Appendix A - Hydrology

Hydrologic Operations Model

Burns & McDonnell's (B&M) Reservoir Network (RESNET) computer simulation model was used to evaluate potential hydrologic impacts for the Integrated Local Water Supply (ILWS) system. The model performs a daily simulation of reservoirs and streams as a circulating network and uses least-cost optimizing procedures to arrive at an optimized solution. The model is based on the Microsoft ACCESS database application and utilizes the database to contain the model input data, output data, and other modeling and solution control parameters and functions.

The operations model calculates a daily water balance for the ILWS system during the 85-year model simulation period (water years [WY] 1923–2007). The model requires the following general data sets for operation:

- Historical mean daily stream discharge at selected points within the project area
- Historical monthly reservoir evaporation rates
- Available storage and other physical data for Cheney Reservoir
- Available storage, natural recharge and other parameters for the Equus Beds aquifer
- City's current and projected water demands
- Irrigation demands for agriculture in the Equus Beds Well Field area
- Minimum desirable streamflow requirements
- Supply capability and other operating parameters for all current and potential water supply sources
- Preferred allocation order for each water supply source

B&M previously utilized the model (based on WY 1923-1996) to evaluate impacts by the ILWS system alternatives for Wichita's 2003 Environmental Impact Statement (EIS)[1]. Appendix C from the 2003 EIS describes the general construct and operations of the model. Reclamation reviewed the 2003 EIS and requested additional documentation from B&M regarding key components of the model. The request for additional information included:

- Details regarding the structure, operations, and data comprising the RESNET database model, and development of executable version of the model for Reclamation (included as Attachment A).
- Supporting documentation for the development of the aquifer-stream gain-loss table (included as Attachment B).
- Details on the development of historic streamflow discharge for RESNET model nodes (included as Attachment C).
- Details on the development of historic evaporation from Cheney Reservoir (included as Attachment D).

This additional requested information is presented as Attachments A-D of this Hydrology Appendix.

Scenarios Evaluated

Three alternatives were simulated by the model for the purposes of the current EIS:

[1] Final Environmental Impact Statement for Integrated Local Water Supply Plan, Wichita, Kansas; prepared by City of Wichita, Department of Water and Sewer; 2003

- Current – This alternative simulates what might be considered the current level-of-development on the supply system. It utilizes the year 2000 raw water demands for the City of Wichita and assumes no components of the ILWS project are in place (including those of phase 1 already built).

- No-Project – This alternative is same as Current above, except the City of Wichita raw water demands are projected to year 2050.

- ILWSP100 – This alternative includes the following proposed components of the ILWS and uses City of Wichita raw water demands projected to year 2050:
    - Aquifer storage and recovery (ASR) project features to capture 60 MGD (million gallons per day) of induced infiltration groundwater and 40 MGD of direct diversion of surface water from Little Arkansas River (ASR)
    - Redevelopment of the Bentley Reserve Well Field
    - Expansion of the Local Well Field

Model Operational Period-of-Record -
A product of the above review process of the 2003 version of the model was the extension of the modeling period by 11 years by B&M to include more current information. The current modeling period now covers an 85-year period and extends from water years 1923 through 2007. The model utilizes historic recorded and estimated daily streamflows and climatological data for that period. The use of this historic sequence for evaluating the proposed system is premised on the assumption that the past historic climatologic sequence will repeat itself in the future. This period includes significant drought events occurring during the 1930's and 1950's.

Model System Network -
A diagram displaying the model network is shown if Figure 1 of Attachment A. The model is comprised of 20 nodes at which daily demands and flows are calculated. Two of the nodes represent system storage: Cheney Reservoir and the Equus Beds Aquifer. Model nodes are connected together by various links representing stream connections, aquifer-stream interactions (accretions and infiltration to and from stream and aquifer), or diversion delivery pipelines. More detailed information on model structure, node connectivity, and decision parameters can be found in Attachment D.

Model Inflows -
Inflows to model stream nodes, and flow gains (unregulated flow) between stream nodes were derived from historic U.S. Geological Survey (USGS) recorded flows at various stations in the basin. Results from the groundwater/surface water interaction analyses in Attachment B were used to adjust unregulated flow in the model to eliminate 'double accounting' of model calculated return flows (see Section 6 – Attachment C).

For nodes where recorded discharge data were incomplete for the entire modeling period, regression analyses and drainage area ratios were used to estimate missing data. See Attachment C for further details on generation of model flow data.

Model Demands –
The model utilizes two primary demands to be applied to the water supply system:
- City of Wichita raw water demands.
- Agricultural diversions from Equus Beds Aquifer.

For the 'Current' modeling scenario, City of Wichita's demands are based on year 2000 average-day demand. For the 'No Project' and 'ILWSP100' alternatives, the demand is based on Wichita's year 2050

average day demand. More details on the development of demands can be found in section 1.5.1 of Attachment A of this Appendix, and in Appendix C of the 2003 EIS.

The agricultural demand from the aquifer is based on an average annual value of 26,500 acre-feet which is distributed evenly over the growing season of mid-May through mid-September (Sect. 1.5.6, Attachment A).

Cheney Reservoir -
Current area-capacity-elevation data are used by the model to calculate pool elevation and reservoir surface area for a given storage volume in Cheney Reservoir. Section 1.3.1 and Table 8 of Attachment A displays the various reservoir allocations used.

The model calculates a daily reservoir evaporation volume based on the simulated surface area and the historic daily evaporation rate. The daily evaporation rate was derived from recorded monthly pan evaporation at Cheney, when that data were available. For months when actual pan evaporation data were not recorded, the evaporation rate was estimated by B&M using their ETCALC model. Monthly evaporation was evenly distributed over month into daily evaporation. See Attachment D for additional details on calculation of reservoir evaporation rates.

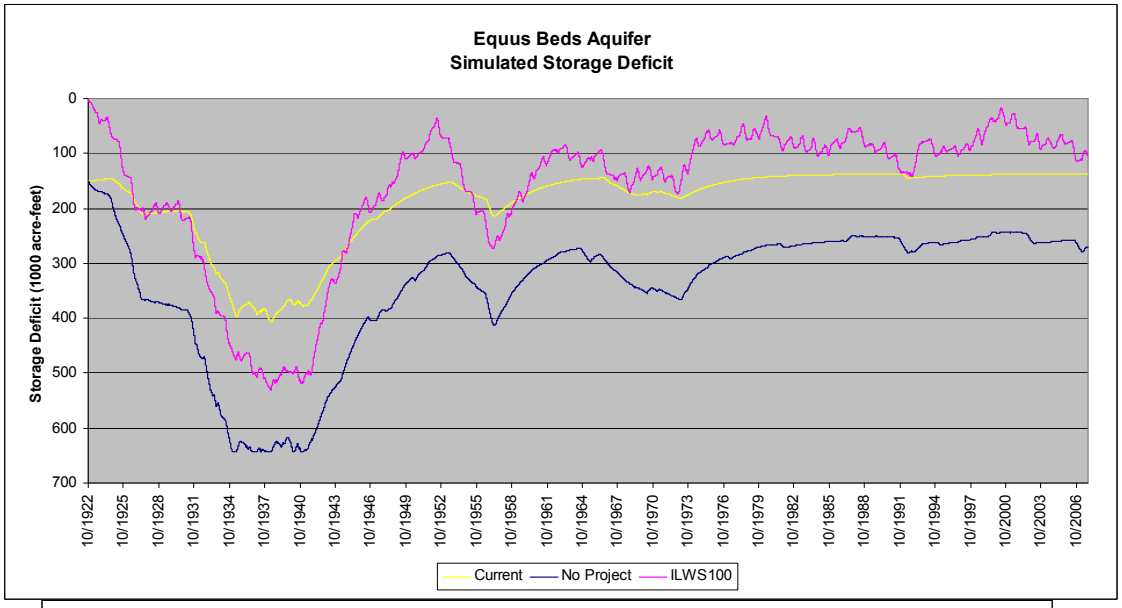
Equus Beds Aquifer -
The model operates the Equus Beds Aquifer similar to how a surface-water reservoir is operated. The USGS MODFLOW groundwater flow model was utilized by B&M to define a table that relates aquifer elevation, aquifer storage deficit, and aquifer gains and losses to the Arkansas and Little Arkansas Rivers (see Table A-1 in Attachment B). With additional model evaluation, the distribution of MODFLOW derived gain/losses to model nodes were modified as indicated in Table 9, Attachment A. The model simulates aquifer gains/losses to the following river nodes: Arkansas River near Maize, Little Arkansas River near Halstead, and Little Arkansas River near Sedgwick.

