Appendix 9-D

Keith-Lincoln Canal Simulation

COHYST 2010 Keith-Lincoln Canal Test Scenario

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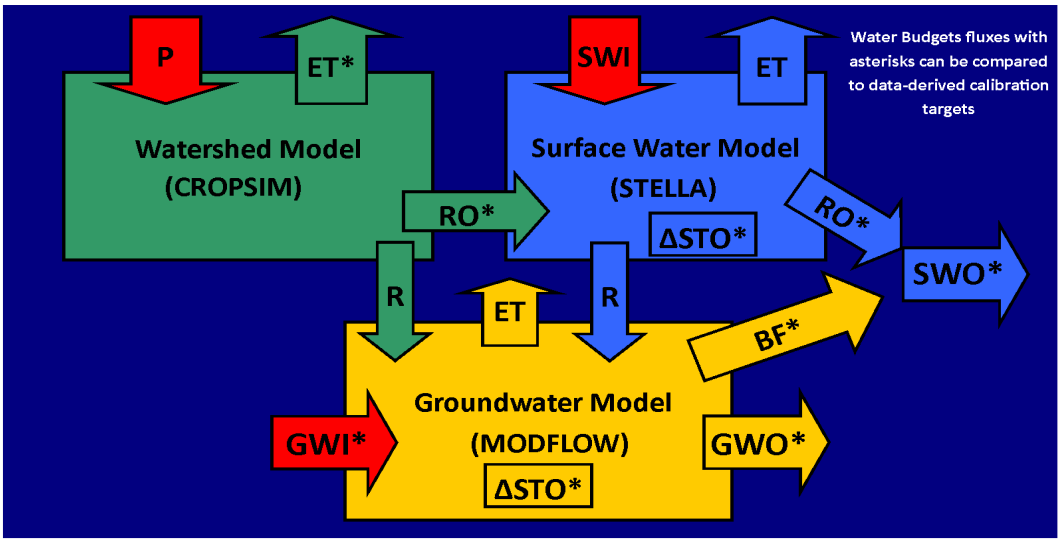
June 6, 2016

Background

The Collaborative Hydrology Study (COHYST) is a hydrologic study of the Platte River drainage basin in Nebraska. The COHYST 2010 project produced a documented model in 2013, and updates have continued to be implemented since its release. The computer-based integrated COHYST model consists of three components: a watershed model, a surface water model, and a groundwater model. The watershed, surface water, and groundwater models are primarily run through the programs CORPSIM, STELLA, and MODFLOW respectively and are supported by several intermediary programs. The models are often referred to as their program names.

The COHYST 2010 model was developed collaboratively between Nebraska local and state government, public power irrigation districts, consultants, and other Nebraska water stakeholders. Due to the cooperative development of the model, each component of the model is altered and run by the party that developed them. Therefore, to perform an integrated model run each party runs their respective model component and passes the required handshake components among the other parties. **Figure 1** shows an overview of the model components and the integrated process. Currently HDR runs the surface water model; Flatwater Group runs the watershed model; and the Nebraska Department of Natural Resources or Lee Wilson and Associates runs the groundwater model.



Green = land/soil water balance.
Blue = surface water balance.
Yellow = aquifer water balance.
Red arrows are external model inputs.
P = precipitation.
R = recharge

RO = runoff
BF = baseflow discharge
ET = evapotranspiration (can include open water evaporation).
SWI and SWO = surface water inflow and outflow.
GWI and GWO = groundwater inflow and outflow.

ΔSTO = change in storage.

Figure 1: COHYST Integrated Model Flow Chart from COHYST 2010 Phase II Draft Report

The necessity for the model developers to run the COHYST model posed limitations on the ability for outside users to operate the model. Due to this limitation, test cases were developed to allow someone outside of the model development team to run a fully integrated COHYST model run and to provide feedback on the process and results. The Keith-Lincoln irrigation canal, located off of the North Platte River, was selected to have its operations altered in a test case scenario because of its conjunctive water management opportunities in the Twin Platte Natural Resources District. The Keith-Lincoln canal serves approximately 5400 irrigated aces, the majority of which are irrigated through commingled groundwater pumping and surface water delivery. An instream flow right of 80.56 cfs belongs to the canal which it diverts from the North Platte River and returns to the South Platte River.

The Keith-Lincoln test case includes two scenarios:

- Scenario 1: All historic surface water irrigated acres and commingled acres supplied by the Keith-Lincoln irrigation ditch are transferred to groundwater pumped irrigation. The natural flow right diverted to meet previous surface water irrigation demands is left in the river leaving the canal dry. All the other model parameters are unaltered. The model simulation is run from 1985 to 2005 and then compared to a baseline over the same time period.
- Scenario 2: All historic surface water irrigated acres and commingled acres supplied by the Keith-Lincoln irrigation ditch are transferred to groundwater pumped irrigation. The canal natural flow right is diverted through the canal for recharge along the main canal with the remainder returned to the South Platte River. All the other model parameters are unaltered. The model simulation is run from 1985 to 2005 and then compared to a baseline over the same time period.

Objectives

The primary objectives for the Keith-Lincoln test case are as follows:

1. To document and provide feedback on the process of setting up and running a scenario through a fully integrated COHYST model run. This includes feedback on the current documentation for model setup and operation.
2. To quantify changes to irrigation canal diversions, Platte River gages, and groundwater levels in the COHYST area due to the changes implemented in each scenario. These results will be analyzed conceptually and technically.
3. To perform an independent review of the modeling process which is generally done by the consultants and groups who normally run the model. The consultants will model the same scenarios independently and compare the results with this case test.

The Keith-Lincoln test case will first be run using the watershed model, surface water model, and groundwater model separately, transferring the necessary handshake files manually.

Secondly, the test scenarios will be run using the latest build of the COHYST Graphical User Interface (GUI). These two methods will then be compared.

