9 Model Evaluation

In the 2013 model documentation report numerous assumptions, uncertainties and limitations were identified. Since that time, many of these have been addressed as described below. Two model test cases were completed by individuals who were not part of the modeling team and show both the usefulness of the model and provide "How-To" examples for future use.

9.1 Model Objectives

Since its inception, the purpose of COHYST has been to further understand the hydrology and geology of the Platte River Basin while developing tools with a high standard for water resource management decisions. Specifically, COHYST was established to:

- Meet the needs of the Platte River Recovery and Implementation Program.
- Assist the NRD's with legislatively mandated analyses (LB92).
- Provide a sound technical basis for water policy development.
- Use the best available data and science.
- Assess and document the groundwater surface water interaction within the study area.

The objectives to be met by the COHYST model calibrated in 2016 include the following.

Properly calibrate the models for the purposes of determining the components of streamflow accretions and depletions. This includes accounting for a complete balanced water budget, parsing precipitation and irrigation water supplies into consumption, runoff, and recharge as well as modeling transient stresses such as precipitation and irrigation recharge, groundwater pumping and surface water diversions, consumptive use from various irrigation types (surface water only, co-mingled, and groundwater only lands), and municipal and industrial uses.

Each individual model (Watershed, Surface Water and Groundwater) were individually calibrated and the integrated model was also calibrated (Section 8). This included comparing the model mass balance to the estimated mass balance. The integrated model runs on a monthly timestep, but several of the individual models run on daily timesteps allowing significant temporal resolution in modeling stresses.

This objective was successfully completed.

Tracking and accounting of the hydrologic system. The calibrated model(s) should determine the monthly changes in Platte River baseflows caused by a variety of stresses. These stresses include recharge changes, groundwater pumping development that occurred prior to 1997, net groundwater pumping from development and retirement of acres that occurred after 1997.

The COHYST model includes aquifer targets as well as streamflow targets. Monthly changes in aquifer/stream interaction results from a base scenario and model scenario are available, as well as daily changes in total stream flow, including the effects of these changes on canal diversions and canal returns. The models all account for changes in recharge, both due to historic precipitation, and due to changes in irrigation water supplies (including surface water diversions and groundwater pumping). While the COHYST technical team did not specifically complete model scenarios to evaluate the net groundwater pumping from development and retirement of acres that occurred after 1997, the team considers that such scenarios could be completed on a regional NRD wide basis. **This objective was successfully completed.**

Explore and select methodologies to incorporate a full water budget. The model(s) shall account for the full water budget and contribute to the regional understanding of integrated management planning on the surface water groundwater interaction.

This is considered the focus of the integrated model. The watershed model was revised (including changes to canal returns, method to calculate recharge from precipitation etc., see Section 8 for more detail) to improve calibration of the other models while still meeting the objective of modeling the entire water budget. Similarly, the groundwater model was revised to include localized drains which improved simulation of the stream/aquifer interaction. It should be noted that the focus of calibration efforts was on the Platte River basin, and thus the modeled stream/aquifer interaction in other basins may not be as accurate as those in the Platte River basin. **This objective was successfully completed.**

Capable of analyzing management and regulation alternatives available to decision makers. Alternatives may include acreage related controls, allocation of water use, change in crop mix to reduce water use, reduced till and/or no till land management practices, and riparian vegetation management strategies.

Two test scenarios were completed by Technical group members, and several modeling scenarios have been completed by the Conjunctive Management Modeling Group. Full documentation and model results for the two model scenarios completed by Technical group members are included in this section. A summary of some of the scenarios completed by the Conjunctive Management Modeling Group are presented in Section 9.3 below. These modeling scenario runs were completed both manually and using the GUI developed by HDR. The technical team suggests that future scenarios utilize the GUI as it simplifies the process significantly. **This objective was successfully completed.**

Maintain and Update Data sets while making information and data available to the public while implementing formal archival procedures and protocols. The previous model data sets shall be updated to 2005 at a minimum. Data sets shall be archived and available to the public through a formal process.