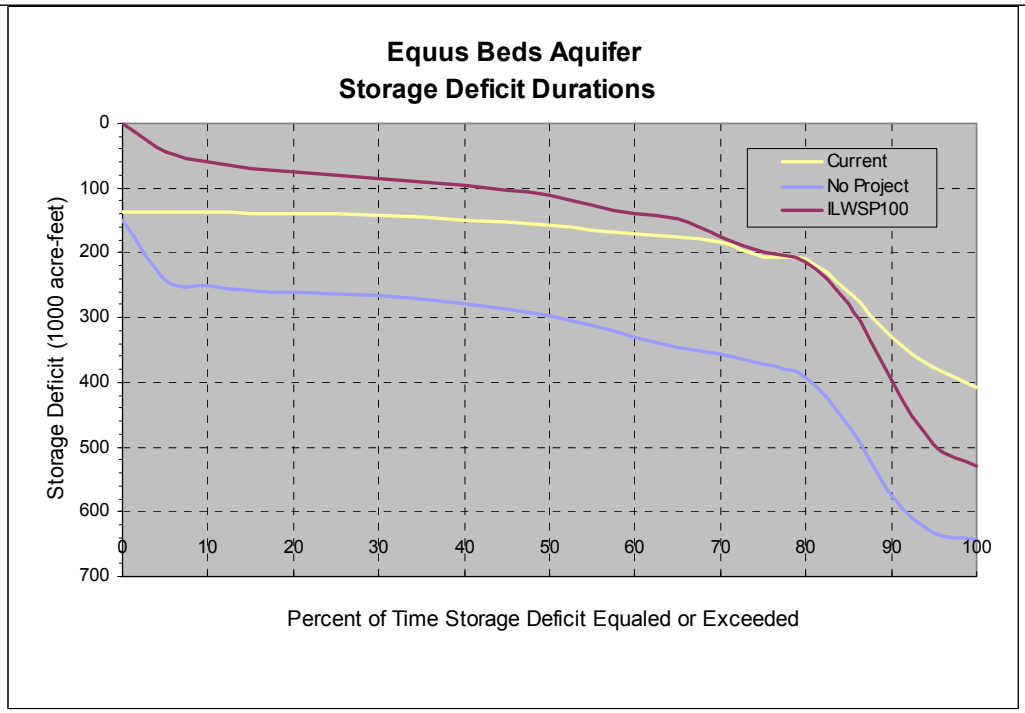
Model Simulation Results

Following is a discussion of simulation results for the three scenarios defined above. It primarily focuses on quantifying the impact differences between the future (year 2050 demands) with and without the preferred ASR 100 MGD project scenario. The inclusion of the 'current' scenario (no project implemented and year 2000 Wichita demands) in various charts is to illustrate the differences that will occur between now and the future planning horizon of year 2050, whether or not the project is implemented. The discussion is categorized by the hydrologic system potentially being impacted.

Equus Beds Aquifer -
In general, the ASR component of this project will increase the volume of water in storage within the Equus Beds aquifer available for later withdrawal. Increasing the aquifer storage volume will result in a corresponding increase in the elevation of the aquifer water table. This increases the hydraulic gradients from the aquifer to the Little Arkansas River, resulting in a potential increase in base-flow accretions to that river. It also results in a general reduction of hydraulic gradients from the Arkansas River into the aquifer, resulting in decreased infiltration from the Arkansas River to the aquifer.

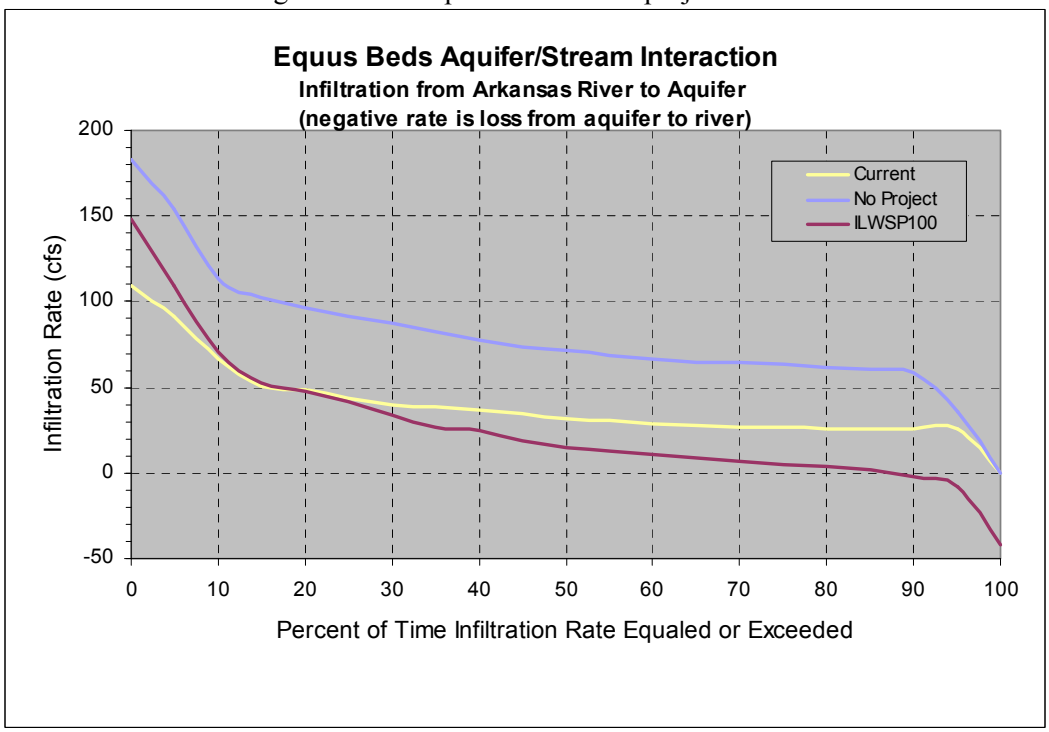
The following chart shows simulated aquifer storage deficit and monthly median water table elevations. Without implementation of the project, increasing demands will decrease aquifer storage from current conditions. With the project, aquifer storage will generally increase to levels above current conditions, with the exception of drought periods. It is estimated that for 70 percent of the time, aquifer levels will be greater than current conditions with the project in place.

