GAGE		
File Name: NoPlatte@Lew.cdr		Date: 05/12/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-1

LYTLE WATER SOLUTIONS, LLC



LEGEND

OBSERVED

SIMULATED

CENTRAL NEBRASKA PPID		
NORTH PLATTE AT MITCHELL GAGE		
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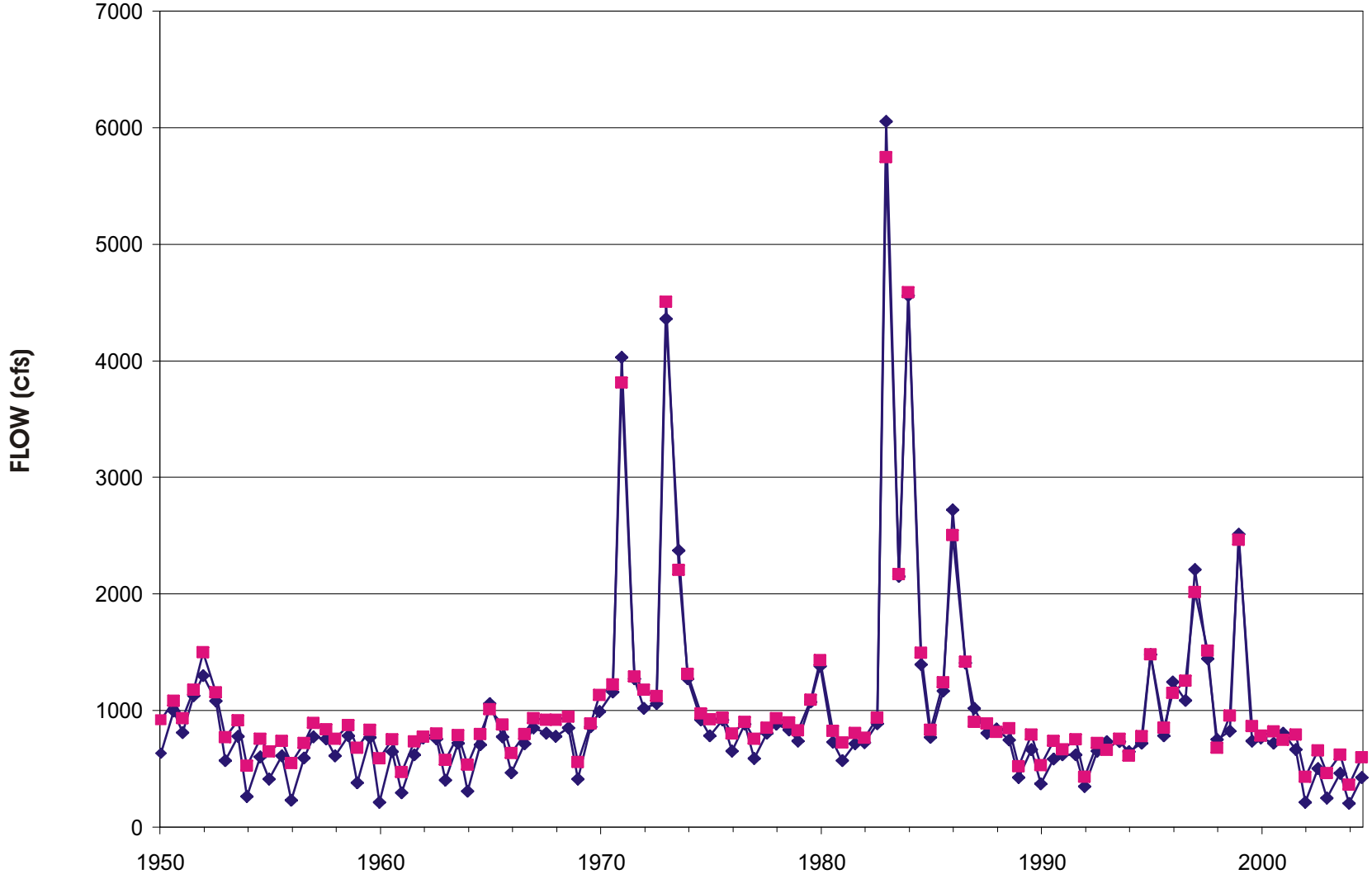
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-2

LYTLE WATER SOLUTIONS, LLC



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OBSERVED

SIMULATED

CENTRAL NEBRASKA PPID		
NORTH PLATTE AT MINATARE GAGE		
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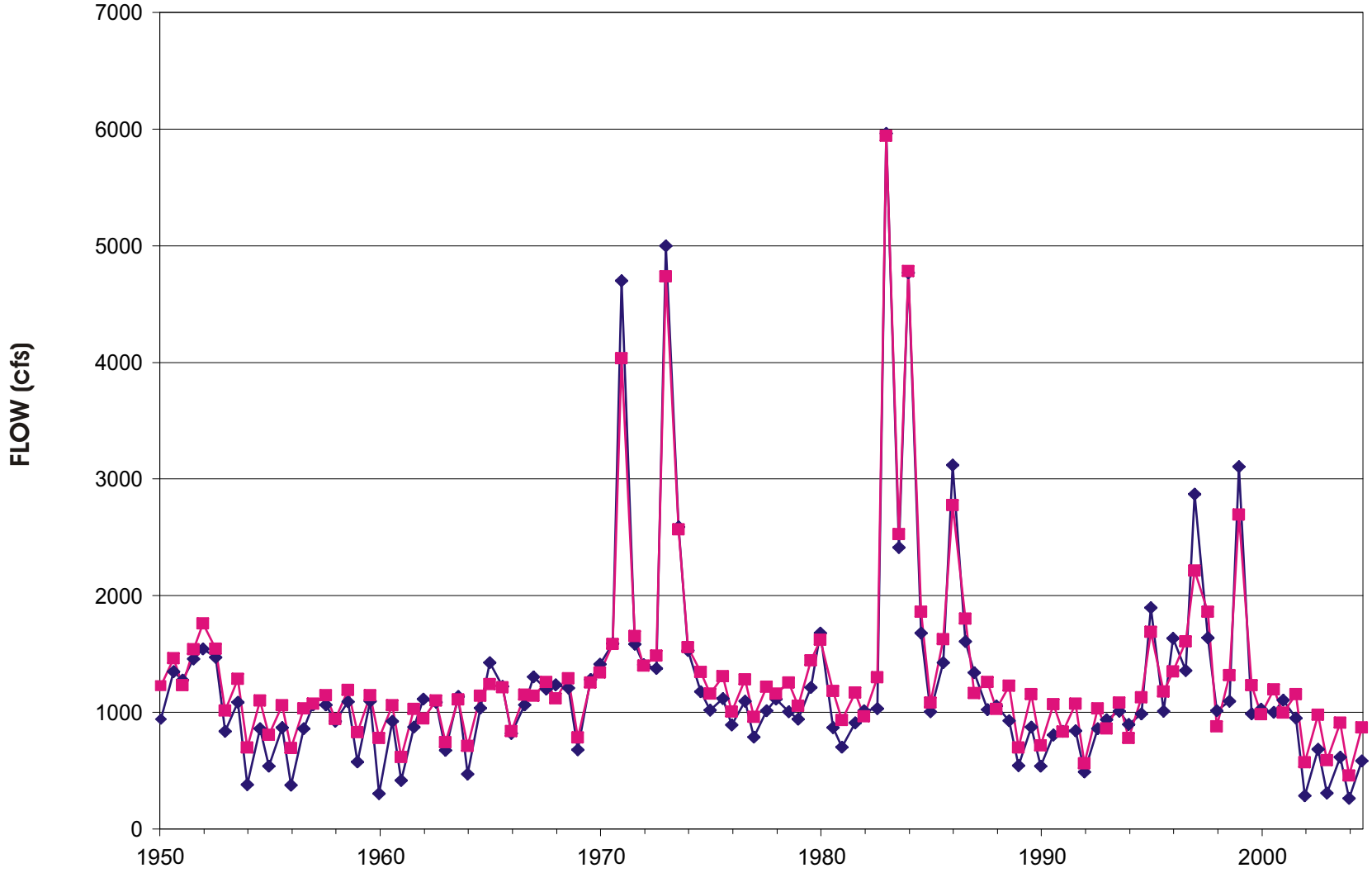
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-3

LYTLE WATER SOLUTIONS, LLC



LEGEND

OBSERVED

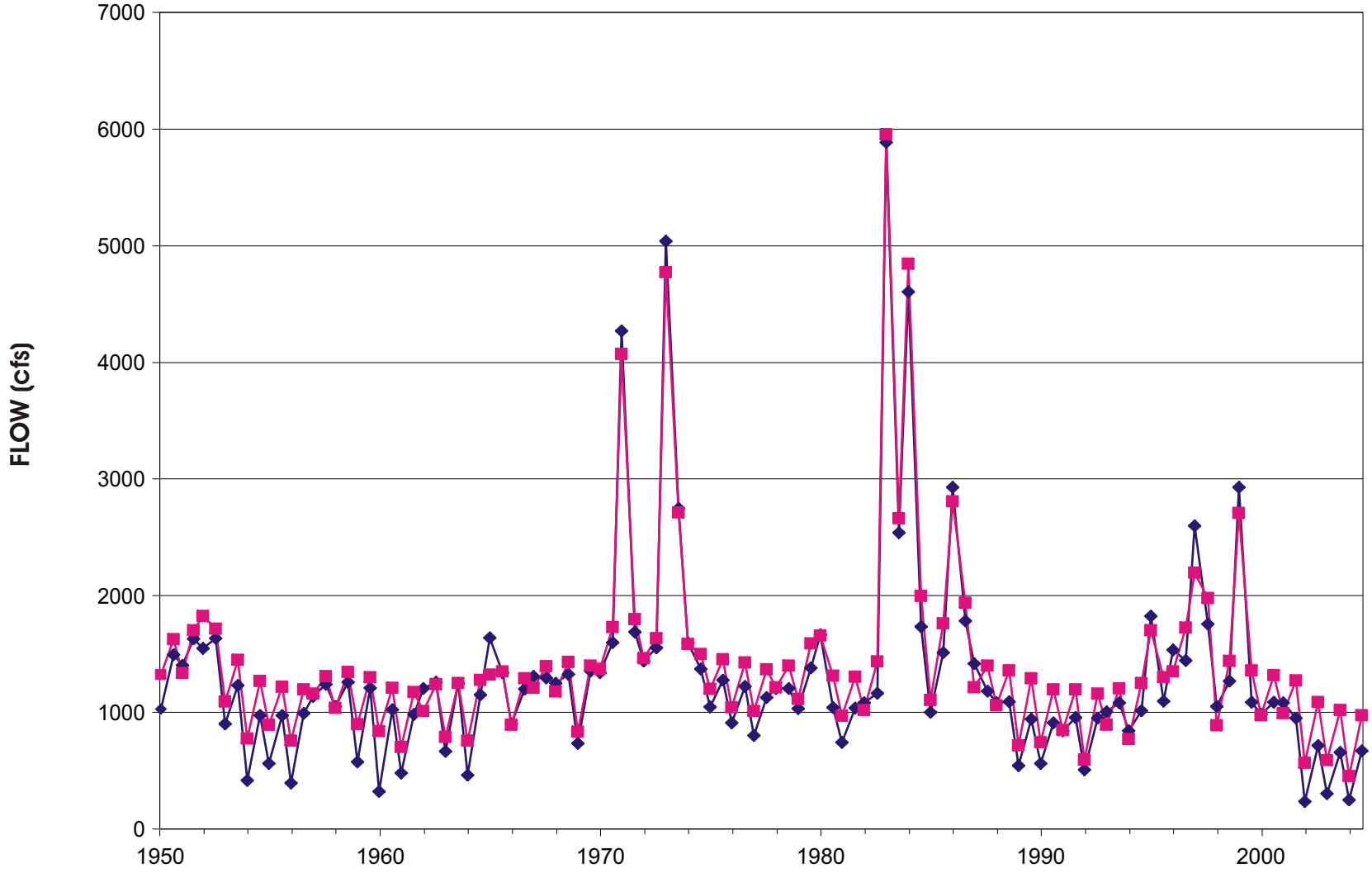
SIMULATED

CENTRAL NEBRASKA PPID

NORTH PLATTE AT BRIDGEPORT GAGE

File Name: NoPlatte@BridgeGage.cdr		Date: 05/12/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-4