The model can be run from 1949 to 2010 or from 1985 to 2010. Datasets, Model Files, and Model Documentation can be found on the COHYST website at http://cohyst.nebraska.gov/ which was re-built as part of the latest modeling effort. **This objective was successfully completed.**

9.2 Model Assumptions and Limitations

One of the main guidelines of modeling is to start simple and add complexity as warranted by the hydrology and hydrogeology as the model shows an inability to reproduce observed data. This requires the modeler to make simplifying assumptions which could have an adverse impact to model results if not fully understood and documented. In the 2013 model documentation report, several major assumptions and uncertainties were listed. Since that time, the technical group has added complexity to the models to better match the observed data. The following section describes the model assumptions and how they've been modified since 2013.

9.2.1 Assumptions and Uncertainties

Hydrologic System. The COHYST2010 integrated model represents the complete hydrologic system at a regional scale. There may be localized geologic features that impact local ground water conditions baseflows, but these are considered to not affect regional water levels or regional baseflows. One example of improvements in modeling the hydrologic system is how the ground water model deals with Sutherland Reservoir seepage which averages 80 cfs. In 2013, the drains near Sutherland Reservoir had not all been modeled, and the modeled water levels were significantly higher than the observed levels near the reservoir. The technical team reviewed the localized geology and concluded that 90% of the reservoir seepage, or 71 cfs, was immediately being intercepted by a system of localized drains that had not been previously modeled. These drains conveyed this water directly back to the South Platte River. The 2017 version of the groundwater model includes these drains and now convey this reservoir seepage directly to the South Platte River. Should future model runs change the seepage from Sutherland Reservoir, these drains will react accordingly, thus providing a better estimate of the impacts on South Platte flows and local groundwater levels.

The drain network was also modified between Brady and Overton to improve the localized water levels in these areas. The addition of the localized drains resulted in an improvement in modeled water levels.

The Technical Team also reviewed the Streamflow Routing Package (**Appendix 9-A and Appendix 7-A**). Changes were made to the location of the Platte River which was originally developed using GIS routines. A manual review of those locations found several errors where the channel was overly simplified or located in the wrong locations. By manually reviewing and modifying these areas with the intent to model the river where it is physically located, the model calibration was improved.

The models still contain simplifying assumptions and there are still locations where the local hydrogeology is more complex than what is modeled. Improvements to the regional calibration may be possible by changes to the hydraulic conductivity zonation or changes in the number of layers. There is one area located in Phelps and Gosper county where the hydrogeology should be re-evaluated if conducting a local evaluation using the model. The current hydraulic conductivity zones developed from specific capacity data on a regional basis, deemed sufficient for the regional COHYST model, result in localized errors in Phelps and Gosper counties. Therefore, prior to using the model for localized evaluations in this area, the model hydrogeology should be re-evaluated to better match these localized head and baseflow values.

Land Use. The land use data set consists of. (1) acreage of individual crops and pastures at the county level, which are estimated periodically and (2) location of land use, such as dryland and irrigated crops, pastures, riparian vegetation, streams, canals, urban, etc. The major assumptions identified in the 2013 documentation report within the watershed modeling package are: (1) land use activities at the county level can be distributed down to the 160-acre MODFLOW cell based on land use data, (2) annual land uses can be interpolated between periodic data sets, and (3) daily recharge and pumping patterns associated with crop irrigation are universal, except as modified by daily climatic data. These assumptions remain today and are a function of the data available rather than the modeling approach selected. Because of this, the model does not accurately model the specific land use of a farm but does model the land use on a county level. This is an acceptable level for a regional model.

Additionally, a discontinuity in the land use data set (starting in 1997) caused by using different techniques to estimate irrigated acres before and after that time is present in the current model. The Sponsors determined that it was necessary to replace the prior dataset for counties within the Platte River drainage, but that the prior dataset could continue to be used outside that drainage (to be replaced at some future time).