Assumptions

An assumption made for both Keith-Lincoln scenarios was that no new wells were needed in the Keith-Lincoln irrigation district to account for the irrigated acres transferred from surface water irrigation to groundwater irrigation. This assumption was made because the majority of acres receiving surface water irrigation were classified as commingled and had a well already in place to supplement increased groundwater demand. The surface water only parcels were all close enough to neighboring wells to assume access to groundwater. In reality, the surface water only acres that do not have access to a well would be excluded, lowering the total amount of canal irrigation acres included in the scenario. For Keith-Lincoln Scenario 2, a constant seepage rate of about 36 percent was used in the canal during the recharge only diversions. This seepage rate used is the default rate used by the COHYST model for Keith-Lincoln and does not change during dry or wet conditions as it would in real world conditions. The diversion were taken from the North Platte River and returned to the South Platte River as they would under normal conditions with the tail gate remaining open.

Model Changes Required

For the Keith-Lincoln case test integrated run of the COHYST model, changes to the watershed model and surface water model were required. For the watershed model the land use files were altered to change surface water irrigated acres to groundwater irrigated acres. This was done using a FORTRAN program that copied the amount of Keith-Lincoln surface water irrigated acres per model grid cell, replaced them with zero, and added them into the portion of groundwater irrigated acres per grid cell. The groundwater concentration files were then altered to make sure each well within the Keith-Lincoln irrigation district is set to pump groundwater only. All other model parameters were left unaltered.

For the surface water model, a number of changes were made to the system in the STELLA software. First, a model node named “Select_KL_Canal_Case_Study_Scenario” was added to the Keith-Lincoln Canal system and linked a slider with three options: baseline, Scenario 1, and Scenario 2. The added node is shown in **Figure 2**.

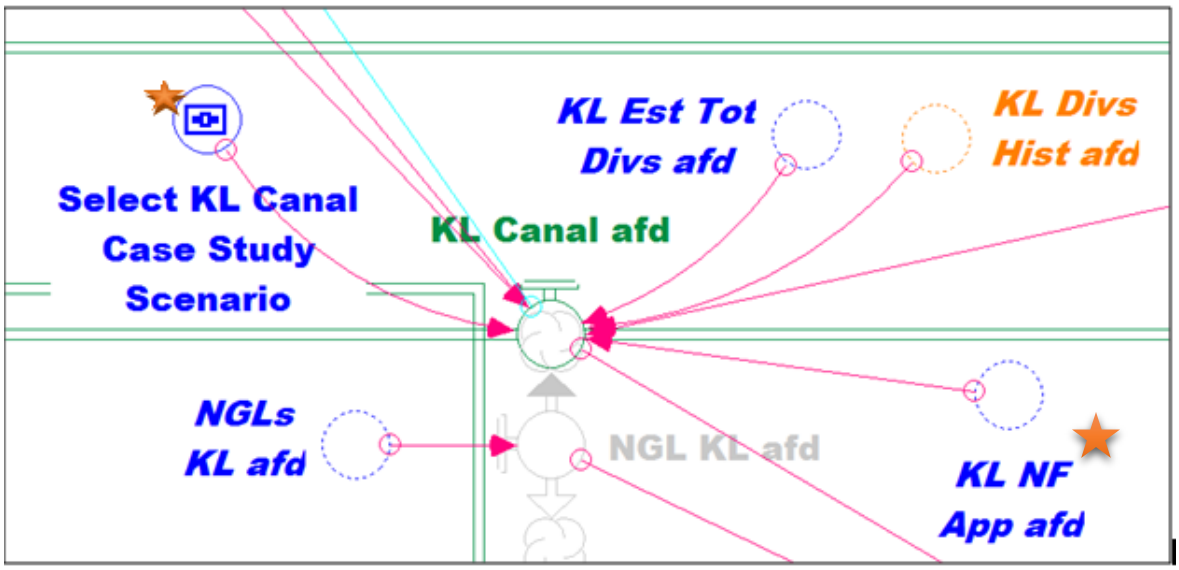


Figure 2: STELLA Modification at the Keith-Lincoln Canal

With new node and slider in place, the logic at the "KL_Canal_afd" node was changed to account for the selection assigned to "Select_KL_Canal_Case_Study_Scenario" and alters the Keith-Lincoln canal operational rules based on where the associated slider is set to baseline, Scenario 1, or Scenario 2. The node "KL_NF_App_afd" was also added to the Keith-Lincoln system to allow for the logic to be changed at the canal. Next, a copy (ghost) of the "Select_KL_Canal_Case_Study_Scenario" node was placed and related to the "KL_Irr_afd" node in the "Keith-Lincoln Canal NGLs afd" box in the STELLA model as shown in **Figure 3**.