LYTLE WATER SOLUTIONS, LLC



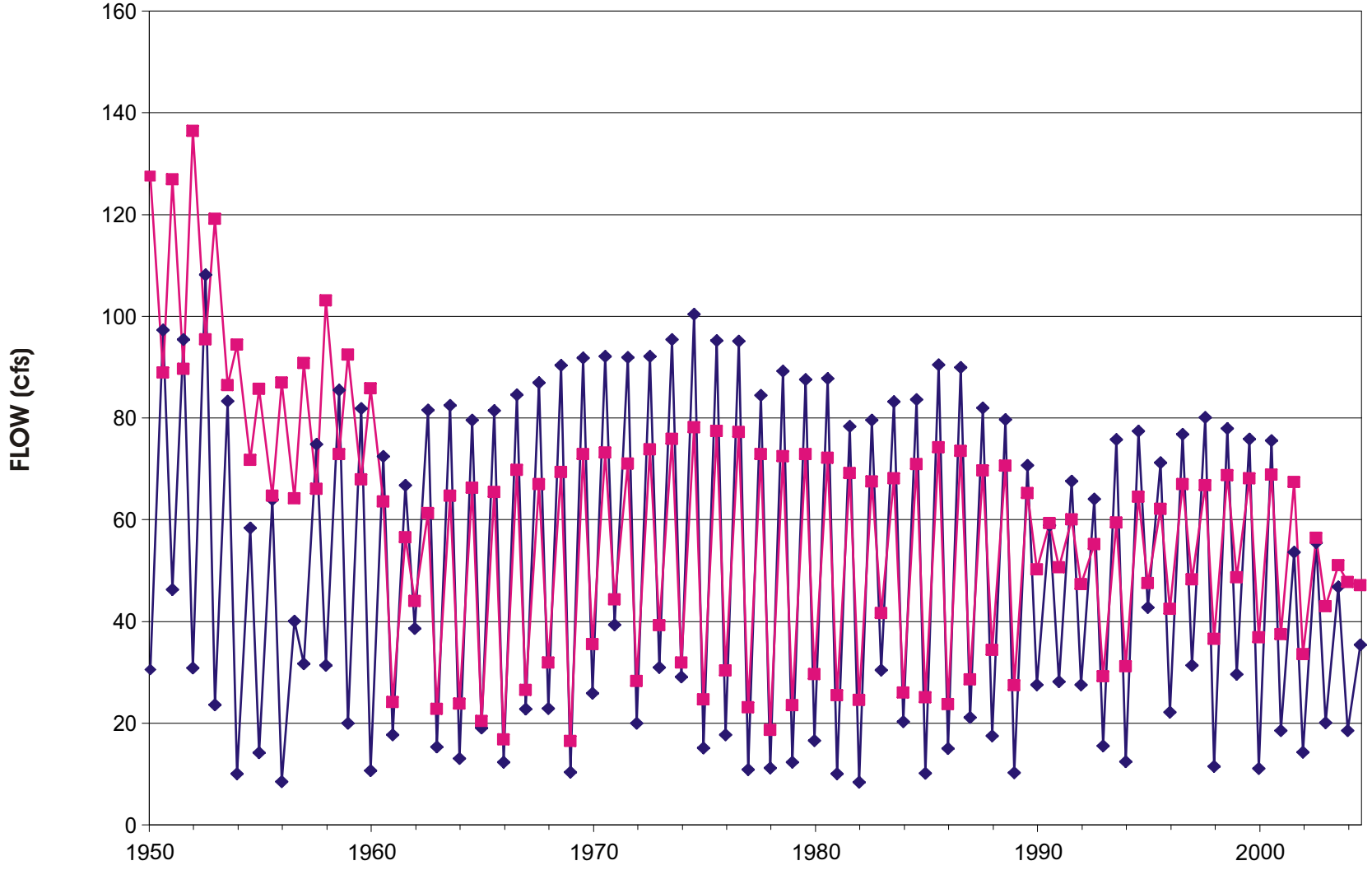
LEGEND

OBSERVED

SIMULATED

CENTRAL NEBRASKA PPID		
NORTH PLATTE AT LISCO GAGE		
File Name: NoPlatte@LiscoGage.cdr		Date: 05/12/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-5

LYTLE WATER SOLUTIONS, LLC



LEGEND

OBSERVED

SIMULATED

CENTRAL NEBRASKA PPID		
SHEEP CREEK GAGE		
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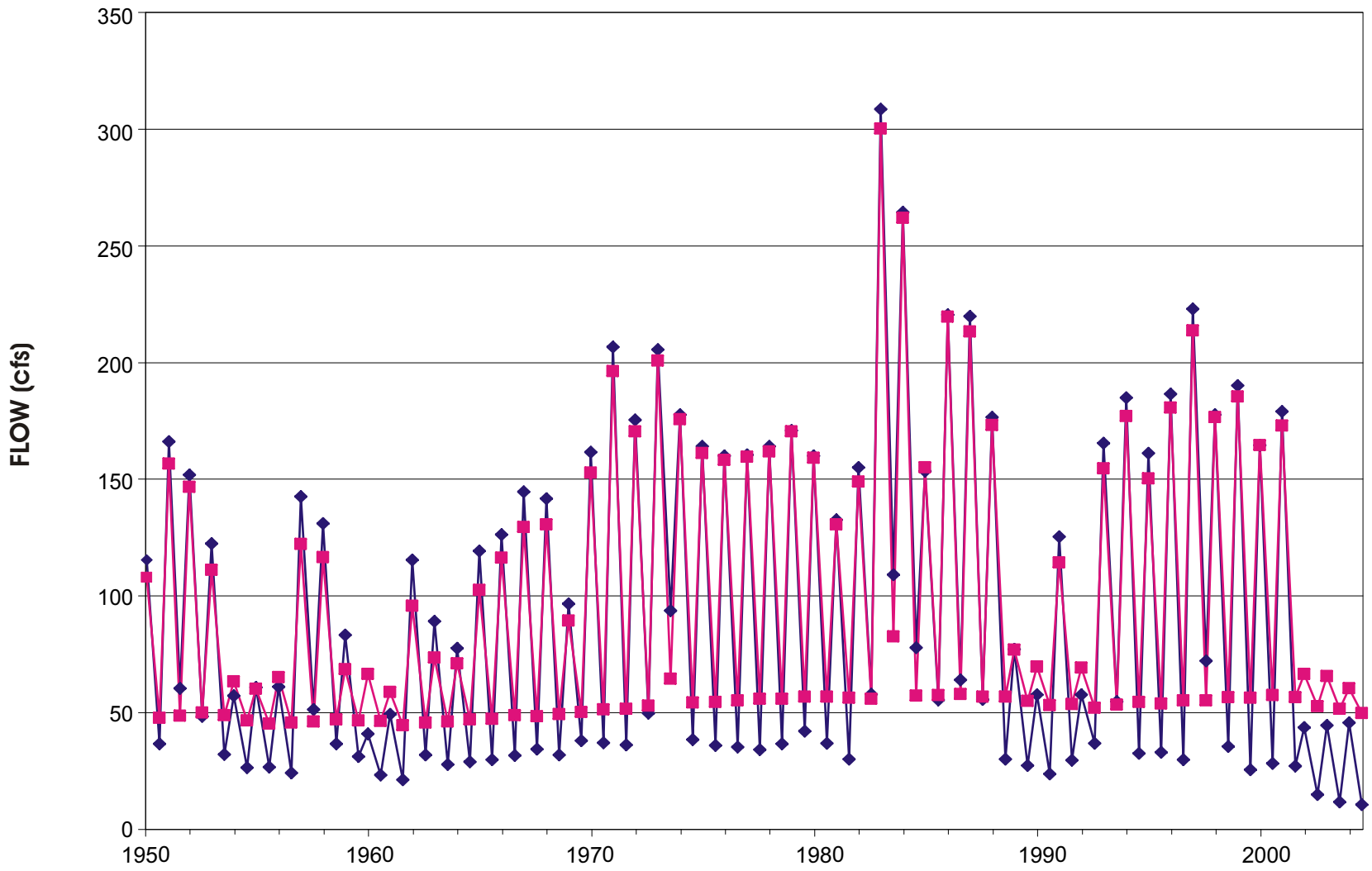
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-6

LYTLE WATER SOLUTIONS, LLC



LEGEND

OBSERVED

SIMULATED

CENTRAL NEBRASKA PPID		
HORSE CREEK GAGE		
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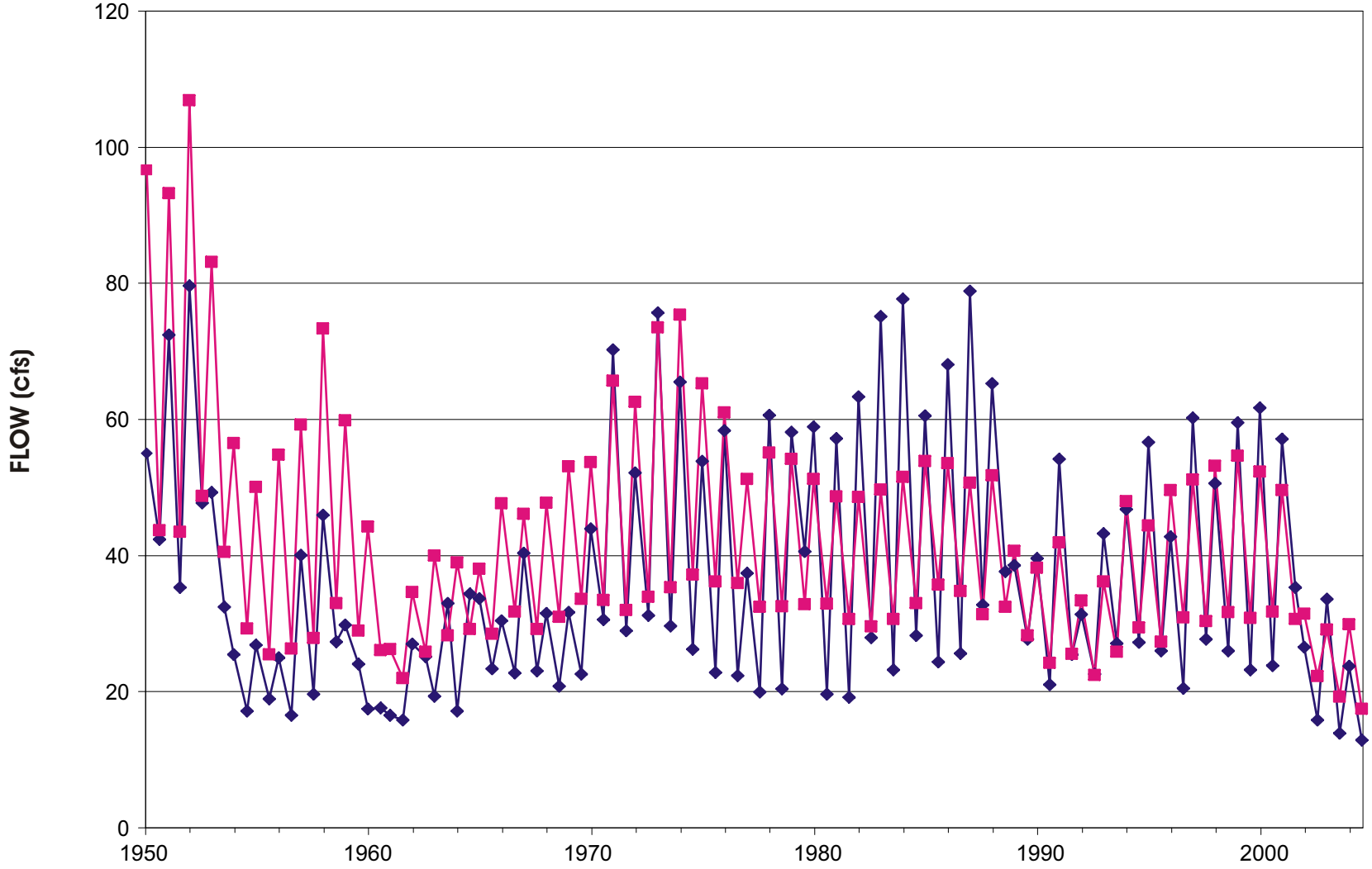
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-7