Temporal Distribution of Precipitation. In 2013 the temporal approach used in the watershed model was to build the evapotranspiration, deep percolation and runoff from annual precipitation data at 33 long-term climate stations and subdivide the results to monthly values based on a standard distribution of precipitation. That approach did not account for monthly or seasonal variations in precipitation that occur from year to year and the model assumption of year-to-year identical seasonality could not capture an extremely dry summer during an average year.

As described in Section 5, the watershed model was revised and completely rebuilt to improve on this simplifying assumption. The watershed model uses daily precipitation and temperature measurements at 77 weather stations over the simulation period 1985-2010 (Figure 5.17 & Table 5.1); with the temperature used to calculate reference ET using a modified Hargreaves-Samani approach. The watershed model uses the soil water balance model CROPSIM to establish initial estimates of evapotranspiration, deep percolation, field runoff, change in soil water content and the net irrigation requirement as a response to precipitation, reference ET, and initial soil water content. This allows the results to better reflect the system response given field conditions (soil water content, residue, crop development); as opposed to a deterministic response strictly tied to precipitation depth as was previously used. The daily results were compiled on a monthly time step for a variety of vegetative coverages on different soils subjected to irrigated and non-irrigated conditions. This methodology then uses local properties (crop type, soil, irrigation system and source, management characteristics, …) to establish the final estimate of irrigation, evapotranspiration, deep percolation, and field runoff. Field runoff is further partitioned to between contributions to stream flow and transmission losses to ET/recharge.

<u>CROPSIM Response Functions</u>. The response functions used in the previous versions of the COHYST model are no longer used; rather, the current methodology is described in the Temporal Distribution of Precipitation section above.

<u>Vadose Zone</u>. The 2013 model assumed the application of recharge to the groundwater model caused an immediate response to the water table. With monthly stress periods in the groundwater model, this assumption was reasonable where the water table is relatively shallow. However, in parts of the study area where the water table can be up to a few hundred feet below the land surface, the water table response to a recharge event may take months, years or even decades. As part of the revised calibration, the groundwater model now accounts for this lag.

This is an important change that may affect future modeling scenarios that focus on recharge activities in these areas. For example, a recharge basin constructed in an area where the depth to water is 100 feet will require specific evaluation of how the vertical travel time may or may not change as the area below the recharge basin becomes saturated.

Single-Layer Groundwater Model. The 2013 model and the current model rely on a 1-layer model. This is a significant simplification from the Central and Eastern COHYST groundwater models where the models consisted of 6 and 8 layers, respectively. This simplification assumes that there is no delay in a response from pumping a partial penetrating well or recharge stress at the water table in affecting the water levels throughout the vertical profile.

This assumption simplifies the model construction and is acceptable for a regional model. However, on a local scale, this assumption may cause reduced model reliability parts of the study area where the aquifer stratification and thickness may be significant.

Surface Water Operating Rules. The 2013 model and the current surface water model operate using a simple set of operating rules for reservoir releases and diversions to canals. These simple operating rules were created by discussions with reservoir operators and by evaluating how well the surface water model matches the observed data. However, in the real world, the operators consider many more factors than are contained in the model rules, and may adjust operations based on then current conditions or the expectation of near-term future conditions, such as snowpack forecasts or expectations of an upcoming rainfall event.

An example is the FERC waivers CNPPID obtained in 2001 – 2005. These waivers allowed CNPPID to reduce releases below the FERC minimum amounts. FERC has since concluded that CNPPID can no longer obtain a FERC waiver. To match the historical operations, the operating rules must be modified to include these operations, however, they are specific to periods in 2001 – 2005 and future scenarios wouldn't be allowed to continue the operations.