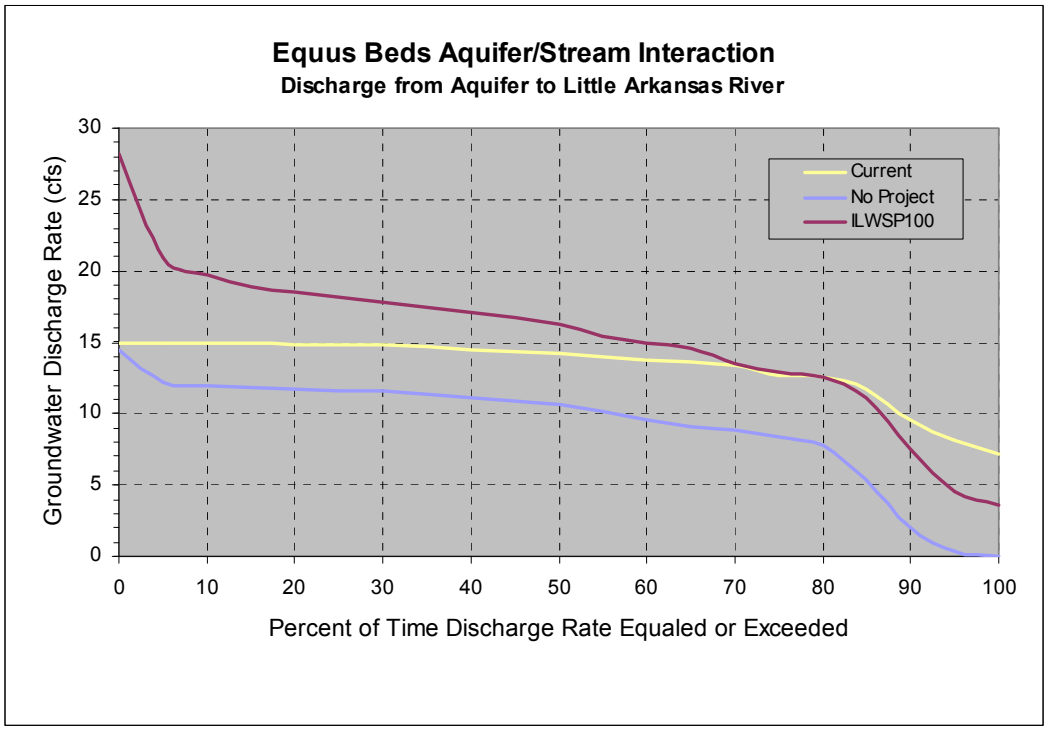




With an increase in aquifer storage, there is an associated decrease in infiltration from the Arkansas River to the aquifer, and an increase in discharge from the aquifer to the Little Arkansas River. Infiltration from the Arkansas River to the aquifer will generally decrease by about 50 cubic feet per second (cfs) for a majority of the time, as compared to without project. This will help reduce the influx of higher saline

water from the Arkansas River to the aquifer. Discharge from the aquifer to the Little Arkansas River is anticipated to increase 4 cfs or greater as compared to without project conditions.

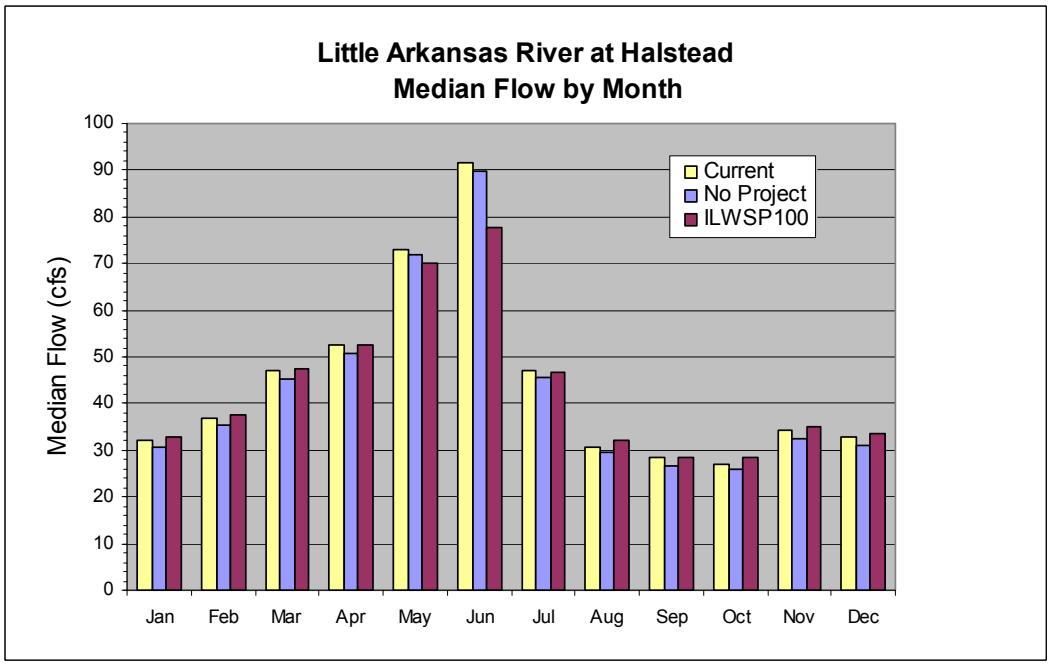




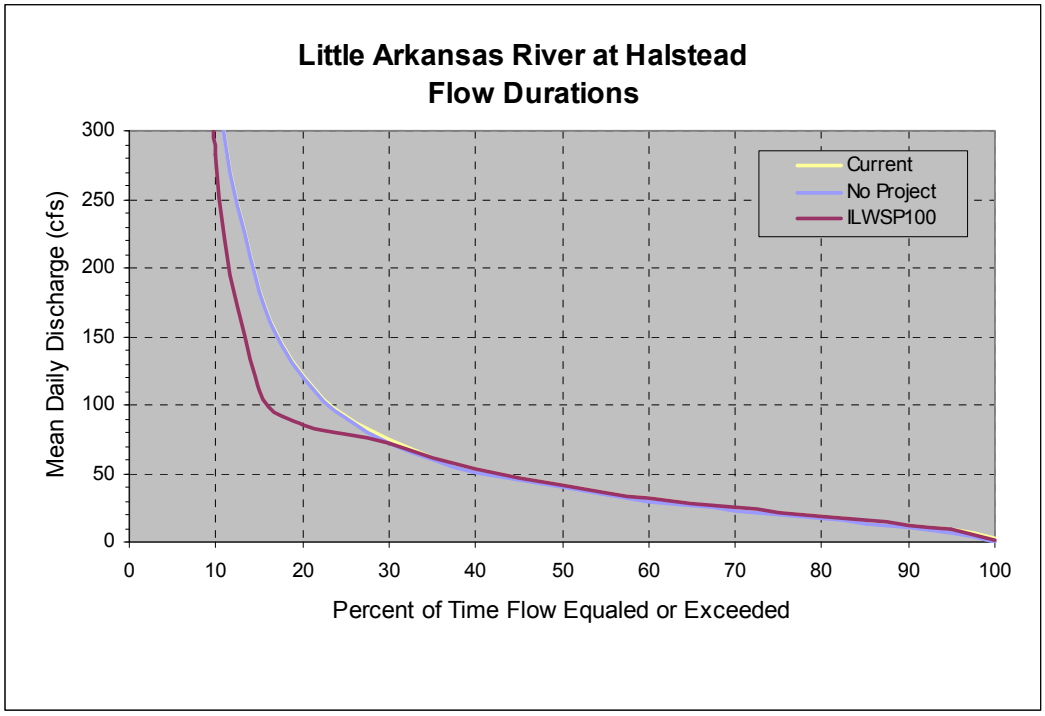
Little Arkansas River at Halstead –

Project features impacting this site are the ASR induced infiltration wells installed above this location. These wells will provide approximately half of the total ASR project diversion capacity. Recharge to the aquifer in the area above Halstead by the ASR component will result in a general increase in the aquifer

water table and a corresponding increase in baseflow accretions to the stream above this location. With the project, median discharge at Halstead is anticipated to increase from 1 to 3 cfs for all months, except May and June, when there will be declines up to 12 cfs. May and June are generally the highest flow periods and it will be during these times that the greatest diversions to the infiltration wells will occur.