LYTLE WATER SOLUTIONS, LLC



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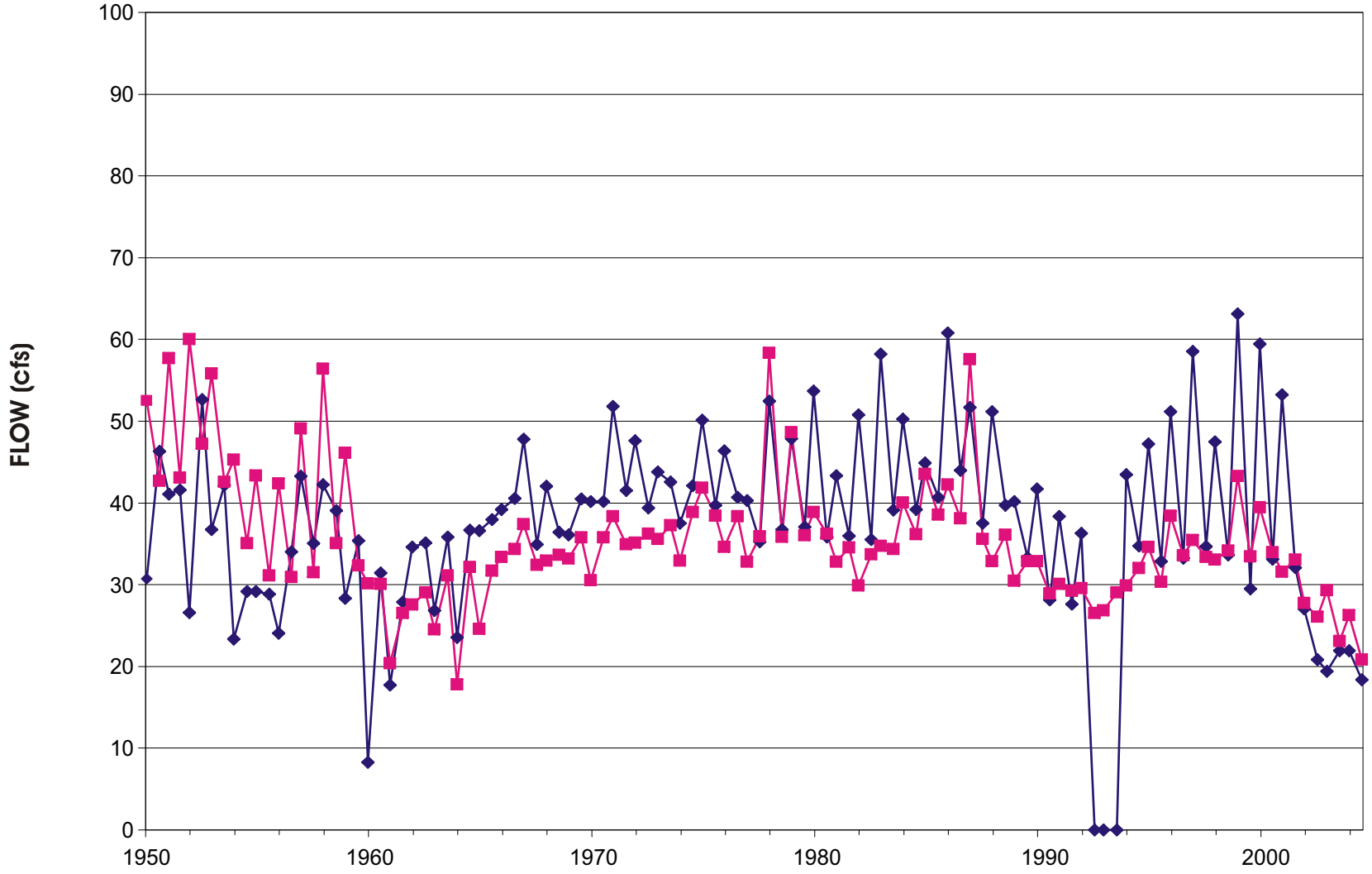
OBSERVED

SIMULATED

CENTRAL NEBRASKA PPID		
DRY SPOTTED TAIL CREEK GAGE		
File Name: DrySpottedTailCrGage.cdr		Date: 05/12/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-8

LYTLE WATER SOLUTIONS, LLC



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OBSERVED

SIMULATED

CENTRAL NEBRASKA PPID		
TUB SPRINGS DRAIN GAGE		
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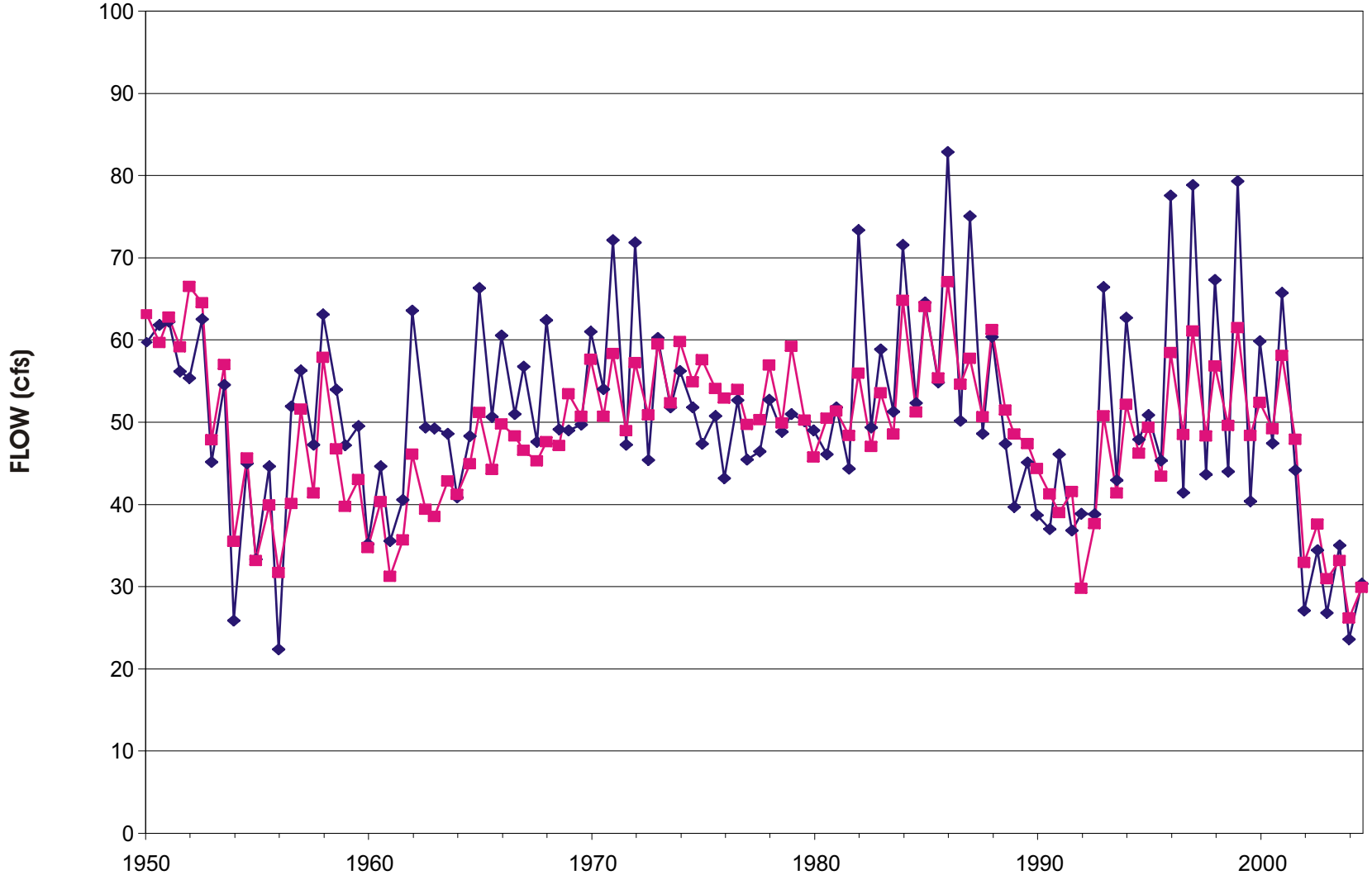
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-9

LYTLE WATER SOLUTIONS, LLC



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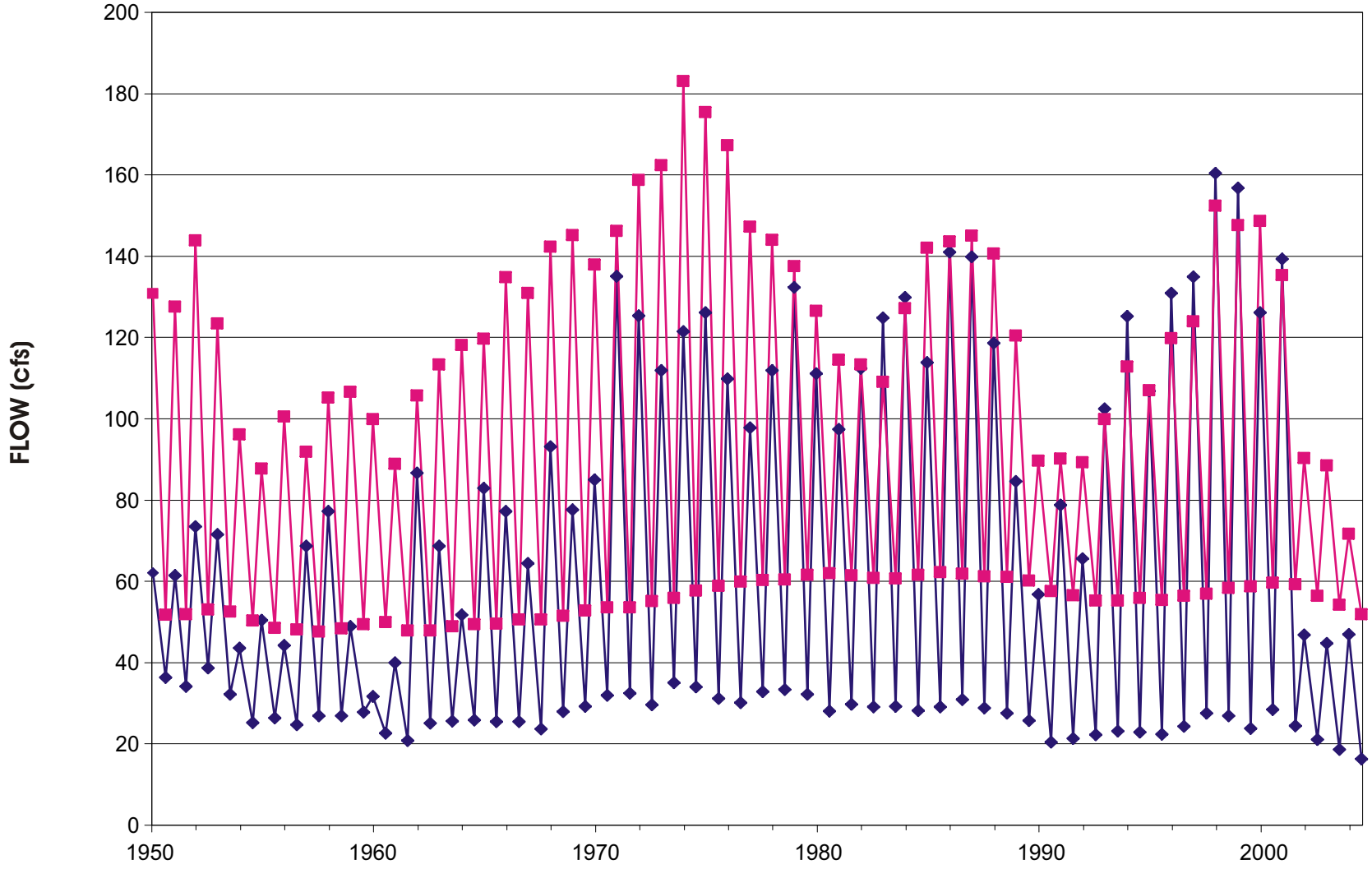
OBSERVED