Another factor affecting releases form Lake McConaughy is Colorado snowpack and Wyoming streamflow forecasts. CNPPID operators use these forecasts to guide their operations in the spring and throughout the winter. The Technical Team evaluated the impacts of changing the operating rules for Lake McConaughy to include the potential for snowpack and North Platte River runoff forecasts as well as FERC waivers. **Appendix 9-B** provides the results as presented to the COHYST Sponsors. While the changes to implement snowpack and streamflow forecasting helped in some instances, there remain instances where the revised operating rules used in the model produce results that are different than historical operations. Additionally, the changes in reservoir operating rules did not significantly affect downstream canal diversions. Because of this, the surface water model continues to operate with similar rules as the 2013 model.

Finally, the translation of demands upstream for use in the operational rules are adjusted based on the anecdotal reach gains, while the computed historic reach gain/loss is used in routing flows downstream through the model extents and to quantify flows at each main stem node.

Canal and Reservoir Seepage. Little local seepage data are available for calibration. As a result, water losses along canals typically were generalized estimates and prorated along the length of the canals. Reservoir seepage was typically estimated by a water budget analysis and prorated based on the reservoir surface area. This approach required assumptions that the other water budget estimates were reasonably accurate, and rates were subject to calibration. These assumptions were present in the 2013 model and have not changed in the current model. Going forward, the model would be improved by acquisition of canal seepage data.

Canal returns for irrigation canals were assumed to be the residual of the diverted volume less the seepage, crop deliveries, and net evaporation. Canal returns in the integrated model are added to the main stem flows and routed downstream. Direct measurement of canal returns could improve this procedure.

Republican River Canals. For the Republican River canals, seepage estimates from the inputs approved for the Republican River Compact Administration were used for the years 1985 - 1998. Given limited public availability of post 1998 values related to litigation activities in the Republican River Basin, the seepage volume from 1998 was carried forward through 2010.

Kearney Canal Demands. Of the 15 districts in the surface water operation model, the demands and supplies are passed between the RSWB and the surface water operations model for 14. For the Kearney canal, the water demand for power production dwarfs the irrigation demand for agriculture. Therefore, during the modeling process it is assumed that the supply to agricultural lands fed by the Kearney canal is sufficient to meet demands.

Evaporation along Waterways. There are limited specific data on evaporation along water ways available despite evaporation being a large component of a hydrologic system's water budget. Both the 2013 model and the current model used the calibration process and consistency with other models in the region, to develop reasonable assumptions.

Evapotranspiration by Riparian Vegetation. The 2013 documentation report identified Riparian ET as a significant uncertainty based on several factors including (1) assuming ET rates vary linearly with depth (2) determining a representative land surface elevation within a groundwater model cell, (2) a coarse discretion of riparian vegetation with a quarter square mile model cell, and (3) not allowing an ET cell to overlap a stream cell.

While many of these challenges are still present, the Technical Team re-evaluated the ET package and made several changes to reduce the uncertainty. First, the watershed model calculates cell ET for many cells which also contained riparian ET cells in the groundwater model. The ET package in the groundwater model was modified to avoid the overlaps. Second, the ET rates were changed to better match known dry-river periods, within known values. The changes to ET rates were within the physically observed values available and result in an acceptable regional evaluation of ET by riparian vegetation.

Any future scenario which focuses on riparian ET should evaluate the sensitivity of the ET package inputs on the results of the scenario to evaluate how much impact they may have on the final scenario results.

Future Model Applications. Phase II primarily focused on calibrating the models to historical conditions. However, the first challenge in evaluating water management scenarios is the development of a future "baseline" condition, which is a continuation of existing water management practices into the future. Because scenario results are based on the difference in model results between a baseline and a scenario run, a future baseline simulation which represents the expected future conditions may have to be created. Creation of a future baseline scenario may have significant assumptions including: 1) how to account for or remove trends in pumping and recharge, 2) future precipitation and surface water supplies, 3) farming practices, and 4) duration of the scenario.