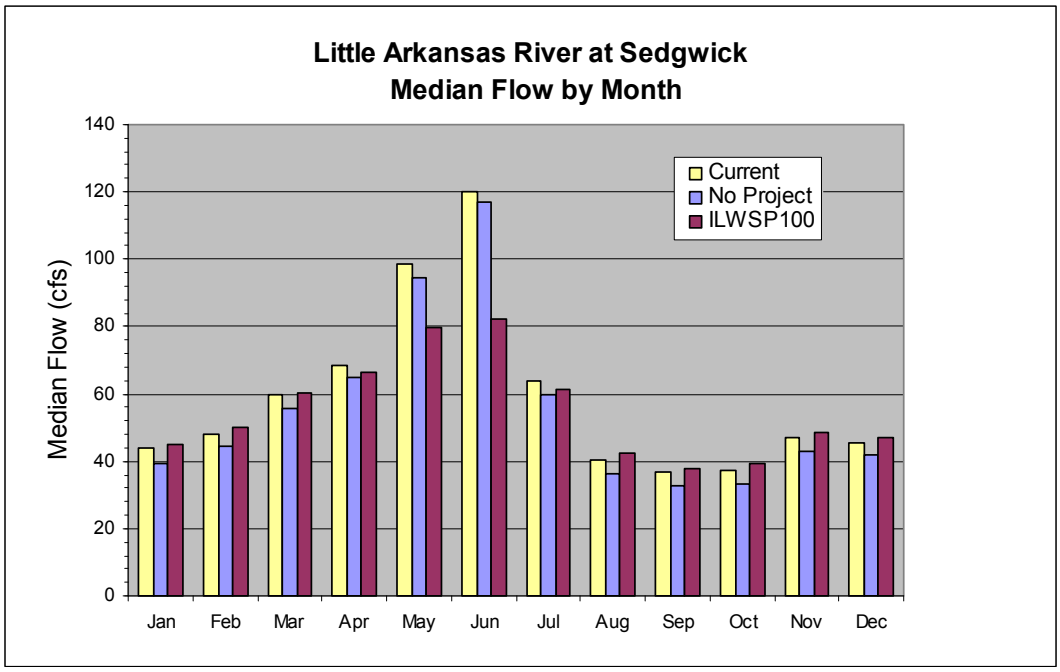


Little Arkansas River at Halstead												
Median Flow by Month (cfs)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No Project	30.5	35.3	45.1	50.6	71.8	89.7	45.6	29.6	26.7	25.9	32.6	31.1
ILWSP100	33.0	37.7	47.4	52.6	70.0	77.8	46.6	32.1	28.5	28.4	35.0	33.4
Difference	2.5	2.3	2.3	2.0	-1.8	-11.8	1.0	2.4	1.8	2.5	2.3	2.3

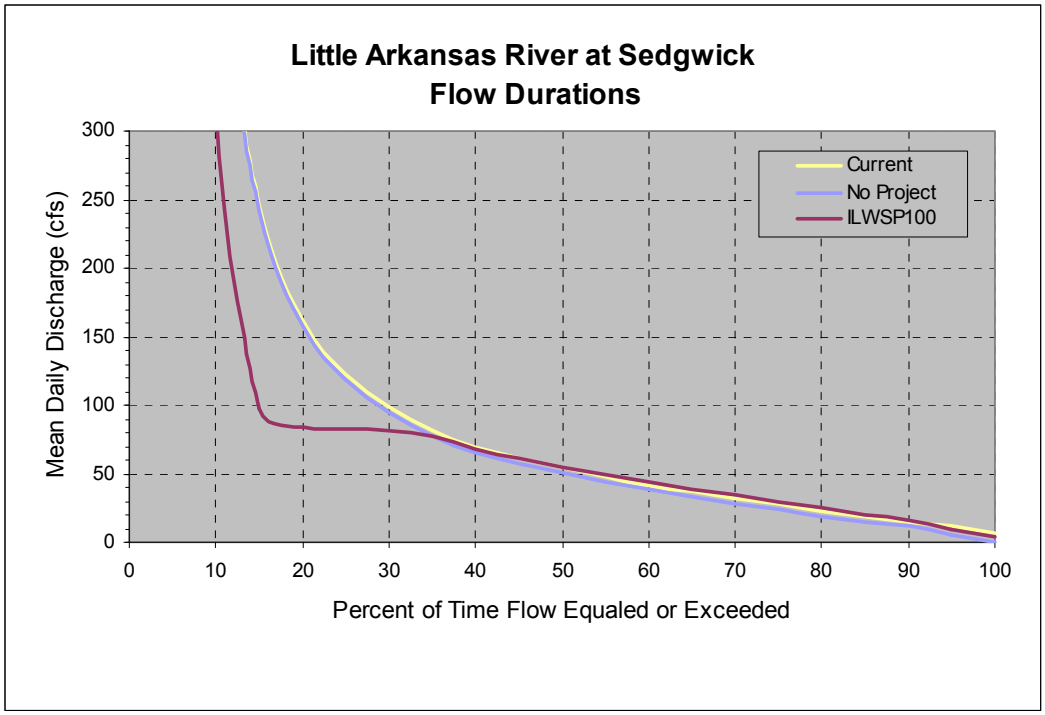


Little Arkansas River at Sedgwick -

The other half of the ASR infiltration well diversion capacity is to be installed between the Halstead and Sedgwick nodes. Sedgwick is also the location for the ASR surface water diversion site. Similar to impacts at the Halstead node, the increased recharge to the aquifer above Sedgwick will generally result in slightly higher aquifer discharge to the Little Arkansas. Median flow in the stream is expected to increase 2 to 6 cfs for all months, except May and June, when greater diversions will result in median flow declines of 15 to 35 cfs.



Little Arkansas River at Sedgwick												
Median Flow by Month (cfs)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No Project	39.3	44.2	55.8	64.7	94.4	116.9	59.7	36.4	32.5	33.4	43.0	41.7
ILWSP100	45.2	49.9	60.0	66.5	79.7	82.1	61.4	42.2	37.6	39.4	48.3	47.1
Difference	5.8	5.6	4.3	1.8	-14.7	-34.8	1.7	5.8	5.1	6.0	5.3	5.3



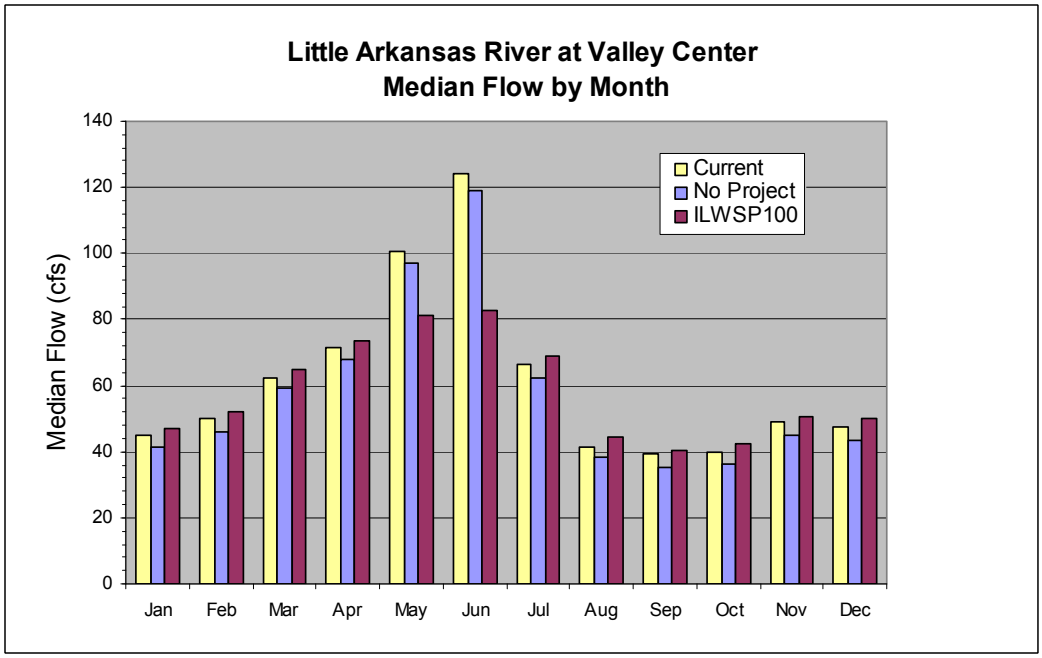
Little Arkansas River at Valley Center –

For all months except May and June, median flows at this location will increase 6 to 7 cfs with implementation of the project. This reflects the increased groundwater contributions to the Little Arkansas River above this location from increased aquifer storage. May and June exhibit a lower median flow than without project due to greater diversions occurring during those months. The simulated flow frequency curves indicate that, at lower flows, streamflow discharge will be generally slightly higher with the project than without.