SIMULATED

CENTRAL NEBRASKA PPID		
WINTERS GAGE		
File Name: WintersGage.cdr		Date: 05/12/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-10

LYTLE WATER SOLUTIONS, LLC



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SIMULATED

CENTRAL NEBRASKA PPID		
GERING DRAIN GAGE		
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Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-11

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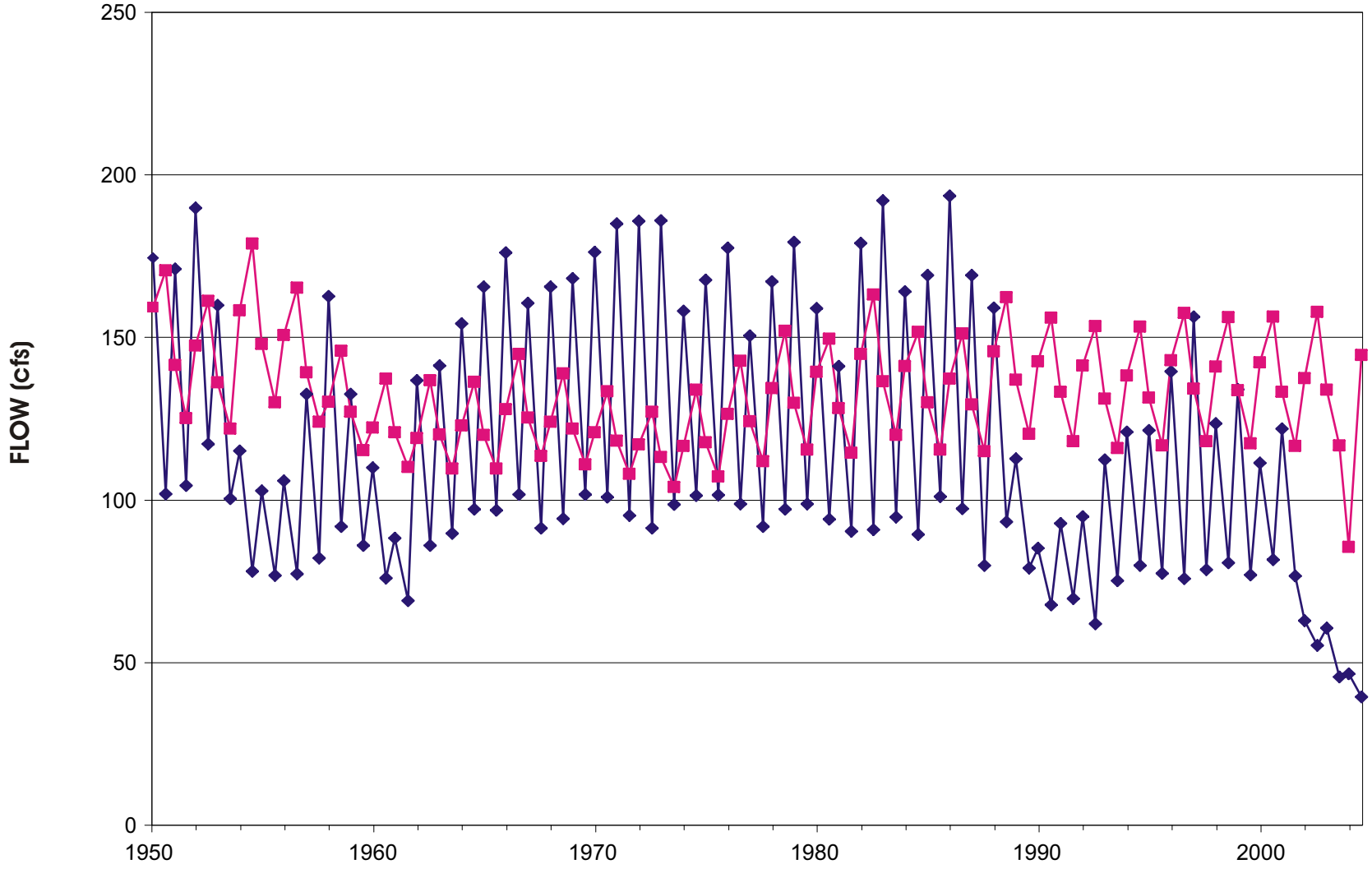

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SIMULATED

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NINEMILE DRAIN GAGE		
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Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-12

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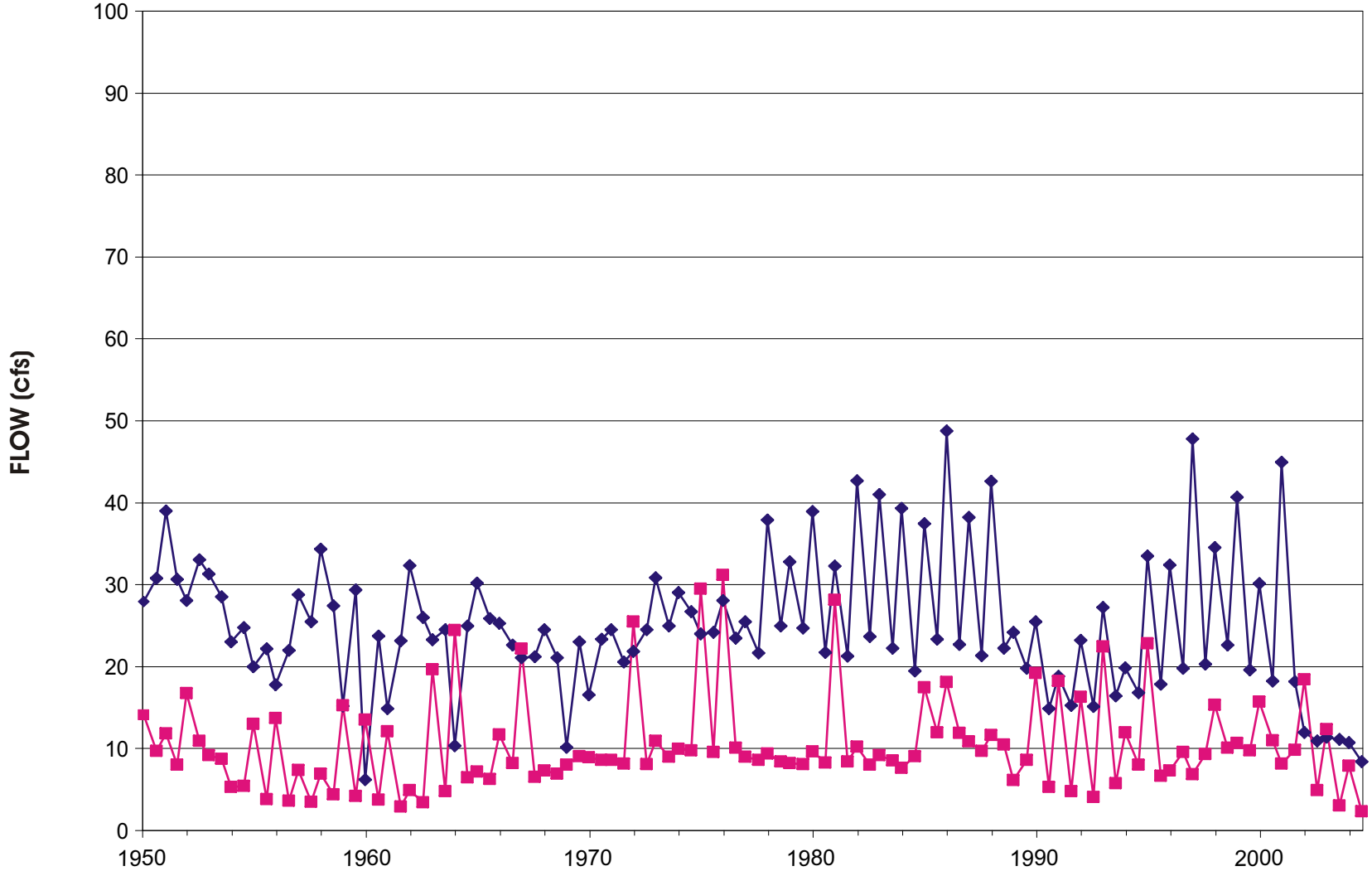

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CENTRAL NEBRASKA PPID		
BAYARD CREEK GAGE		
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Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-13

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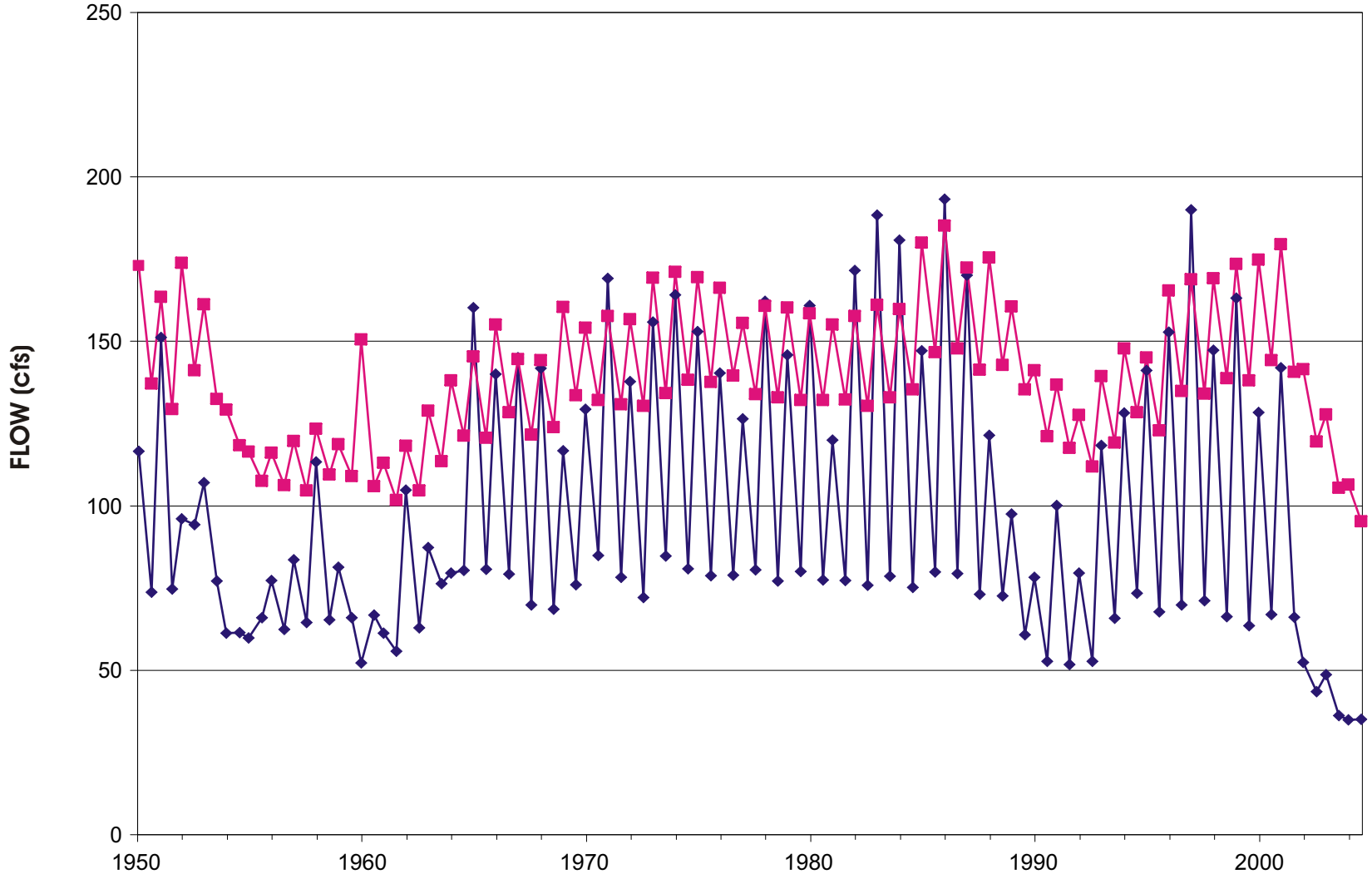