An alternative to creating this future baseline simulation is to evaluate how a model scenario performs assuming the baseline scenario is a repeat of history. In this case, the present model can be run from 1949 through 2010, providing a significant time period to evaluate the proposed scenarios impacts to the system.

Should the modeler choose to develop a new baseline simulation, it is recommended that a sensitivity analysis on the baseline assumptions be performed to determine how these assumptions are affecting the scenario results.

Model Calibration in Buffer Area. The area of interest to COHYST is the Platte River basin. However, for hydrologic completeness, the study area encompasses the area north of Frenchman Creek and the Republican River and south of the Loop River system. The buffer area is the domain of the study area outside the Platte River basin. This buffer area is fully represented by the groundwater model and the watershed model but was not the focus area during the most recent calibration.

As an example, the modification to the recharge rates caused by significant depths to water outside of the Platte River Basin improved overall model calibration, including in select areas of the Platte River Basin. However, this assumption contradicts other models developed in Nebraska and likely needs additional evaluation to vet its appropriateness and to consider alternative concepts. Given this assumption has limited impact on Platte River streamflow depletion analyses, decisions to include or exclude it from certain Platte Basin management scenarios is not likely to impact the analyses that the will be conducted in the Platte River Basin.

Groundwater Level Data. The 2013 modeling spent considerable effort to improve the accuracy of the land surface elevation data for groundwater wells used as calibration targets. The targets were also reviewed to remove or revised suspect data transcribing or field measurement errors. However, there may still be wells with bi-annual measurements which may not fully represent the water level conditions at that location, and many of the wells are irrigation wells which may have residual effects from pumping. To focus calibration on the Platte River Basin, a revised calibration data set was developed with 402 locations that largely concentrated in and near the

Platte River areas. This approach is considered reasonable given the uncertainties in the data sets available.

Baseflow. The calculation of baseflow estimates along the Platte River has been a great challenge to the Technical Team. The initial step in the making the estimates was the calculation of a water balance residual (baseflow) from reach inflows, outflows and diversions. The process is subject to the lack of data on runoff from tributaries, return flows, losses to riparian vegetation, miscellaneous and minor diversions and returns. It is also greatly hampered by relatively inaccurate streamflow data, especially during moderate to high flow conditions and ice conditions. This process resulted in a baseflow hydrographs that were very noisy with more variability than is normally associated with groundwater inflows. Numerous attempts were made to smooth these residual hydrographs to provide a more reasonable estimate of baseflow, including a delineation based on professional judgment and an automated filter method to reduce the high and low amplitude signals. The selected process used the automated filtering procedure, so that there is no potential for bias by the hydrologist. The selected baseflows still have a dynamic that does not appear to be fully reasonable, but the centroid of the baseflow hydrographs is reasonable. In consideration of this uncertainty, the current model excluded the baseflow targets from the parameter estimation dataset, and only relied on the targets to provide a qualitative evaluation of calibration.

However, the calibration of the integrated model run did evaluate the model's ability to match total flows at various gage locations throughout the Platte basin and the models can be used to reasonably determine the change in stream/aquifer interaction between a baseline and model scenario. Should the baseflow separation process be used in future simulations, it is recommended that a sensitivity analysis be completed to determine the potential impacts of this uncertainty.

Pumping. Pumping estimates are based on a parcel's unmet crop demand. This unmet demand is based on estimates of total crop demand (which include consideration of land use type, farming practices, effective precipitation at that location, etc.) and estimates of precipitation and (where applicable) surface water available to meet some of that crop demand (which includes estimates for canal loss, canal returns and evaporation, farming practices, etc.). In the

COHYST model the pumping estimates were distributed to model cells based on land use data since developing a specific well pumping volume for each individual well is difficult.