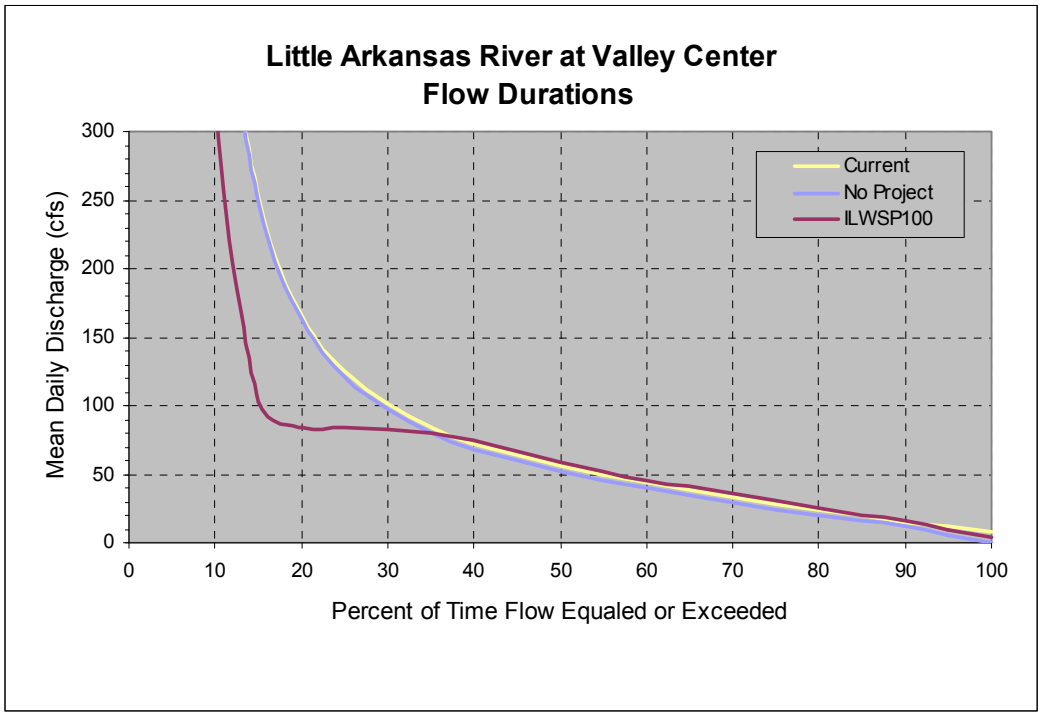
Median water surface elevations are anticipated to be about the same with project as compared to without project for all months, except May and June, when there will be declines of about 0.1 - 0.2 feet.

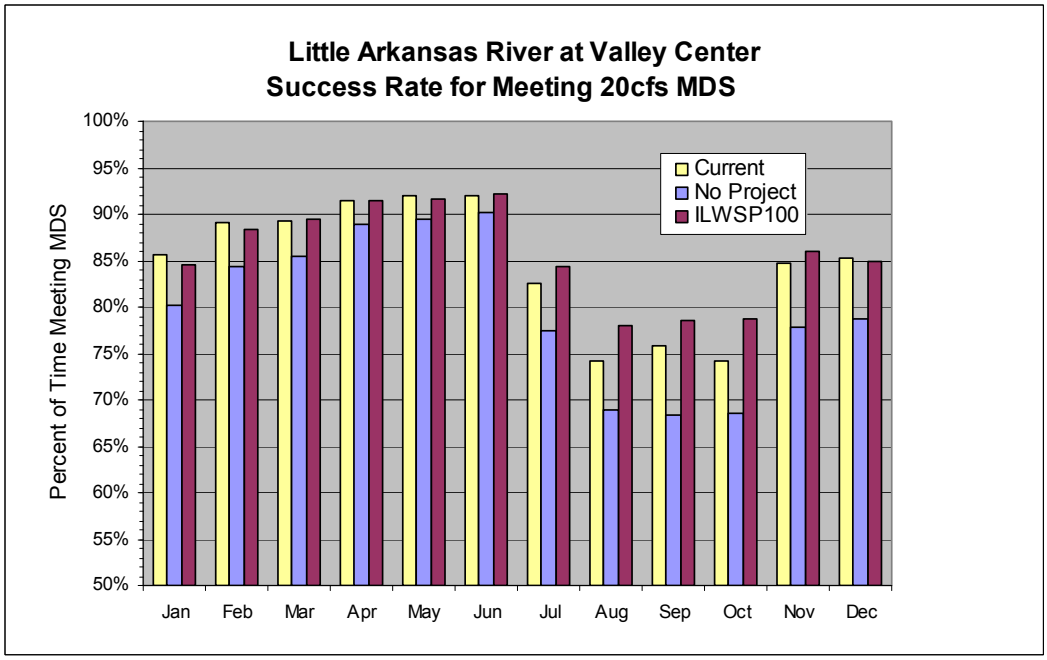
Kansas has established a minimum desirable streamflow (MDS) of 20 cfs for all months at this location. Simulated median monthly flows with the project in place are greater than the MDS. Simulated daily discharge with the project is anticipated to exceed this MDS 74 percent to 92 percent of the time, depending on month. Implementation of the project will increase the probability of streamflows meeting or exceeding the MDS as compared to without project.

The Kansas Department of Wildlife and Parks (KDWP) has recommended higher minimum flow values of 60 cfs in April, May, and June; and 34 cfs for the remaining months. The success rates for meeting those flows with the project in place will be greater than those without the project, varying from 51 percent in December to 74 percent in June.



Little Arkansas River at Valley Center												
Median Flow by Month (cfs)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No Project	41.2	45.9	59.0	67.8	97.0	119.0	62.4	38.2	35.1	36.5	44.9	43.5
ILWSP100	47.2	52.2	64.8	73.7	81.3	82.7	68.8	44.2	40.6	42.3	50.8	50.1
Difference	6.0	6.3	5.7	5.9	-15.6	-36.3	6.4	6.0	5.5	5.8	5.9	6.6




Little Arkansas River at Valley Center
Success Rate for Meeting 20cfs MDS
Percent of Time Meeting MDS
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
Jan
Feb
Mar
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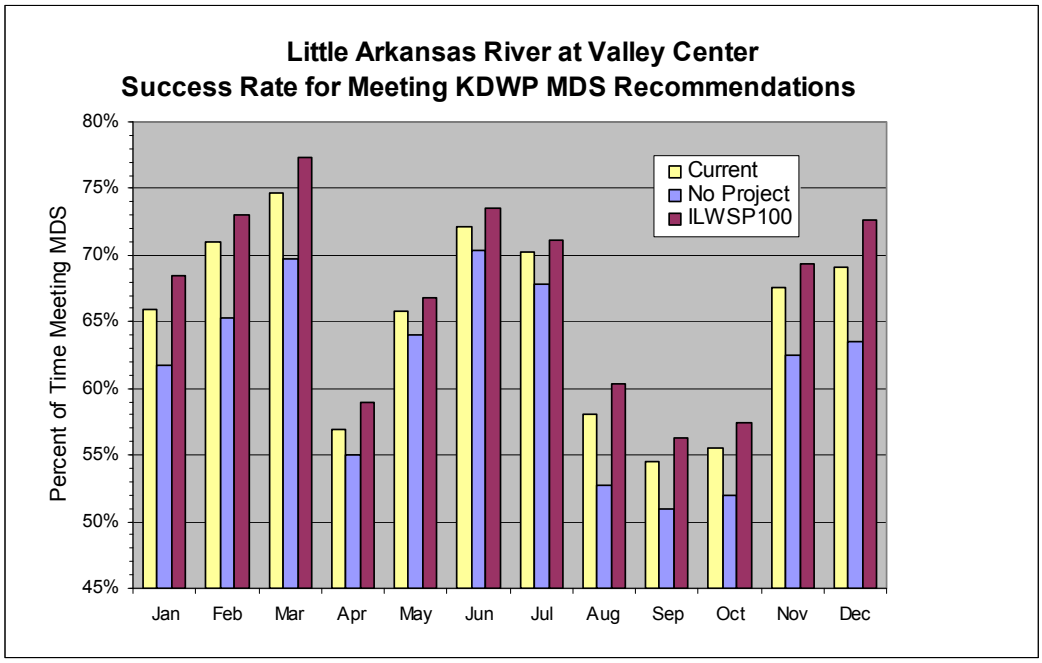
Nov
Dec
Current
No Project
ILWSP100