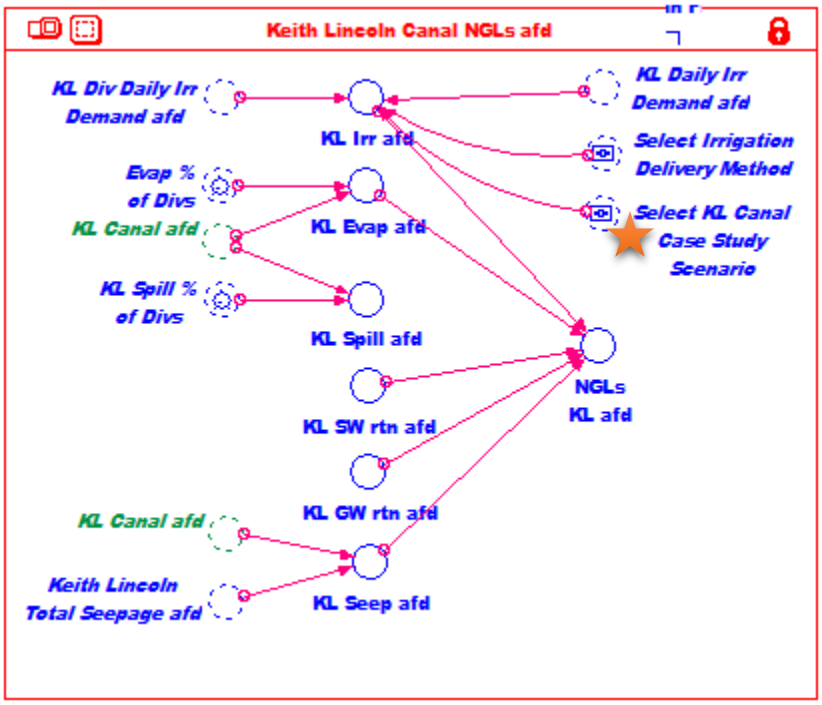


Figure 3: Keith-Lincoln Canal NGLs afd Modifications

In addition, a ghost of "Select_KL_Canal_Case_Study_Scenario" was added to the "Keith_Lincoln_Canal_Estimated_Diversions_afd" box and connected to "KL_Est_Tot_Divs_afd". Finally, with these nodes in place the storage release for demands from Lake McConaughy was altered by changing the code in converter "KL_Est_Tot_Divs_afd" to change the reservoir's releases based on what scenario is selected. This is shown in **Figure 4**. This code prevents Lake McConaughy from releasing water to satisfy surface water irrigation demand in the Keith-Lincoln district for both scenarios. In Scenario 2 Keith-Lincoln only pulls water from the North Platte River when water is available based on their water right instead of water being diverted as part of a specific irrigation demand call from Lake McConaughy.

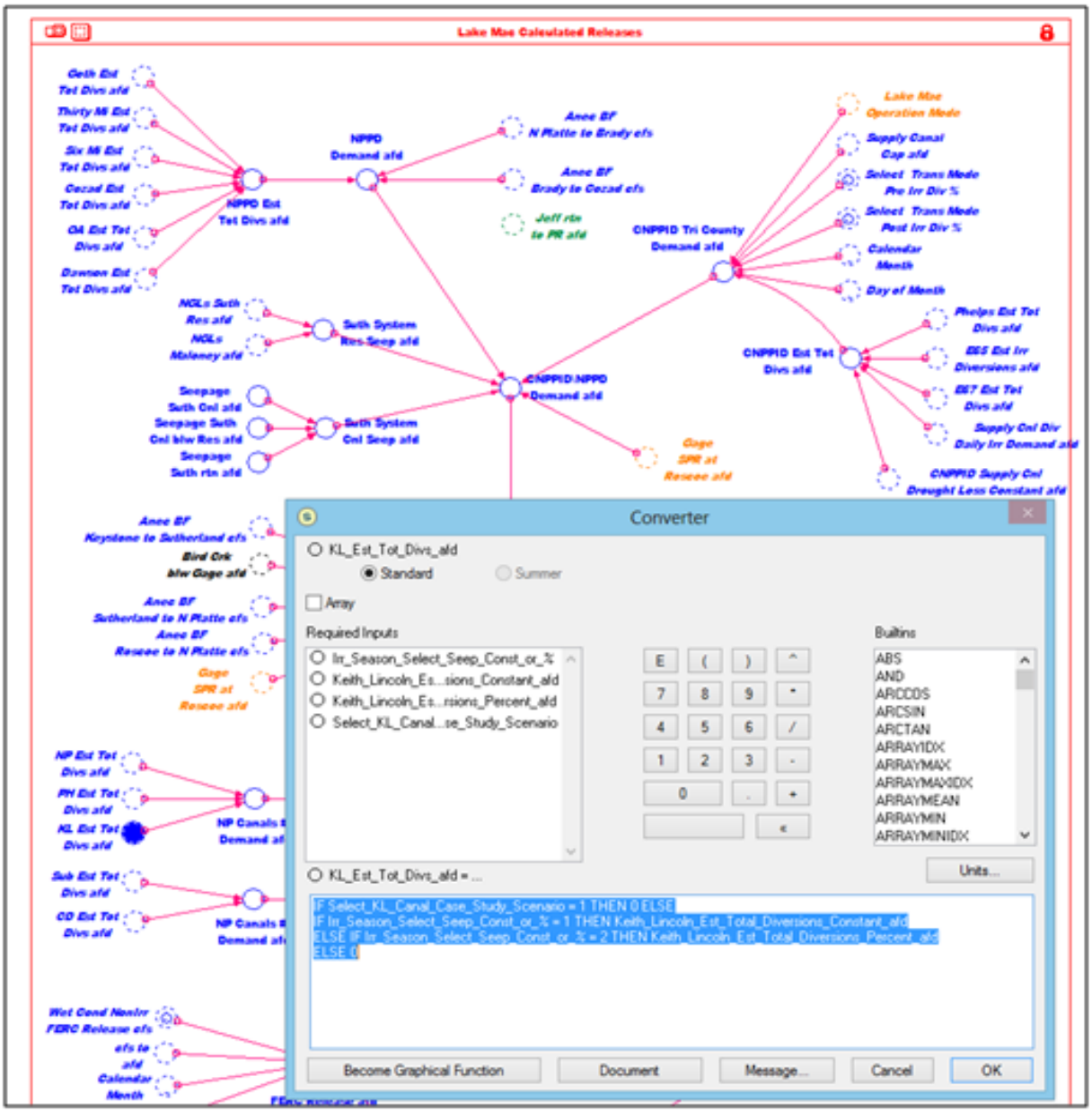


Figure 4: Change to Lake McConaughy Releases in STELLA

Scenario Results

In February 2015 the results of the first attempt at a manual integrated model run were presented at a COHYST workshop and were checked against independent HDR runs. The results showed excessive groundwater declines outside of the Keith-Lincoln area to the southwest of the canal many miles away. The canal diversion gages also showed incorrect diversions for the Orchard Alfalfa canal and surrounding districts as a result. These results were not expected and, upon comparison with the independent review model runs, were shown to be incorrect. After checking that the model changes were set up correctly in the preparation phase of the modeling, error in the integrated modeling process was determined to be the cause by the independent review. Because of the complexity of the model setup and operation, the exact step or steps in which the user error or errors occurred were not determined in this study or by the independent reviewers.