There are a few localized measurements of pumping amounts which have been used to constrain the model pumping estimates during calibration and are believed reasonable for a regional model. However, this parameter still has some uncertainty and may not reflect localized conditions where land use is significantly different than modeled, or where local water levels are controlled by nearby pumping wells which irrigate significant quantities of land. Future simulations should evaluate these possibilities and perform sensitivity analysis or revise the model pumping as needed.

Recharge. As discussed earlier, recharge consists of several components, including deep percolation in the watershed and seepage from reservoirs, canals and streams. Each component has potential errors. However, like pumping, the errors are greatly constrained by calibration to groundwater levels and to baseflow and are believed to be reasonable when interpreted at a regional scale.

Watershed Runoff. In the current model runoff contributions to stream flow make up approximately 4% of the total applied water (Table 5.4). Runoff is a function of daily precipitation, soil water content, and timing in conjunction with applied irrigation and the application efficiency. Water leaving the field as runoff is further partitioned between contributions to stream flow as transmission losses to ET and recharge. There continues to be limited collected data on runoff contributions to streamflow; but, it continues to be constrained by calibration with the surface water operation model and the groundwater model to total stream flow in the Platte River and its tributaries.

Reservoir Seepage. In the 2013 model, reservoir seepage losses from Lake McConaughy were estimated by the surface water model as the residual in a water balance calculation, while the, the groundwater model estimated reservoir seepage in the aquifer from a general head boundary. In the current model, seepage from Lake McConaughy is calculated using the groundwater model and a general head boundary and passed to the Surface Water model. This boundary was calibrated to historic seepage values, which were assumed equal to the residual of inflows minus other outflows.

At Sutherland Reservoir, seepage rates are based on surface water model operating rules which attempt to match observed seepage rates. In other reservoirs, the seepage estimates made by the surface water modelers are used directly. The calculation of reservoir seepage rates are believed to be reasonable on a regional scale; however, there may still be local errors. As with other uncertainties, future scenarios may need to evaluate the potential impact of these uncertainties.

Canal Seepage and Return Flows. The current modeling effort continues to have sparse data on specific canal seepage and its distribution as well as canal return flows. The watershed model and surface water model have been calibrated within range of values provided by field staff and irrigation district personnel. This is a primary aspect of the current water budget which might be substantially improved through a program of field measurements.

Underflow into and Out of the Study Area. As with the 2013 model, the underflow into and out of the study area is based on generalized aquifer properties and hydraulic gradients and are represented by MODFLOW's General Head Boundary (GHB). The modeled values from those estimated in the Phase I water budget. These water budget items are relatively small and have very limited dynamics.

Initial Heads in Groundwater Model. Ideally, a groundwater model starts during predevelopment conditions so that the modeler does not have to estimate water levels throughout the model area during a dynamic and trending period. For the 2013 model, a considerable number of tests were conducted, and extensive efforts were made to develop an initial water level condition that is numerically in equilibrium at the beginning of the simulation. To the extent possible, inconsistencies in initial heads were removed with a 5-year warm-up simulation that leads into the calibration period.

9.2.2 Limitations

The technical team has calibrated each model component individually and calibrated the integrated model to observed conditions from 1990 to 2005. The team concludes that the model results are reasonable for the intended purposes and that the model can be used for many types of regional evaluations that compare a baseline scenario to a model scenario. As described above, there are still model inputs with significant simplifying assumptions or uncertainties, but confidence in each is strengthened by the requirement of a consistent water budget amongst each induvial model. A wealth of water level data, considerable streamflow data, and dry river occurrences greatly constrain the modeling errors and reduce bias of any of the water budget components. To the extent systematic errors may occur, they are acceptable.

Despite this, there are model limitations associated with the current COHYST model. The primary intended purpose of the model is the evaluation of water management plans and thus, direct use of the models at an individual well or well field is beyond the scope of the design and, if undertaken, may not produce reliable detailed results.

The overall conceptual design of the model is at a regional scale and is most suitable at the township-range and county level. The most suitable time scale is years or decades, not seasons or months. The model provides a suitable regional framework for the development of local scale models with a refined grid.