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SIMULATED

CENTRAL NEBRASKA PPID		
RED WILLOW CREEK GAGE		
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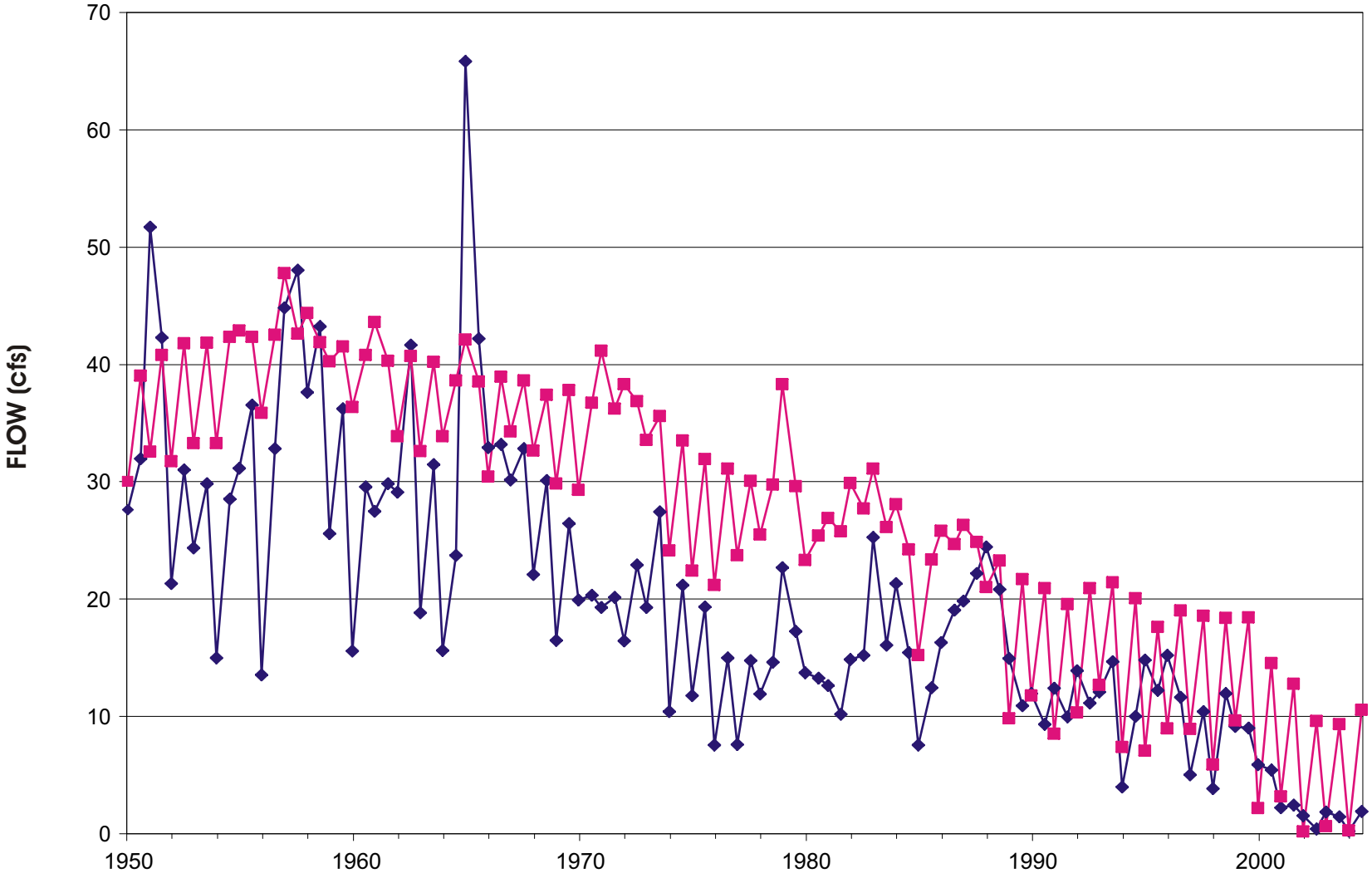
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-14

LYTLE WATER SOLUTIONS, LLC



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SIMULATED

CENTRAL NEBRASKA PPID		
PUMPKIN CREEK GAGE		
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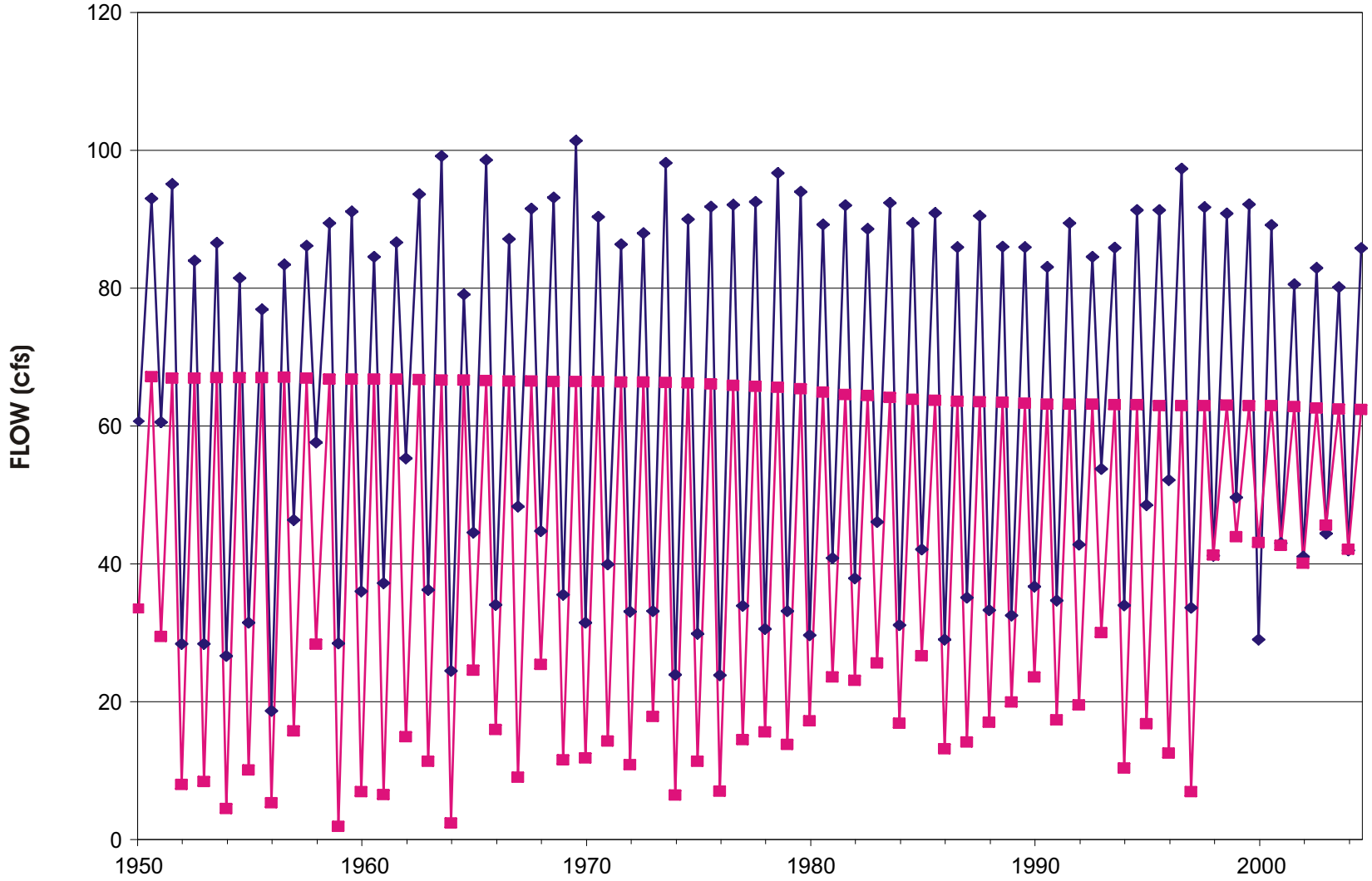
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-15

LYTLE WATER SOLUTIONS, LLC



LEGEND

OBSERVED

SIMULATED

CENTRAL NEBRASKA PPID		
BLUE GAGE		
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Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-16

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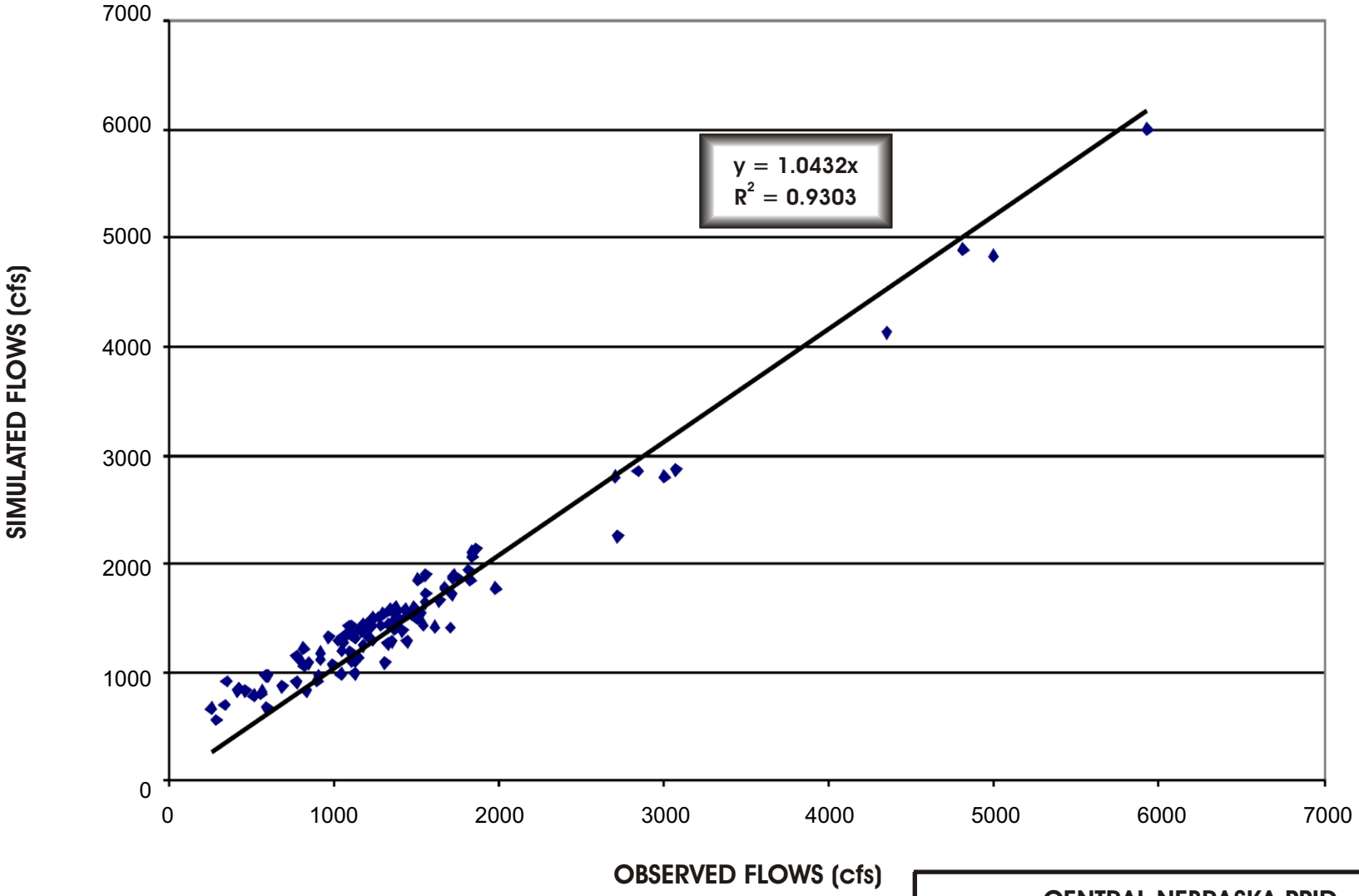