Little Arkansas River at Valley Center
Success Rate for Meeting KDWP MDS Recommendations
Percent of Time Meeting MDS
80%
75%
70%
65%
60%
55%
50%
45%
Jan
Feb
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Nov
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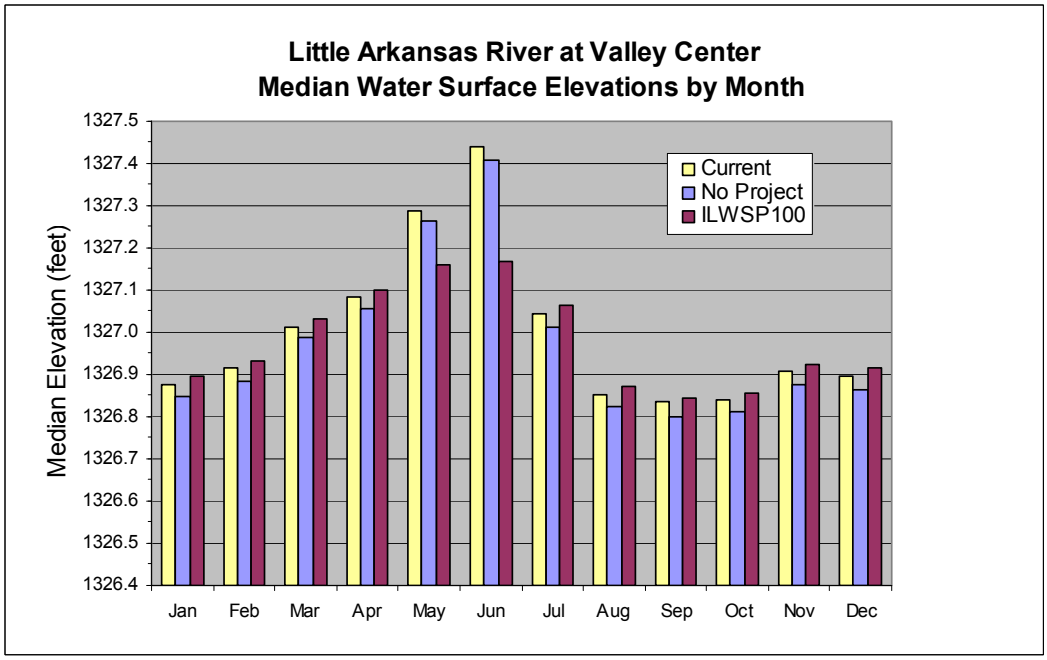
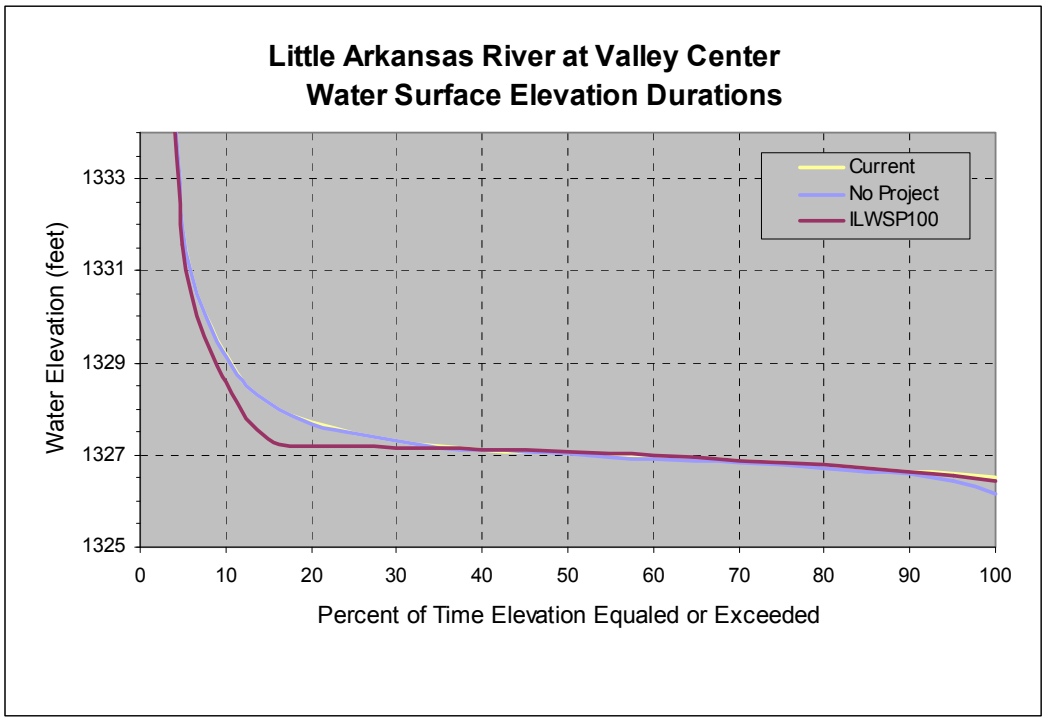
Current
No Project
ILWSP100

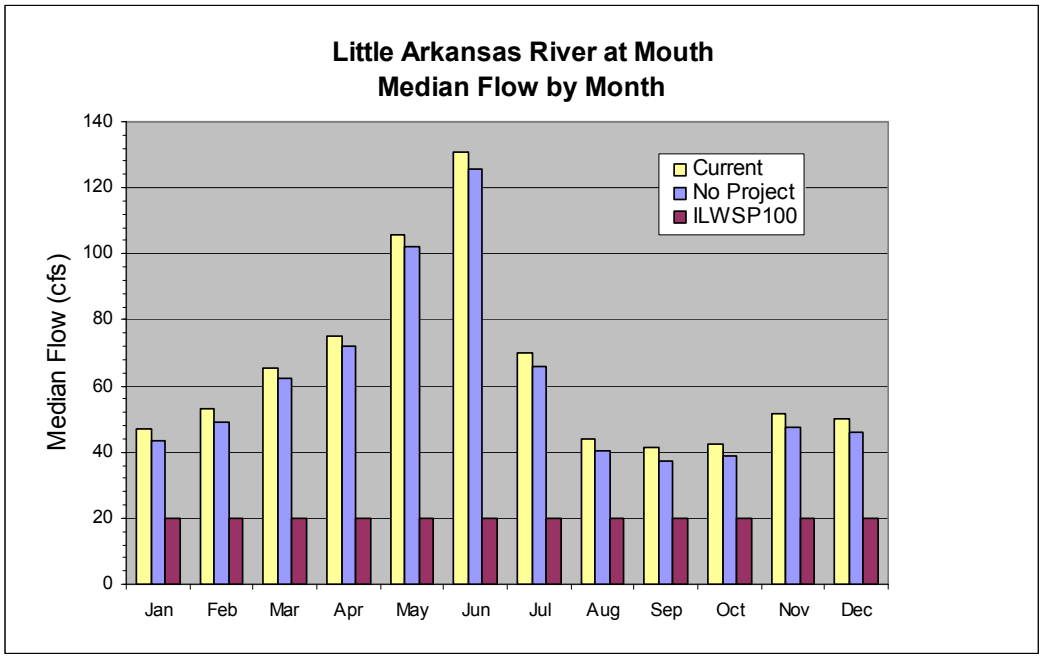


Little Arkansas River at Valley Center												
Median Water Surface Elevation by Month (feet)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No Project	1326.8	1326.9	1327.0	1327.1	1327.3	1327.4	1327.0	1326.8	1326.8	1326.8	1326.9	1326.9
ILWSP100	1326.9	1326.9	1327.0	1327.1	1327.2	1327.2	1327.1	1326.9	1326.8	1326.9	1326.9	1326.9
Difference	0.0	0.0	0.0	0.0	-0.1	-0.2	0.0	0.0	0.0	0.0	0.0	0.1