After COHYST 2010 model updates including a major update to the stream package in MODFLOW, another manual run was performed for the Keith-Lincoln scenarios in the July 2015. The results of this run showed groundwater changes near the Keith-Lincoln Canal that were close to the independent review, but also showed large recharge to the groundwater occurred around Sutherland Reservoir and Lake Maloney that did not match the independent review. In addition, erroneous diversions occurred at the Orchard Alfalfa canal. With the model setup confirmed correct, the differences in the model run from the independent review occurred during the integrated run process when the Orchard Alfalfa demands were incorrectly altered and effected the entire system due to incorrect Lake McConaughy releases.

The latest runs of the Keith-Lincoln scenarios were performed with the Graphical User Interface (GUI) developed by HDR for the COHYST 2010 model. For these runs, the same modeling changes to the watershed and surface water models were implemented as before but the model was run entirely through the GUI instead of the manual integrated modeling process. The Lake McConaughy releases were also hardcoded in the STELLA model for each scenario. The hardcoding of Lake McConaughy releases were determined to be the correct process during the development of the GUI. The HDR consultants found that scenario changes could trigger different reservoir release conditions than those found in the baseline, making scenario change comparisons to the baseline difficult. By insuring that Lake McConaughy releases are the same in the scenarios and the baseline, any changes between scenario runs and baseline runs are attributed to directly to the scenario model run. For the Keith-Lincoln scenario runs, the results were compared to the baseline Run026 of the model. Head change results from the groundwater model are shown in **Figures 5, Figure 6, and Figure 7**.