CENTRAL NEBRASKA PPID

SIMULATED VS OBSERVED FLOWS AT LEWELLEN

File Name: ObSimLew.cdr		Date: 05/12/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-17

LYTLE WATER SOLUTIONS, LLC

LEGEND

- PRE-GROUND WATER DEVELOPMENT TARGETS
- STREAMS
- ACTIVE CELL OUTLINE
- MODEL DOMAIN OUTLINE

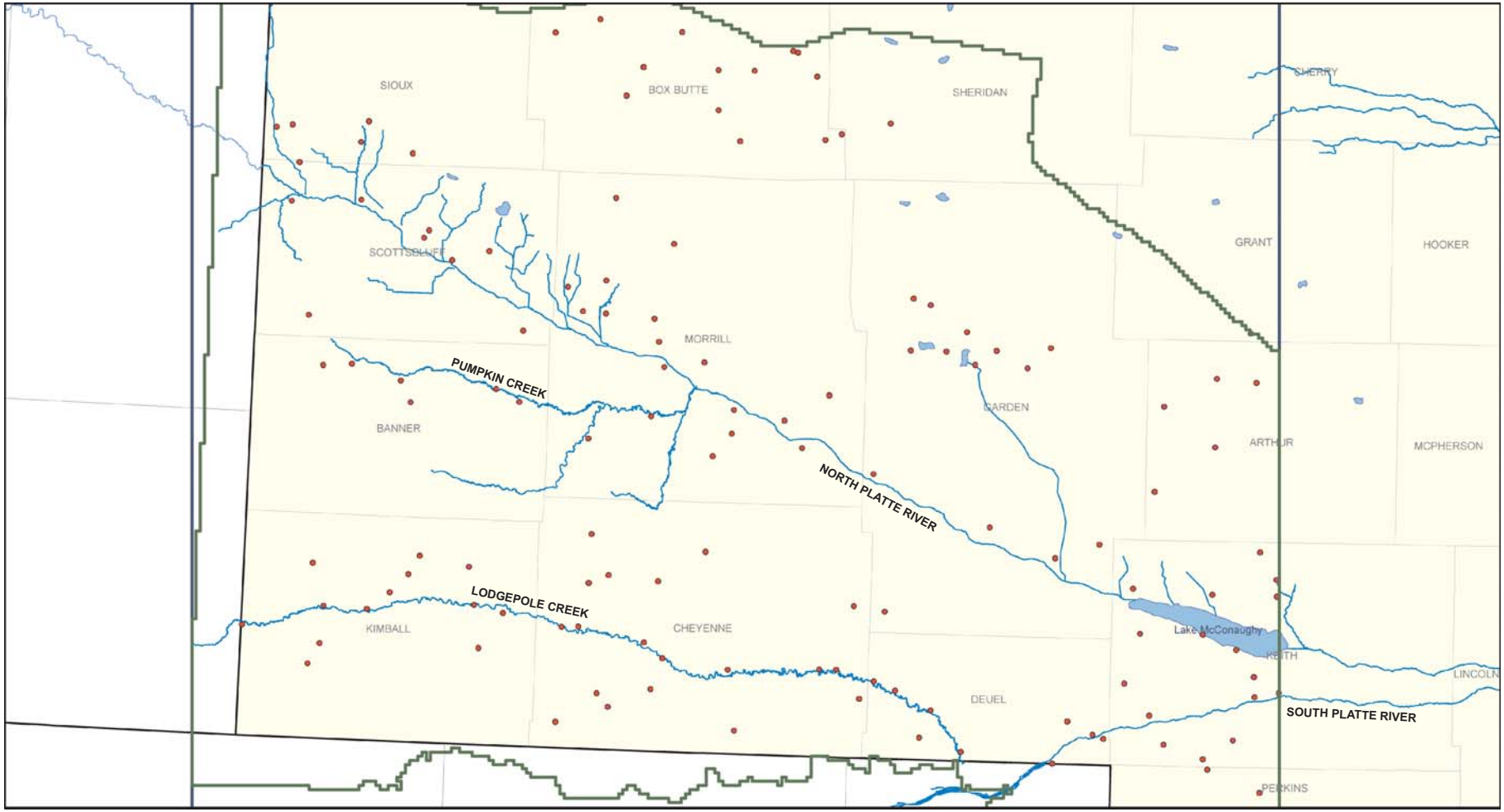
Notes:
1) Vertical Datum: NGVD 1929.
2) See Figure 1 for Model Domain.
3) The Pre-Ground Water Development Period represents all modeling periods prior to May 1950.

N

0 10 20 miles

CENTRAL NEBRASKA PPID		
PRE-GROUND WATER DEVELOPMENT PERIOD WATER LEVEL CALIBRATION TARGETS		
File Name: Pre-DevCalibration.cdr		Date: 02/16/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-18

LYTLE WATER SOLUTIONS, LLC



LEGEND

- DEVELOPMENT PERIOD TARGETS
- STREAMS
- ACTIVE CELL OUTLINE
- MODEL DOMAIN OUTLINE

Notes:
1) Vertical Datum: NVGD 1929.
2) See Figure 1 for Model Domain.
3) The Development Period represents all modeling periods from May 1950 to April 2005.

N

0 12.7 25.4 miles

CENTRAL NEBRASKA PPID		
DEVELOPMENT PERIOD WATER LEVEL CALIBRATION TARGETS		
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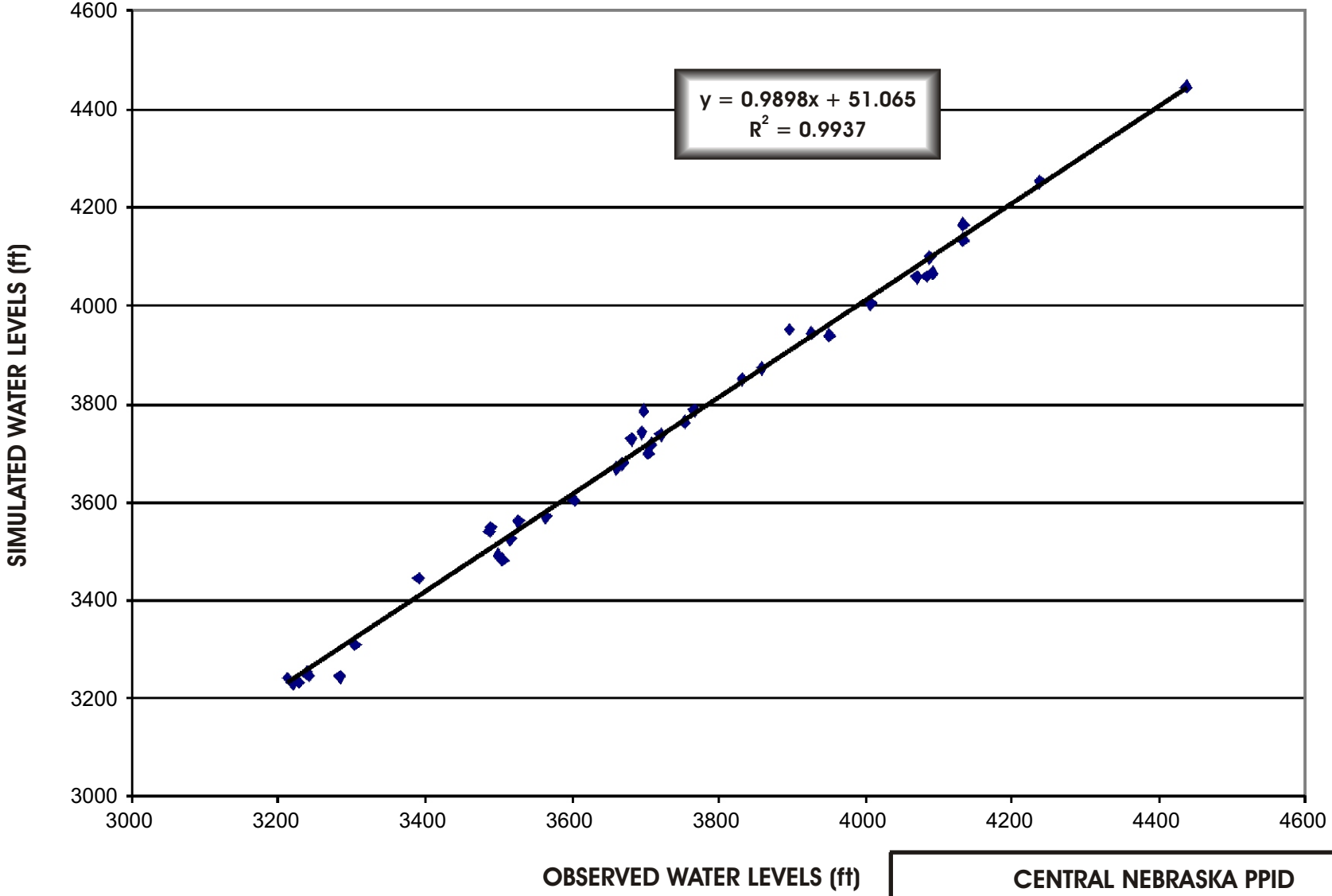
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-19

LYTLE WATER SOLUTIONS, LLC



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PRE-GROUND WATER DEVELOPMENT PERIOD WATER LEVELS		
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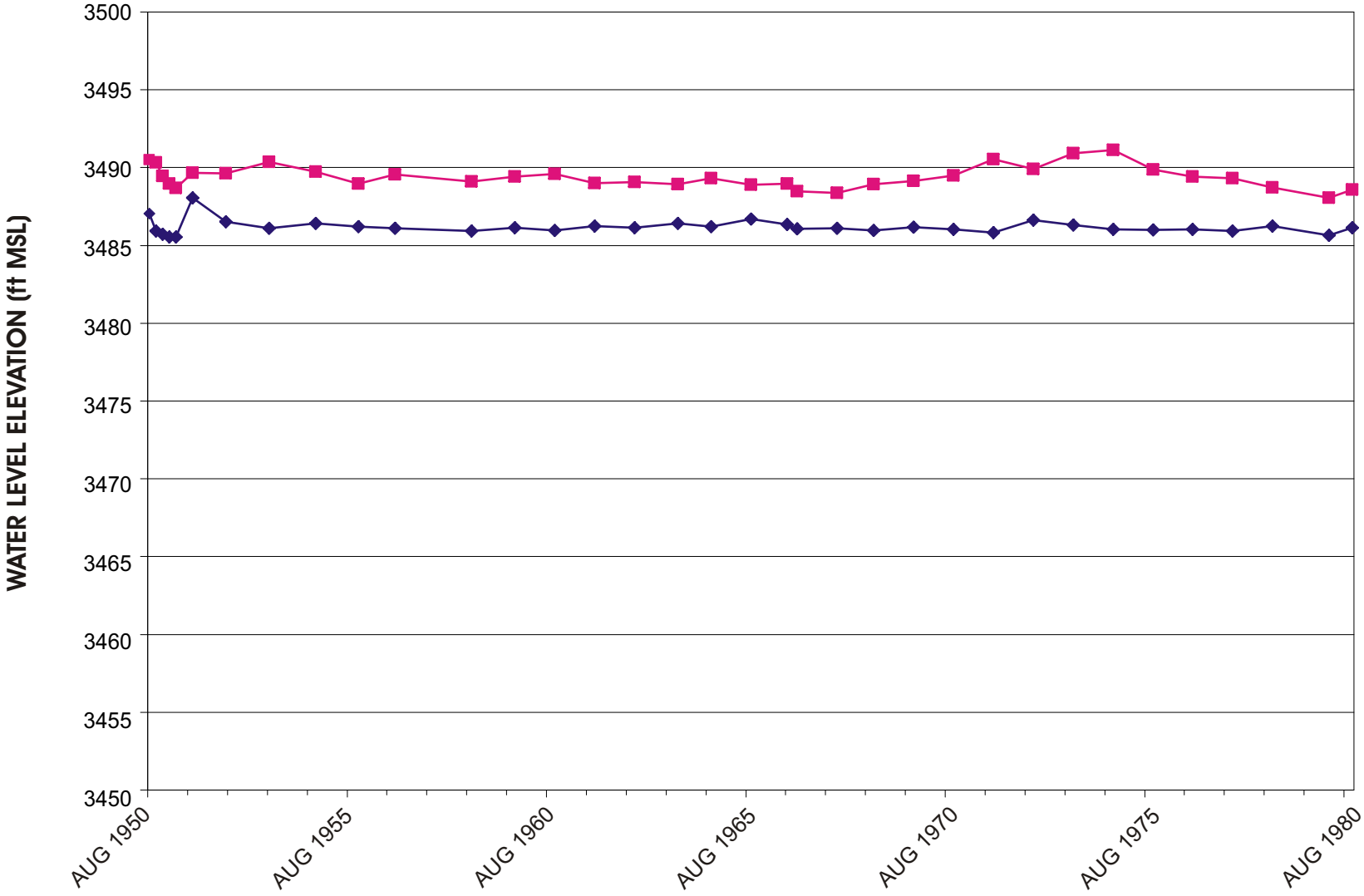
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-20