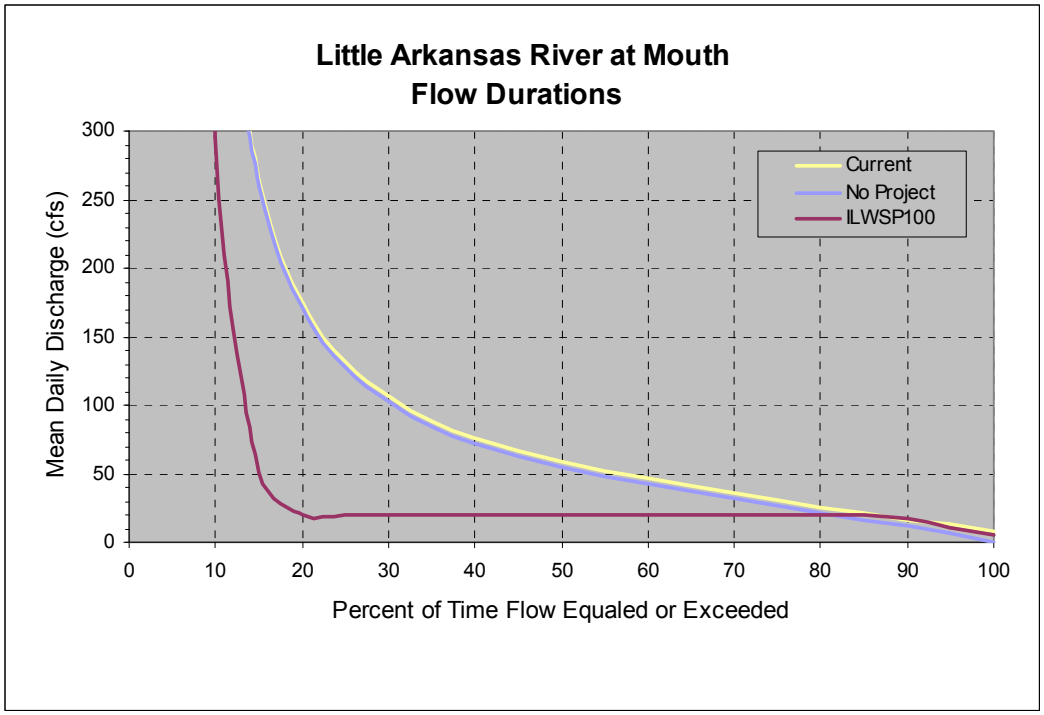


Little Arkansas River at Mouth –

The most significant changes to flows affected by the ILWSP are those occurring at the mouth of the Little Arkansas River. In addition to ASR diversion impacts occurring further upstream, the expansion of the Local Well Field will have the most significant impact on streamflow at this location. The expansion is proposed to divert up to 45 MGD (about 70 cfs) from the Little Arkansas River. Those diversions will be limited to those periods when flow in the river at this location is above 20 cfs. Therefore, with the project in place, the median monthly discharge for all months is anticipated to be 20 cfs. This results in reductions of monthly median discharge ranging from 17 to 106 cfs versus no-project conditions. Simulated daily flow durations indicate that for 80 percent of the time, discharge at this location will be significantly less than without project.



Little Arkansas River at Mouth												
Median Flow by Month (cfs)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No Project	43.5	48.9	62.4	71.9	102.1	125.9	65.8	40.3	37.1	38.8	47.5	46.0
ILWSP100	20.0	20.0	20.0	20.0	20.0	20.1	20.0	20.0	20.0	20.0	20.0	20.0
Difference	-23.5	-28.8	-42.4	-51.9	-82.1	-105.8	-45.8	-20.3	-17.1	-18.8	-27.5	-26.0