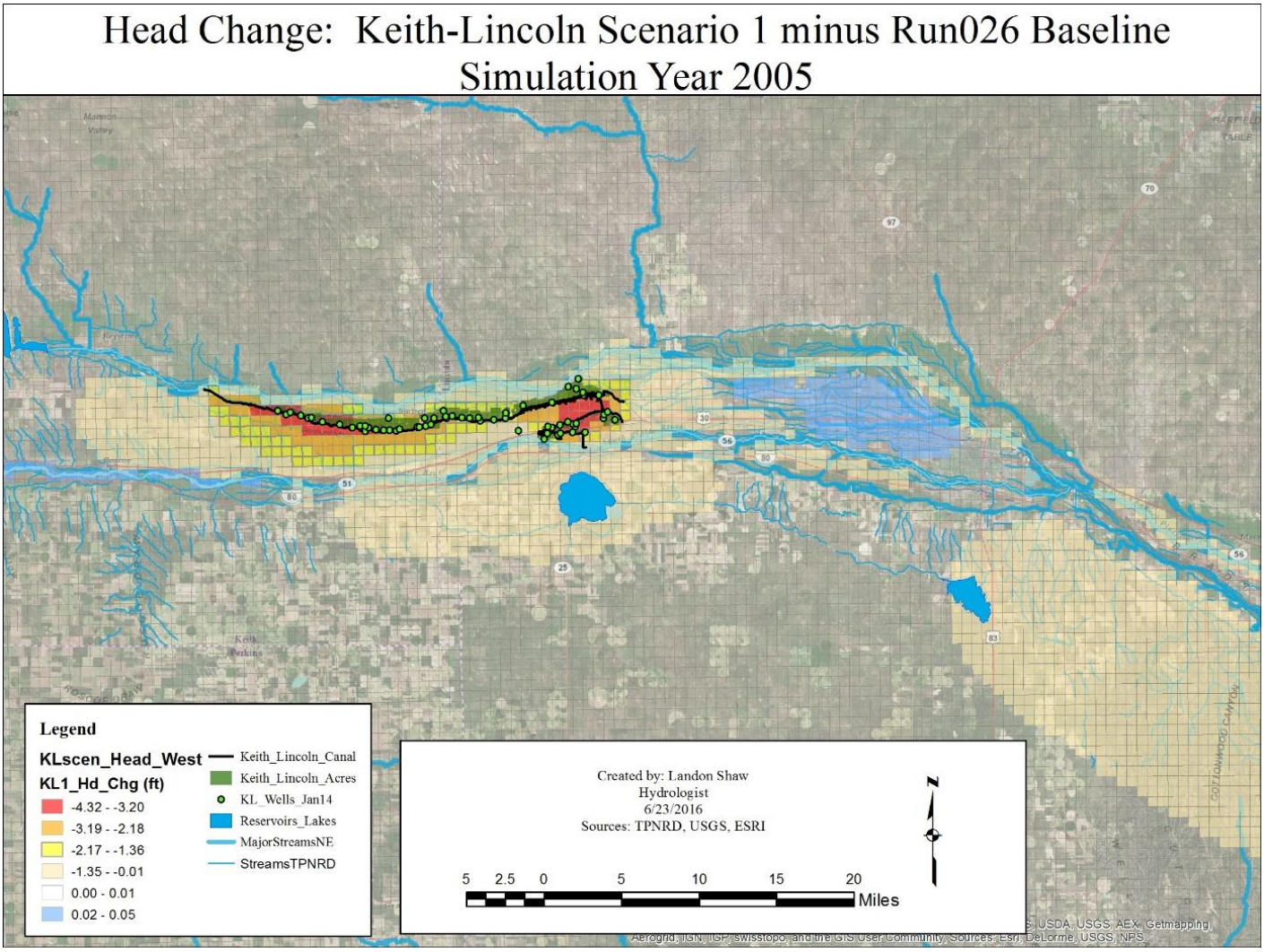


Figure 5: Aquifer Head Change Keith-Lincoln Scenario 1 from Baseline Run026

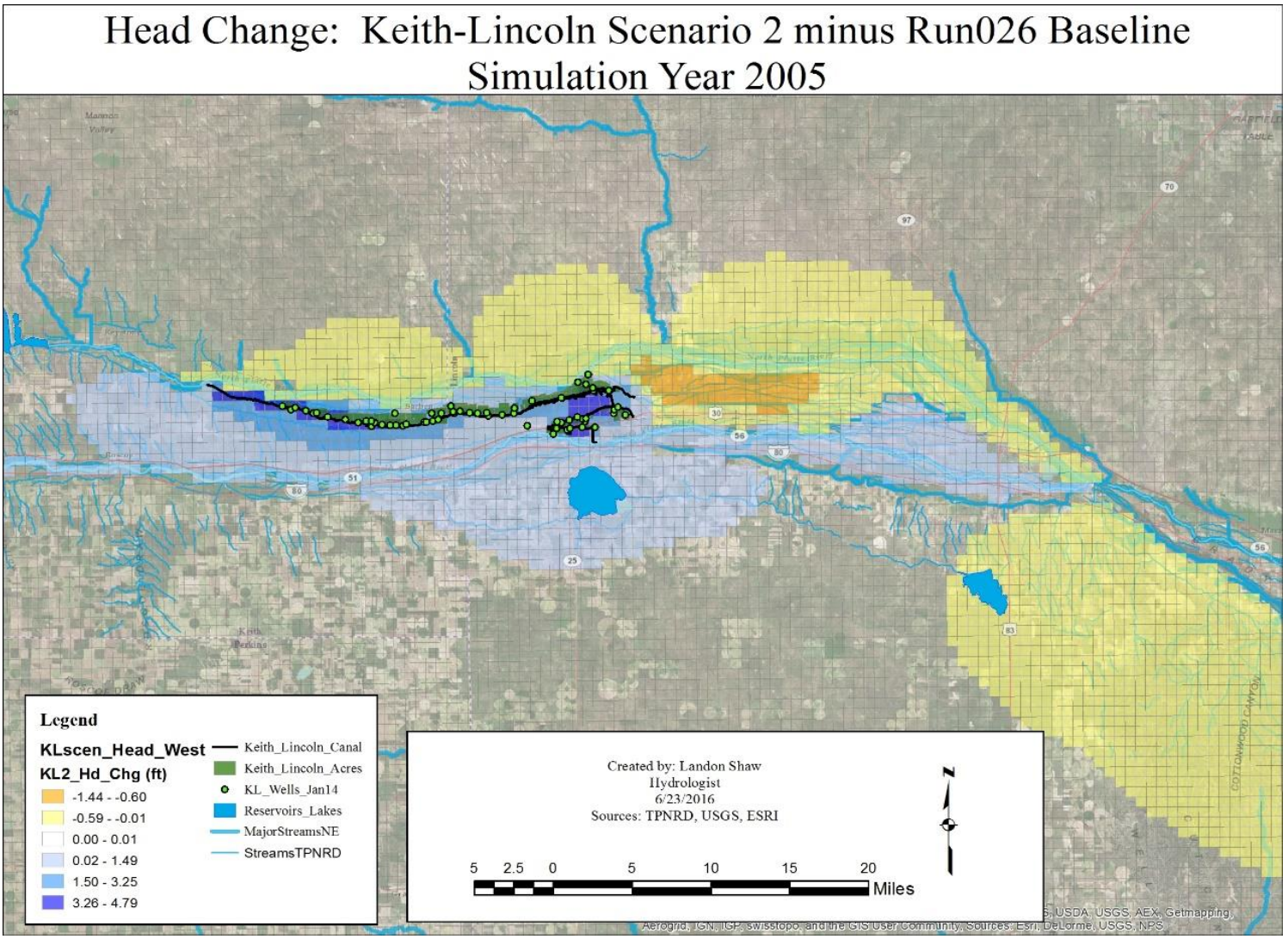


Figure 6: Aquifer Head Change Keith-Lincoln Scenario 2 from Baseline Run026

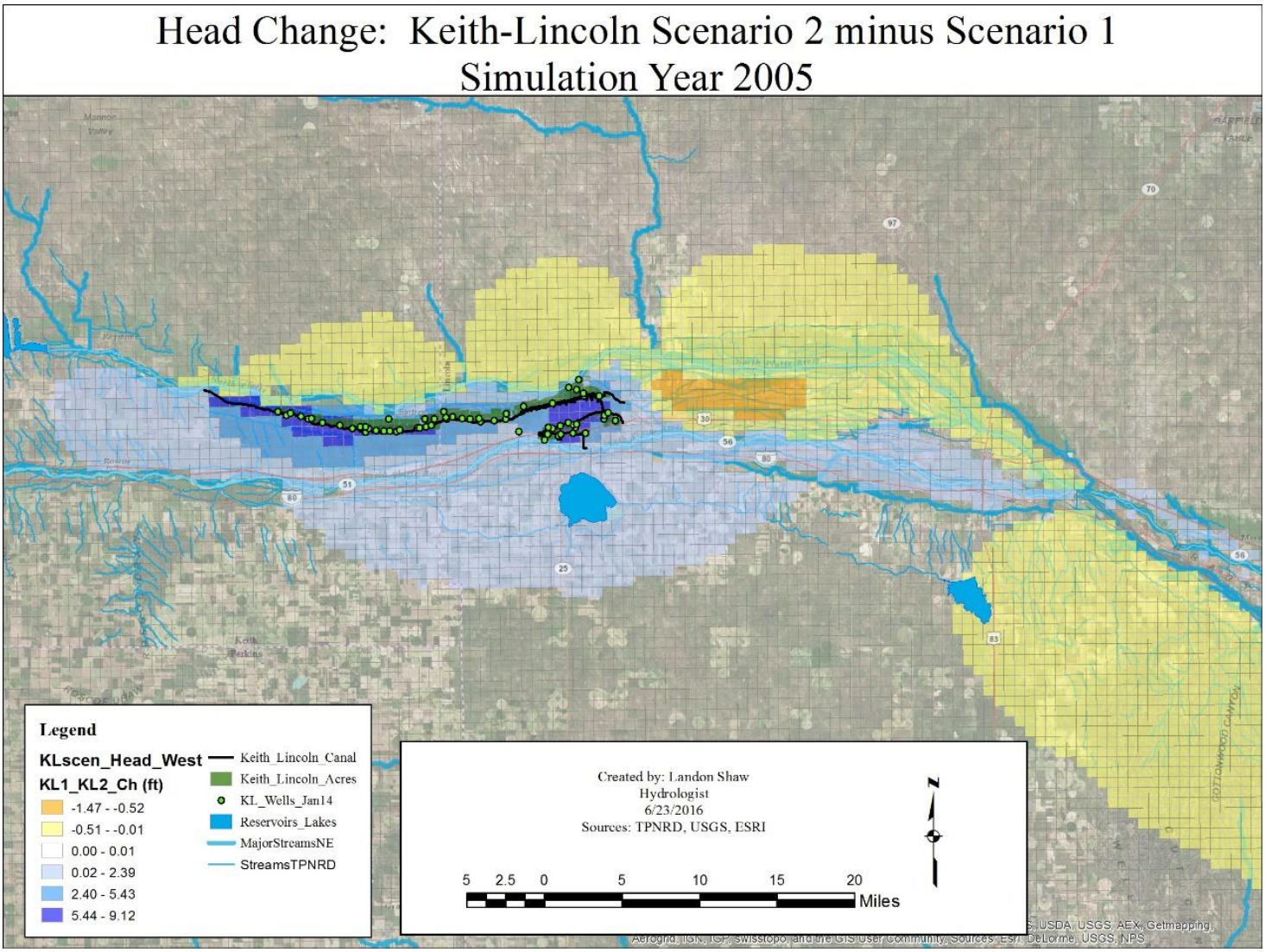


Figure 7: Aquifer Head Change Keith-Lincoln Scenario 2 from Scenario 1

Near Keith-Lincoln canal the groundwater head change results from the GUI run were found to closely match the independent review, with a few slight differences. The slight differences between GUI runs and manual runs were in the Keystone diversion and where determined to be negligible as explained in their project documentation for the development of the GUI. In scenario 1 (**Figure 5**), there are no diversion into Keith-Lincoln canal and increased groundwater pumping which results in decreased groundwater levels along the canal as expected. This is due to the elimination of recharge from historically diverted water and the increase of groundwater pumping. The water level declines are most prominent near the wells along the canal and cone out from there. They are greatest near the beginning and end of the canal with maximum water level declines of close to 4 feet.

For Scenario 2 (**Figure 6**), the increase of diversions into the canal are shown to have increased groundwater levels along the canal while decreasing water levels directly to the East. This matches the expected results where recharge occurs along the canal and less water is found in the North Platte River after the canal diversion structure. Without irrigation deliveries along the canal and overall more water diverted along the canal, we can see greater recharge than in the baseline run. Maximum groundwater level declines to the west are close to 1.5 feet and maximum groundwater level increases are close to 5 feet right along the canal. The slight declines in the groundwater table above the North Platte river where not expected, but could be explained by increased baseflow activity in the river up gradient due to less river flow than there was historically. The results also show slight increases in groundwater levels along the Korty Canal and Sutherland Canal for Scenario 2 and slight decreases in groundwater levels in this same area in Scenario 1. This is likely due to the baseflow increase or decrease tied to Keith-Lincoln canal recharge.

The changes in the South Platte River canal diversions are seen in **Tables 1**, **Table 2**, and **Table 3** of the surface water model results. **Table 1** and **Table 2** show increased Keystone diversions of about 1270 AF for both scenarios. These results may show that there are slight differences in the GUI generated runs verses the independent consultant manual runs. While ideally the two runs should be identical, the differences are being documented and were determined to be acceptable and explainable by the COHYST technical committee. The explanation can be found in the HDR model documentation. In the future, these small differences may be addressed.