LYTLE WATER SOLUTIONS, LLC



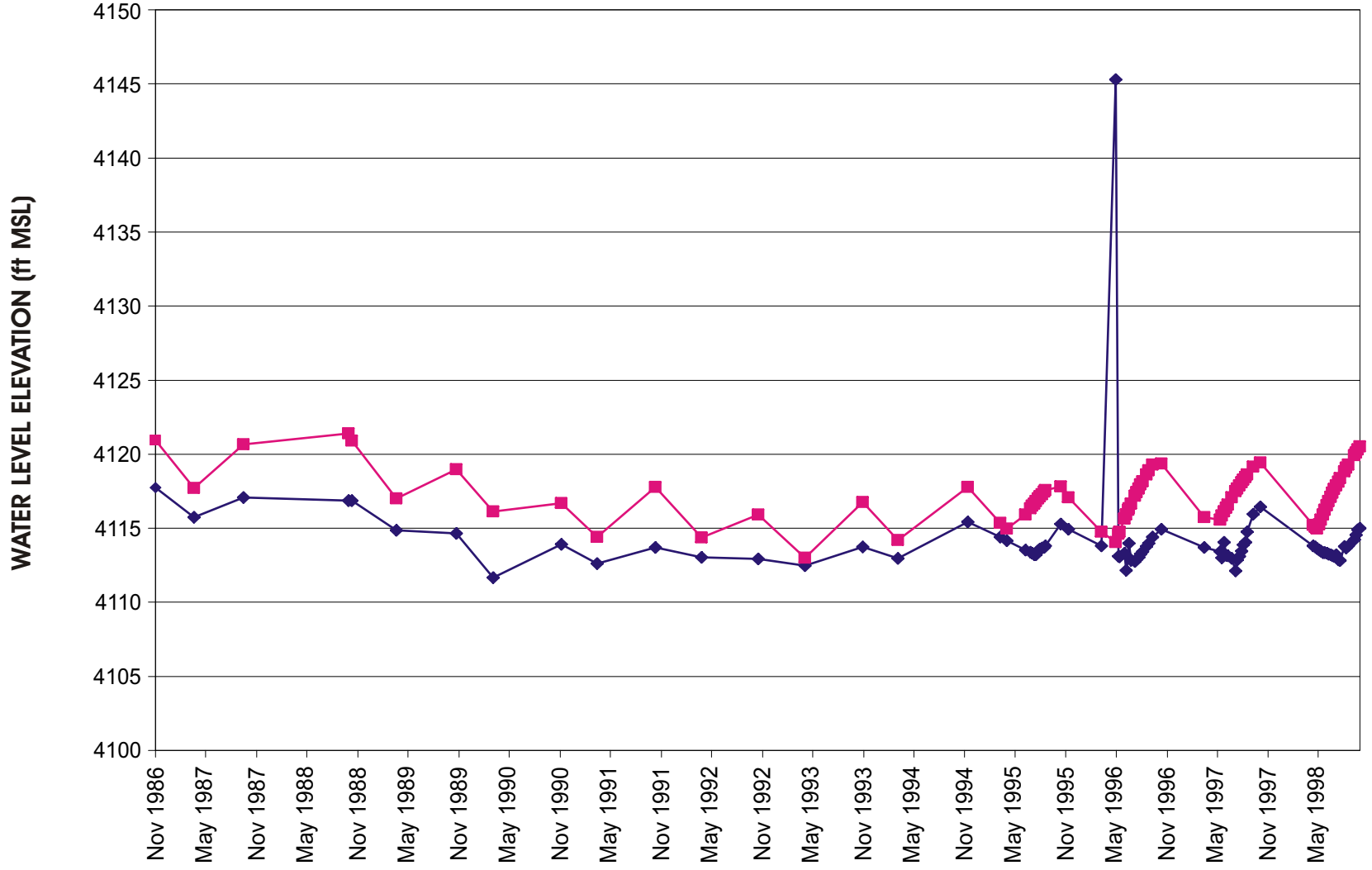
LEGEND

OBSERVED

SIMULATED

CENTRAL NEBRASKA PPID		
WELL NO. 412952102370301		
File Name: Well#0301.cdr		Date: 05/12/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-21

LYTLE WATER SOLUTIONS, LLC



LEGEND

OBSERVED

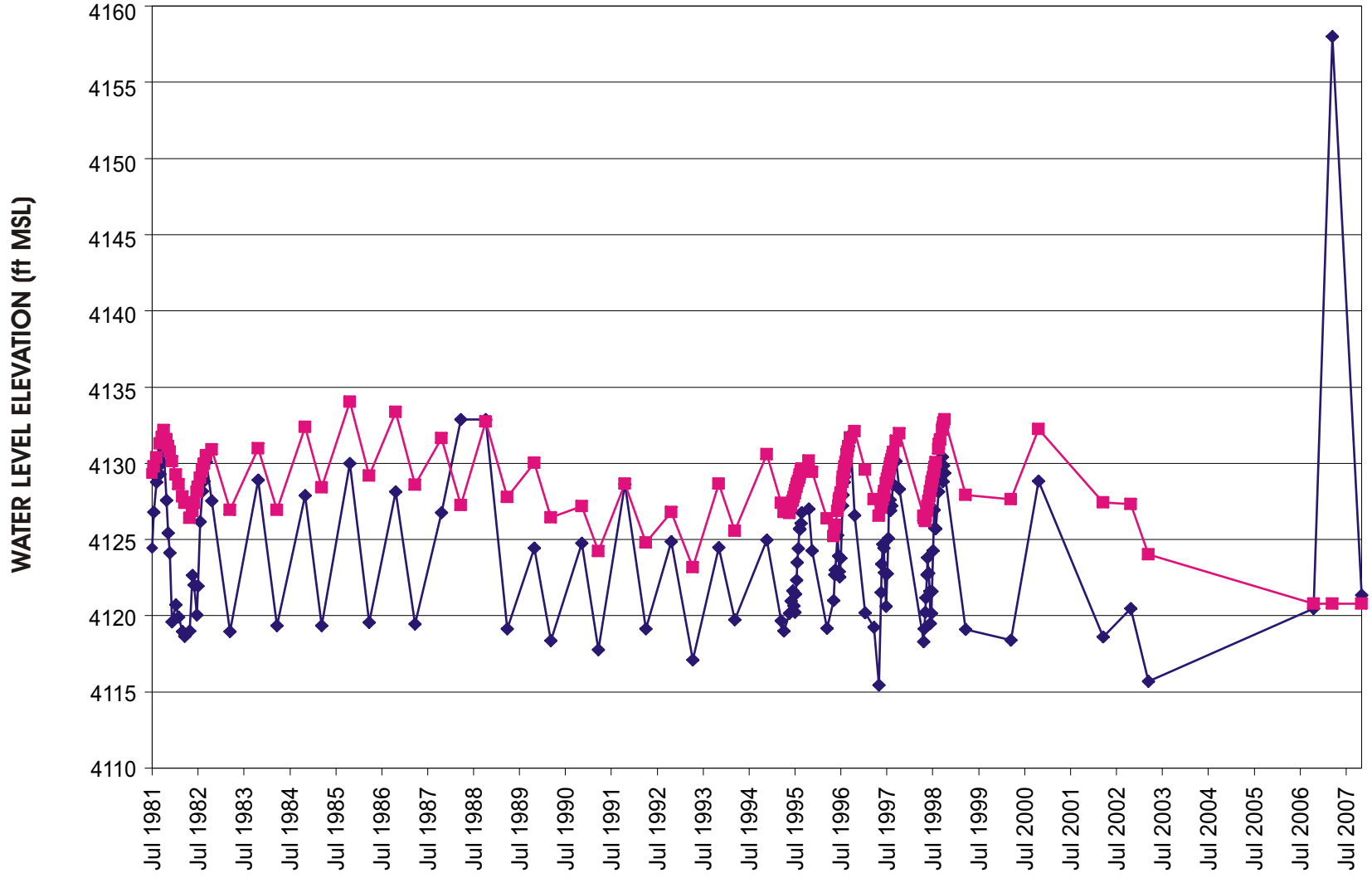
SIMULATED

CENTRAL NEBRASKA PPID

WELL NO. 420324104012701

File Name: Well#2701.cdr		Date: 05/12/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-22

LYTLE WATER SOLUTIONS, LLC



LEGEND

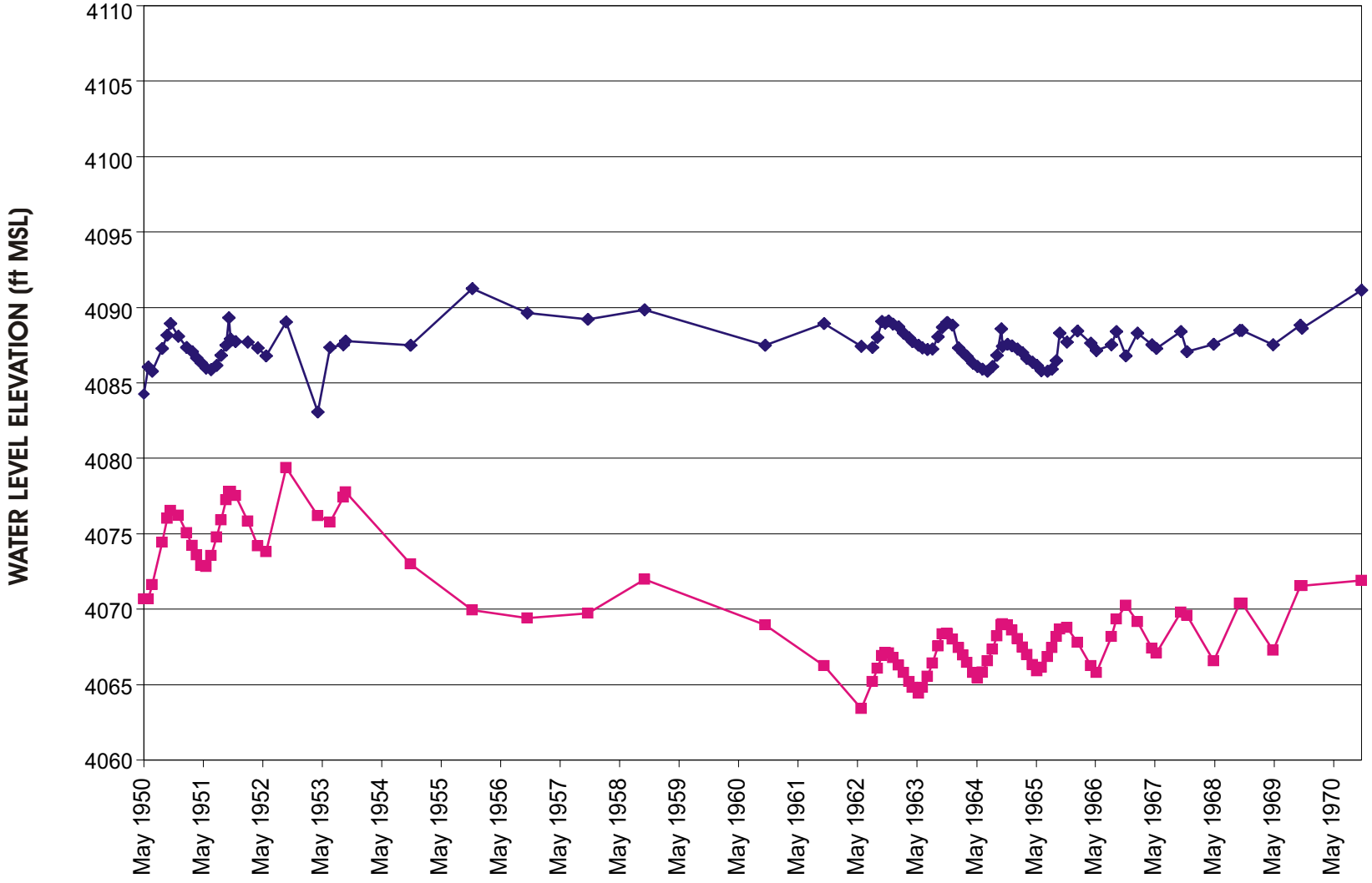
- OBSERVED
- SIMULATED

CENTRAL NEBRASKA PPID

WELL NO. 420218103492901

File Name: Well#2901.cdr		Date: 05/12/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-23