The groundwater model has been constructed to purposefully be less accurate at predicting high flow conditions to better predict low flow conditions during critical dry periods. While the calibrated model does predict periods of dry river, they may not be equal to the physical extent and duration that existed throughout history. The model results should be evaluated with a focus on the potential impacts that dry river reaches could have on the results. For example, evaluation of delivery of water downstream past a dry reach may not be adequately evaluated if the dry reach is not correctly modeled.

The groundwater model is designed and calibrated as a hydrologic model and is not suitable for mass transport simulations without further calibration and testing.

The model may be used to evaluate model scenarios in conjunction with a baseline scenario and results should be evaluated as the calculated difference between the baseline simulation and the scenario simulation. Model results taken directly, such as estimates of stream flow at a specific location, rather than changes in stream flow from a baseline and a simulation at that same location, may not be reasonable and such results should be critically evaluated before being used for management decisions. In some instances, it may be prudent to use only one component of the integrated model to evaluate a scenario. For example, due to the way the surface water model is constructed, it is possible that small changes in surface flows can result in significant changes to operational rules, and that these changes to operational rules can cause significant changes to model results. Model users should evaluate each model run to determine if such operational changes are reasonable, or if they should be held consistent between baseline and scenario runs.

Another approach to the above issue may be to utilize the groundwater model independently to evaluate the changes to reach gain losses rather than using the surface water model to calculate changes to total flow. In each case, the model results should be reviewed to understand what variables result in model changes between runs and if these changes are reasonable.

Attention should be paid to the effect of model assumptions and data uncertainty on model results. It is recommended that future modeling runs perform sensitivity analyses on model results to quantify their reliability if the assumptions and uncertainties outlined above are suspected of directly affecting the model results.

9.3 Peer Review

The fundamental approach and structure of the 2013 model was subject to external peer review and remains unchanged. Peer review of the current model was conducted by the Technical Group throughout the process. Additionally, the technical group conducted two model simulations manually and using the GUI (**Appendices 9-C and 9-D**). These modeling simulations were used to evaluate the ability of the model to reasonable evaluate different management operations, as well as to confirm that the GUI matched the manual method. The scenarios evaluated are as follows.

- Lining of CNPPID E-67 canal and its effects on ground water levels, other canal diversions, and Lake McConaughy releases. The specifics of the modeled scenario, results, and a detailed description of the modeling steps are presented in **Appendix 9-C**.
- Keith-Lincoln management operations including two scenarios
    - Scenario 1: All historic surface water irrigated acres and commingled acres supplied by the Keith - Lincoln irrigation ditch was assumed to be transferred to groundwater pumped irrigation. The natural flow right diverted to meet previous surface water irrigation demands was left in the river leaving the canal dry. All the other model parameters were unaltered. The model simulation was run from 1985 to 2005 and then compared to a baseline over the same time.
    - Scenario 2: All historic surface water irrigated acres and commingled acres supplied by the Keith-Lincoln irrigation ditch were transferred to groundwater pumped irrigation. The canal natural flow right was diverted through the canal for recharge along the main canal with the remainder returned to the South Platte River. All the other model parameters were unaltered. The model simulation was run from 1985 to 2005 and then compared to a baseline over the same time.

The modeling assumptions, results, and details of how the models were modified are included in **Appendix 9-D.**

In addition to the Technical Group, the model has been used by the Conjunctive Management Group to evaluate several management scenarios including but not limited to:

- no surface water deliveries to Dawson area canals, irrigation water supplied by groundwater pumping instead;
- no seepage from CNPPID Tri-County system;
- recharge non-consumptive use demand via canals;
- expanded surface water deliveries without current limitations such as canal capacity.

These modeling efforts indicate that the COHYST model can be used to reasonably evaluate management options and has met the objectives of the COHYST work plan.