Location of Gage / Canal	Average Annual Diversions (ac-ft/yr)			What happened in the model	What was expected
	Run026	KL1	Delta		
Key Div afd	679,725	680,995	1,270	more div in KL1, small	same releases
KL Canal afd	13,296	0	-13,296	no diversion for KL1	No diversion for KL1
NP Canal Div afd	40,355	40,613	258	Increase in water available for NP canals	Increase in water available for NP canals
PH Canal afd	14,447	15,226	779		
Sub Canal afd	18,406	18,871	465		
CD Canal Div afd	5,183	5,183	0		
Bird Canal afd	11,673	11,673	0		
West Canal afd	14,835	14,835	0		
Korty Div afd	181,448	181,359	-89	Change in SP river canal diversions	Little change expected, KL recharge decrease
Suth Cnl afd	832,603	833,778	1,175		
TriCo Div afd	1,087,326	1,085,625	-1,700	Less diversion into TriCo	Less diversion into TriCo
Goth Div afd	50,033	50,040	6	Negligable to small changes to PR downstream of North Platte	Negligable to small changes to PR downstream of North Platte
Thirty Mi Div afd	32,029	32,060	31		
Six Mi Canal afd	2,066	2,066	0		
Cozad Div afd	24,803	24,811	8		
Orch Alf Canal afd	7,387	7,387	0		
Dawson Div afd	62,479	62,639	159		
Phelps Canal Div afd	102,321	102,404	84		
Kearney Div afd	77,809	77,815	7		
E65 Div afd	90,326	90,309	-18		
E67 Canal afd	9,201	9,201	0		
Jeff rtn afd	48,167	46,982	-1,184		
J2 rtn afd	549,885	549,410	-475		
Suth rtn afd	696,244	697,411	1,167	Increased suth rtn	Not expected
Gage NPR at Lewellen afd	881,190	881,190	0		
Mac\Ogal Rel to NPR afd	889,116	888,496	-620	KL1 < Mac releases than Run026	No change expected
Gage NPR nr Key afd	209,391	207,502	-1,890	Smaller KL1 Key diversions	Not expected
Gage NPR nr Suth afd	211,720	217,081	5,360	Increased water in NP river	Increased water in NP river from KL water right
Gage NPR at NP afd	329,027	334,398	5,371		
Gage SPR at Jules afd	423,866	423,866	0	Decrease of water in SP river	Decrease of water in SP river due to shut off KL div
Gage SPR at Roscoe afd	409,113	409,110	-3		
Gage SPR at Paxton afd	236,516	235,717	-799		
Gage SPR at NP afd	314,590	309,172	-5,418		
Gage PR blw TriCo Div afd	277,580	280,762	3,182	Increase of water for KL1 in the Platte River compared to baseline	Increase of water for KL1 in the Platte River compared to baseline from KL water right left in the river
Gage PR at Brady afd	317,816	320,969	3,153		
Gage PR nr Cozad afd	316,852	318,506	1,654		
Gage PR nr Overton afd	974,198	975,390	1,191		
Gage PR nr Odessa afd	1,016,903	1,018,241	1,338		
Gage PR nr Kearney afd	1,024,744	1,026,084	1,340		
Gage PR nr Gl afd	1,140,620	1,141,965	1,345		
Gage PR nr Duncan afd	1,271,612	1,272,952	1,340		

Table 1: Keith-Lincoln Scenario 1 Summary of Surface Model Results

Note: Delta is calculated by subtracting Run026 (baseline) from KL1 (no diversions)

Location of Gage / Canal	Average Annual Diversions (ac-ft/yr)			What happened in the model	What was expected
	Run026	KL2	Delta		
Key Div afd	679,725	680,994	1,270	More diversions in KL2	Same releases
KL Canal afd	13,296	35,512	22,216	KL2 has higher diversions	KL2 has higher diversions
NP Canal Div afd	40,355	39,184	-1,171	Smaller diversions into NP, PH, Sub NP canals for KL1 because of more water in NP river	Smaller diversions into NP, PH, Sub NP canals for KL1 because of more water in NP river
PH Canal afd	14,447	12,322	-2,125		
Sub Canal afd	18,406	18,180	-226		
CD Canal Div afd	5,183	5,183	0		
Bird Canal afd	11,673	11,673	0		
West Canal afd	14,835	14,835	0		
Korty Div afd	181,448	181,359	-89	creased Korty/Suth canal diversio	No change expected
Suth Cnl afd	832,603	833,778	1,175		
TriCo Div afd	1,087,326	1,086,918	-408	Less diversions in TriCo and negligable to small increases in downstream canals	More diversions in TriCo and small increases in downstream canals
Goth Div afd	50,033	50,066	33		
Thirty Mi Div afd	32,029	32,177	149		
Six Mi Canal afd	2,066	2,066	0		
Cozad Div afd	24,803	24,814	11		
Orch Alf Canal afd	7,387	7,387	0		
Dawson Div afd	62,479	62,708	229		
Phelps Canal Div afd	102,321	102,469	148		
Kearney Div afd	77,809	77,834	26		
E65 Div afd	90,326	90,365	39		
E67 Canal afd	9,201	9,201	0		
Jeff rtn afd	48,167	48,463	296		
J2 rtn afd	549,885	549,003	-881		
Suth rtn afd	696,244	697,411	1,167	larger return in KL2	not expected, due to
Gage NPR at Lewellen afd	881,190	881,190	0		
Mac\Ogal Rel to NPR afd	889,116	888,496	-620	KL2 has less Mac releases	No change expected
Gage NPR nr Key afd	209,391	207,501	-1,890	KL2 diverts NP water into KL, less water for NP canals	KL2 diverts NP water into KL, less water for NP canals
Gage NPR nr Suth afd	211,720	191,786	-19,935		
Gage NPR at NP afd	329,027	307,559	-21,468		
Gage SPR at Jules afd	423,866	423,866	0		
Gage SPR at Roscoe afd	409,113	409,112	-1		
Gage SPR at Paxton afd	236,516	236,886	370		
Gage SPR at NP afd	314,590	335,512	20,921	Scenario KL2 has KL returns to SP	KL diversion returns to SP
Gage PR blw TriCo Div afd	277,580	278,424	844	Increases and decreases of water in the Platte River compared to baseline downstream of North Platte	Greater increases in Platte River flows from KL return. Difference between KL recharge and returns?
Gage PR at Brady afd	317,816	318,675	859		
Gage PR nr Cozad afd	316,852	317,273	421		
Gage PR nr Overton afd	974,198	973,748	-450		
Gage PR nr Odessa afd	1,016,903	1,016,666	-237		
Gage PR nr Kearney afd	1,024,744	1,024,511	-232		
Gage PR nr Gl afd	1,140,620	1,140,423	-197		
Gage PR nr Duncan afd	1,271,612	1,271,418	-194		

Table 2: Keith-Lincoln Scenario 2 Summary of Surface Model Results

Note: Delta is calculated by subtracting Run026 (baseline) from KL2 (diversions)