LYTLE WATER SOLUTIONS, LLC



LEGEND

OBSERVED

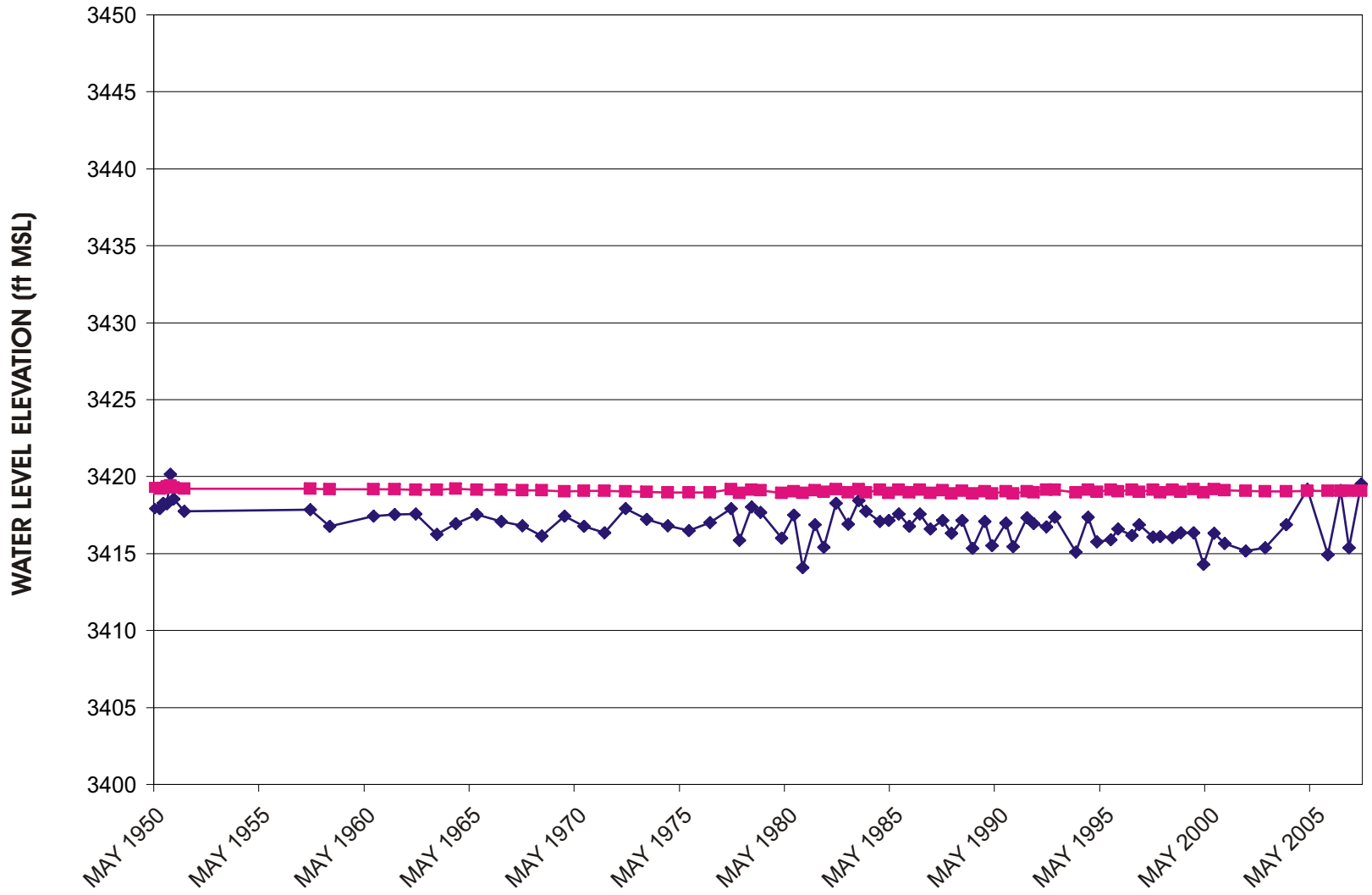
SIMULATED

CENTRAL NEBRASKA PPID

WELL NO. 420355102564001

File Name: Well#4001.cdr		Date: 05/12/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-24

LYTLE WATER SOLUTIONS, LLC



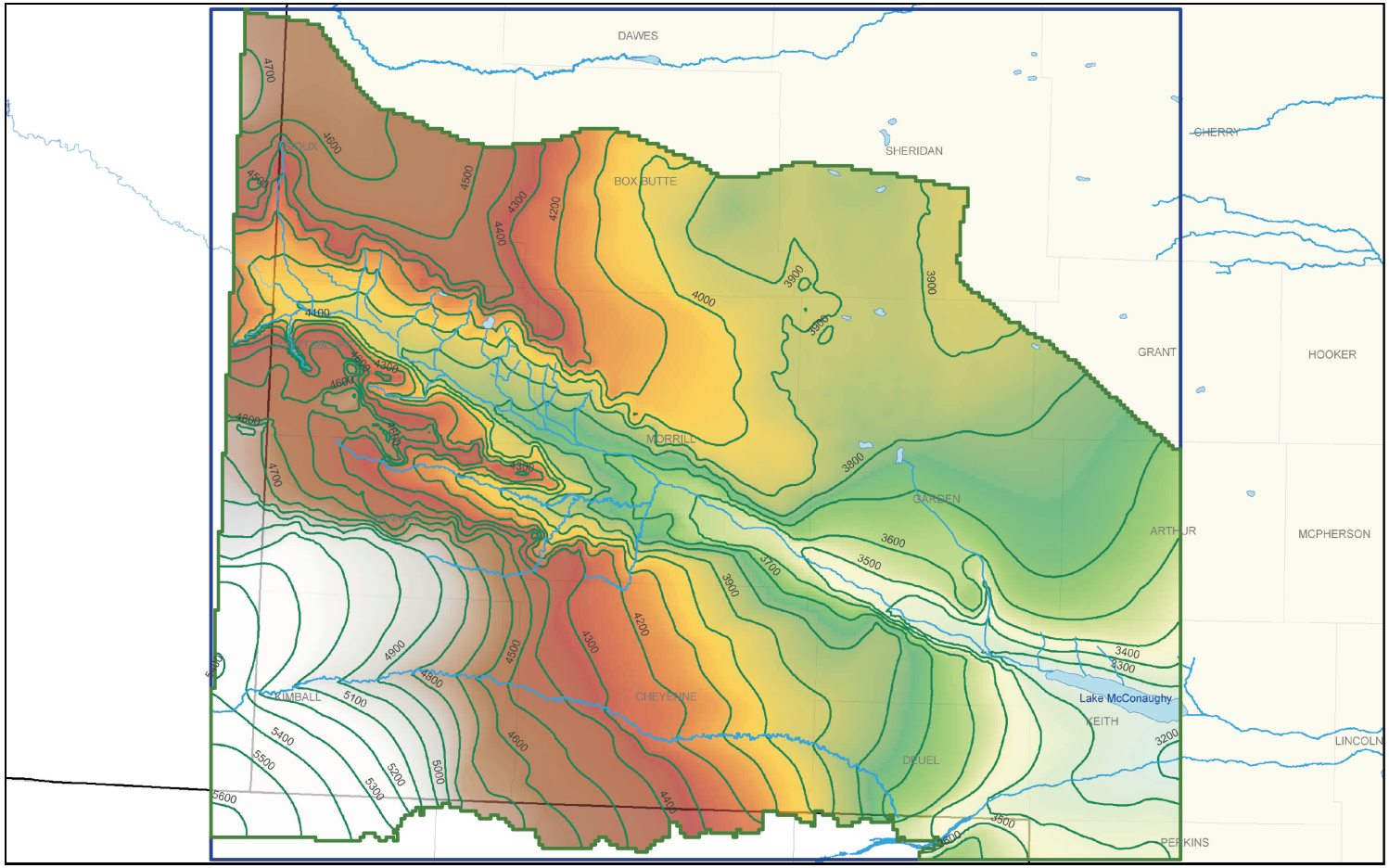
LEGEND

OBSERVED

SIMULATED

CENTRAL NEBRASKA PPID		
WELL NO. 410010102105101		
File Name: Well#5101.cdr		Date: 05/12/2009
Project No.: 1165-08	Drawn By: VAL	Fig. No.: G-25

LYTLE WATER SOLUTIONS, LLC



LEGEND

- 100-FT CONTOURS
- ACTIVE CELL OUTLINE
- MODEL DOMAIN OUTLINE
- STREAMS

DEVELOPMENT PERIOD WATER LEVEL ELEVATION SURFACE (ft MSL)

HIGH: 5618

LOW: 3181

N

0 15 miles

Notes:
1) Water surface elevation contours represent water levels at the end of the final stress period of the Development Period Model.
2) Vertical Datum: NGVD 1929

CENTRAL NEBRASKA PPID		
FINAL WATER LEVELS FOR DEVELOPMENT PERIOD MODEL RUN		
File Name: Development_FinalWL.cdr		Date: 05/13/2009
Project No.: 1165-08	Drawn By:VAL	Fig. No.: G-26

APPENDIX H
FLOW RECOVERY ESTIMATES

Table H1 -Flow Recovery at Lewellen after 5 Years (ac-ft/yr)				
Projected NetPumping Rate (ac-ft/yr)	25% Net Pumping Reduction	50% Net Pumping Reduction	75% Net Pumping Reduction	100% Net Pumping Reduction
170,000	24,500	49,000	71,500	96,000
120,000	17,000	34,500	50,000	67,500
90,000	13,000	26,000	37,500	50,000

Table H2-Flow Recovery at Lewellen after 10 Years (ac-ft/yr)				
Projected Net Pumping Rate (ac-ft/yr)	25% Net Pumping Reduction	50% Net Pumping Reduction	75% Net Pumping Reduction	100% Net Pumping Reduction
170,000	28,000	56,000	81,000	110,000
120,000	20,000	36,500	56,500	76,500
90,000	13,000	26,500	41,500	56,500

Table H3-Flow Recovery at Lewellen after 50 Years (ac-ft/yr)				
Projected Net Pumping Rate (ac-ft/yr)	25% Net Pumping Reduction	50% Net Pumping Reduction	75% Net Pumping Reduction	100% Net Pumping Reduction
170,000	34,000	68,000	102,000	139,000
120,000	24,000	47,000	73,000	99,000
90,000	17,000	36,000	56,000	75,000

Notes: All values rounded.