Location of Gage / Canal	Average Annual Diversions (ac-ft/yr)			What happened in the model	What was expected
	KL1	KL2	Delta		
Key Div afd	680,995	680,994	0	Same diversions	Same diversions
KL Canal afd	0	35,512	35,512	KL2 diversions, KL1 zero diversions	KL2 diversions, KL1 zero diversions
NP Canal Div afd	40,613	39,184	-1,429	Smaller diversions into NP canals NP, PH, Sub, CD for KL2	Smaller diversions into NP, PH, Sub NP canals for KL2 because of more water in NP river in KL1
PH Canal afd	15,226	12,322	-2,903		
Sub Canal afd	18,871	18,180	-691		
CD Canal Div afd	5,183	5,183	0		
Bird Canal afd	11,673	11,673	0		
West Canal afd	14,835	14,835	0		
Korty Div afd	181,359	181,359	0		
Suth Cnl afd	833,778	833,778	0		
TriCo Div afd	1,085,625	1,086,918	1,293	Little to modest increased diversions in Scenario KL2 because of more water bypassing	More diversions in Scenario KL2 because of more water bypassing NP canals and returned to SP river
Goth Div afd	50,040	50,066	26		
Thirty Mi Div afd	32,060	32,177	118		
Six Mi Canal afd	2,066	2,066	0		
Cozad Div afd	24,811	24,814	2		
Orch Alf Canal afd	7,387	7,387	0		
Dawson Div afd	62,639	62,708	70	Small increase in diversion for KL2	Small decrease in diversions for KL2
Phelps Canal Div afd	102,404	102,469	64		
Kearney Div afd	77,815	77,834	19		
E65 Div afd	90,309	90,365	56		
E67 Canal afd	9,201	9,201	0		
Jeff rtn afd	46,982	48,463	1,481	More returns in KL2 with more diversions	More returns in KL2
J2 rtn afd	549,410	549,003	-407		Not expecting less returns from J2
Suth rtn afd	697,411	697,411	0		
Gage NPR at Lewellen afd	881,190	881,190	0		
Mac\Ogal Rel to NPR afd	888,496	888,496	0		
Gage NPR nr Key afd	207,502	207,501	0		
Gage NPR nr Suth afd	217,081	191,786	-25,295	KL2 diverts NP water into KL, less water in NP River	KL2 diverts NP water into KL, less water in NP River
Gage NPR at NP afd	334,398	307,559	-26,838		
Gage SPR at Jules afd	423,866	423,866	0		
Gage SPR at Roscoe afd	409,110	409,112	2		
Gage SPR at Paxton afd	235,717	236,886	1,169		
Gage SPR at NP afd	309,172	335,512	26,339	Scenario KL2 has KL returns to SP	KL diversion returns to SP
Gage PR blw TriCo Div afd	280,762	278,424	-2,338	Declines of water in the Platte River compared to KL1	Less water in PR downstream of North Platte due to KL diversions
Gage PR at Brady afd	320,969	318,675	-2,294		
Gage PR nr Cozad afd	318,506	317,273	-1,233		
Gage PR nr Overton afd	975,390	973,748	-1,641		
Gage PR nr Odessa afd	1,018,241	1,016,666	-1,575		
Gage PR nr Kearney afd	1,026,084	1,024,511	-1,572		
Gage PR nr GI afd	1,141,965	1,140,423	-1,543		
Gage PR nr Duncan afd	1,272,952	1,271,418	-1,534		

Table 3: Keith-Lincoln GUI run Summary of Surface Model Results

Note: Delta is calculated by subtracting KL1 (no diversions) from KL2 (diversions)

Conclusions

After running the integrated COHYST 2010 model manually and with the GUI, it is clear that the GUI is more accessible for model users outside of the inner circle of COHYST developers. Running the model manually allows for a much greater chance of user error due to the complexity of procedures. Despite the usefulness of the GUI, there are still small model inconsistencies between a GUI run and manual run as shown by the comparison done in the independent review. With these small differences documented, the GUI for the COHYST 2010 model is suggested to become the standard for further use.

The case test also shows that significant modeling modifications are needed even for relatively simple management scenarios. Modifications to canal and river systems require Stella model changes to logic trees that must branch all the way upstream to Lake McConaughy. Changes in a scenario's land use require watershed model input file modifications and consistencies in naming conventions. Groundwater change analysis must be considered spatially in terms of the groundwater model grid cells that are 160 acres each. Although the GUI automation has drastically improved the modeling process, in depth expertise is needed to accurately set up the model for management scenarios.

Technical results for the Keith-Lincoln case test show useful change modeling results for the canal itself and the immediate surrounding area. The changes to the groundwater levels around the scenario focus points show expected and explainable results. There are also changes in canal diversion and river gage values that are not as easily explained, particularly in the Keystone canal. The differences show that the model is sensitive to small changes made through scenarios, there are changes that occur that are hard to explain, and that there are small differences between the COHYST GUI and independent runs. System wide changes are expected to some degree in a fully integrated model, but sensitivities are something that need to be evaluated further by the COHYST technical committee.

In conclusion the objectives of this study were met and the GUI looks to be a useful tool for running scenarios in the COHYST model while noting the differences between a GUI and independent run. Moving forward, it is recommended that the differences between the GUI COHYST model runs and independent review manual runs continue to be evaluated. First, the operation modes present in the Stella model for Lake McConaughy should be evaluated in their response to the Keith-Lincoln case test changes. Finding the operational trigger differences that are present in each approach is necessary to explain and fix differences. Additionally, it is suggested that any change model runs similar to the Keith-Lincoln case test should use the hard coded mode of operation to match the independent review. This will isolate the model results apart from Lake McConaughy operations to determine if the GUI runs and independent review runs contain additional inconsistencies.