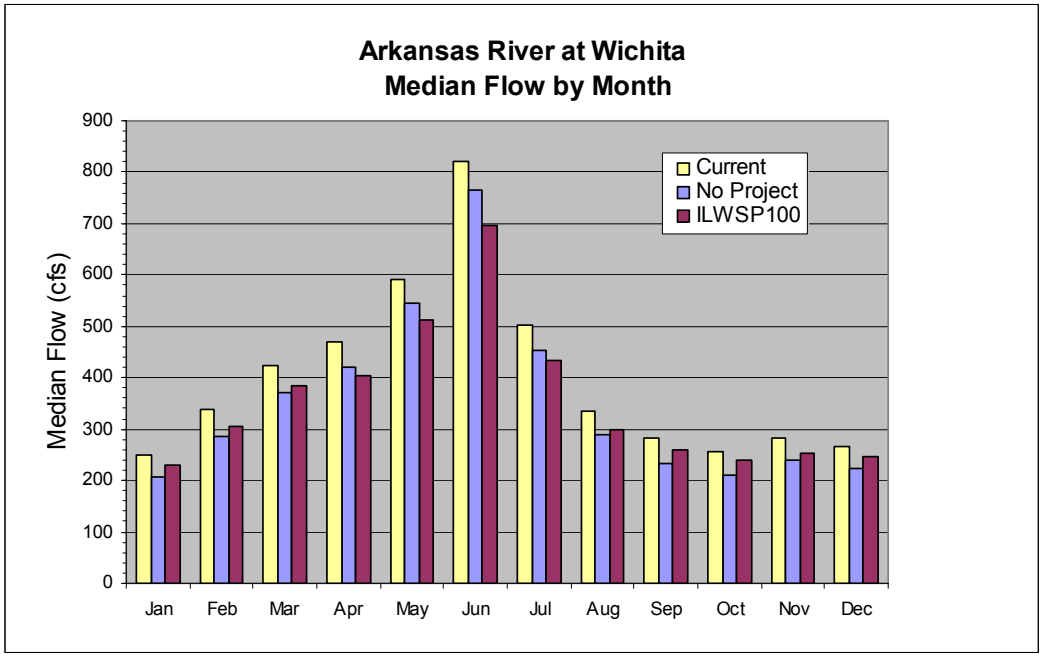


Arkansas River at Wichita -

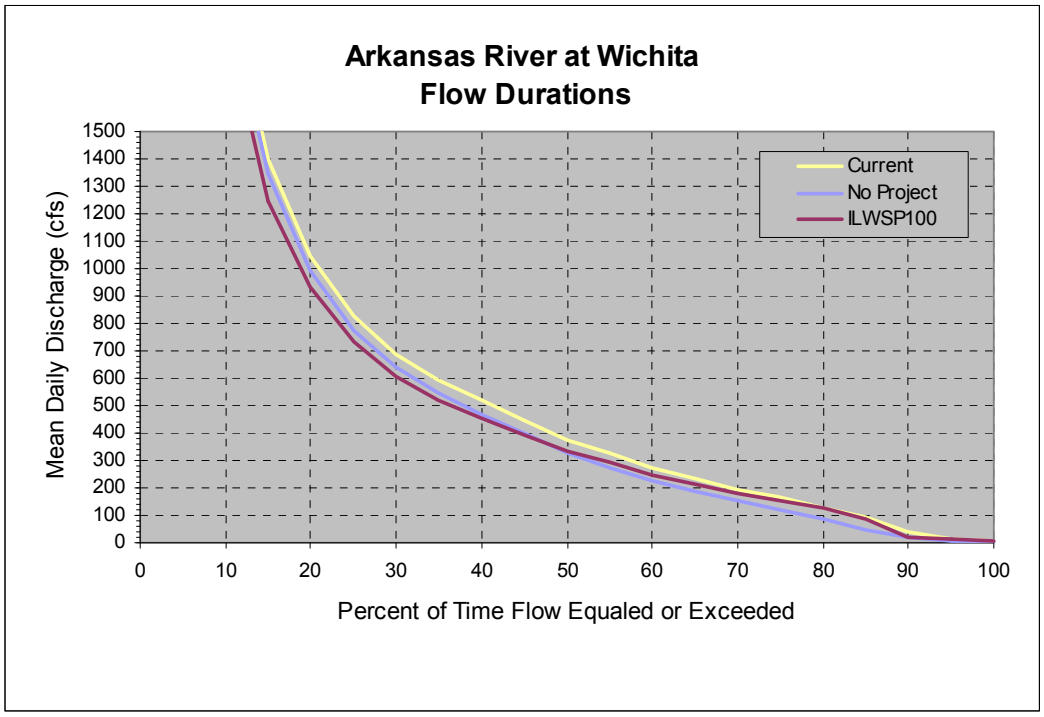
This location represents the USGS streamflow gauging station located just downstream from the confluence of the Arkansas and Little Arkansas Rivers. Therefore, impacts to stream discharge at this location are a culmination of several ILWSP impacts to the Little Arkansas and Arkansas Rivers. These impacts include:

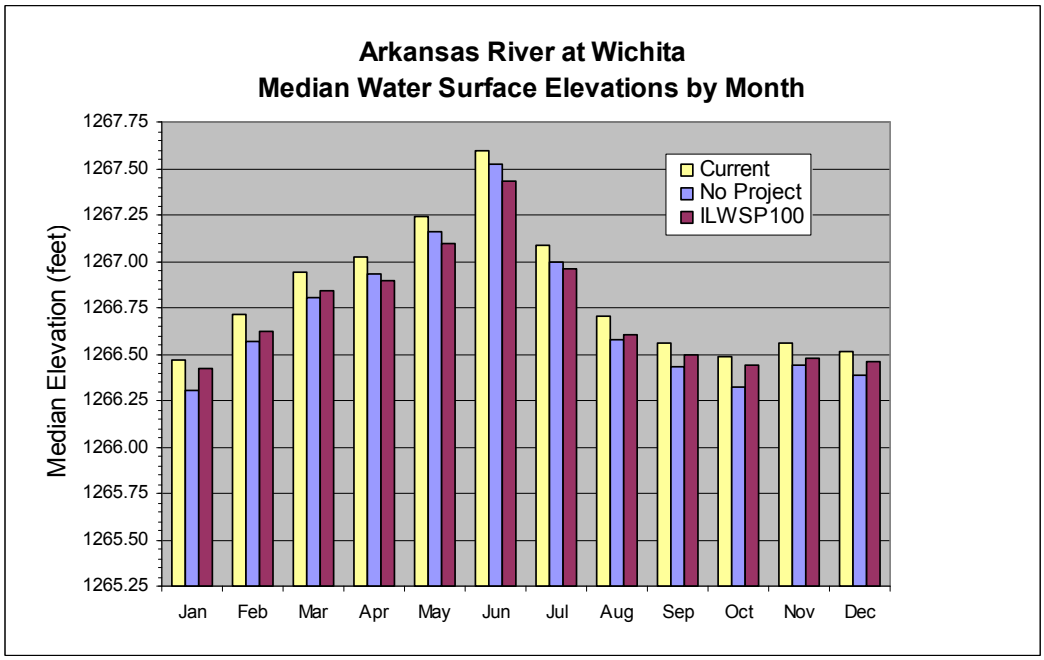
- Induced infiltration from the Arkansas River resulting from redevelopment of the Bentley Reserve Well Field.
- Changes in stream/aquifer interaction rates between the Equus Beds Aquifer and the Little Arkansas and Arkansas Rivers.
- Induced infiltration from the Arkansas River resulting from operation of the existing Local Well Field.
- Diversions from the Little Arkansas River for recharge of Equus Beds Aquifer.
- Induced infiltration from the Little Arkansas due to operation of the expanded Local Well Field.

With relatively greater discharge at this location, the impacts from diversions are a smaller percentage of overall discharge. Simulated flow duration curves indicate that during lower flow periods, flows with the project will be generally higher than without project. Conversely, during higher discharge periods, flows with the project will be generally lower than without project. Water surface elevations are anticipated to only vary within approximately 0.1 feet from without project conditions to with project.

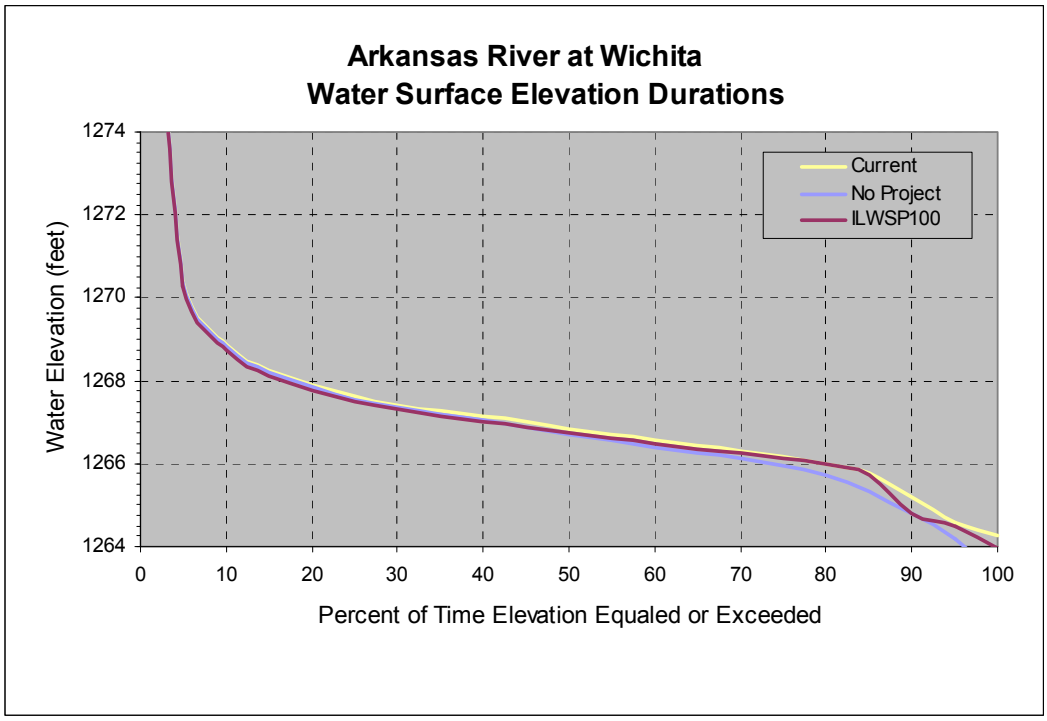


Arkansas River at Wichita												
Median Flow by Month (cfs)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No Project	205.5	286.8	372.0	419.5	544.2	764.7	454.5	288.9	234.6	209.8	238.1	223.4
ILWSP100	231.4	306.8	385.9	405.1	511.0	697.0	434.9	299.7	258.8	240.0	252.6	247.5
Difference	25.9	20.0	13.9	-14.3	-33.2	-67.7	-19.6	10.8	24.1	30.2	14.4	24.1





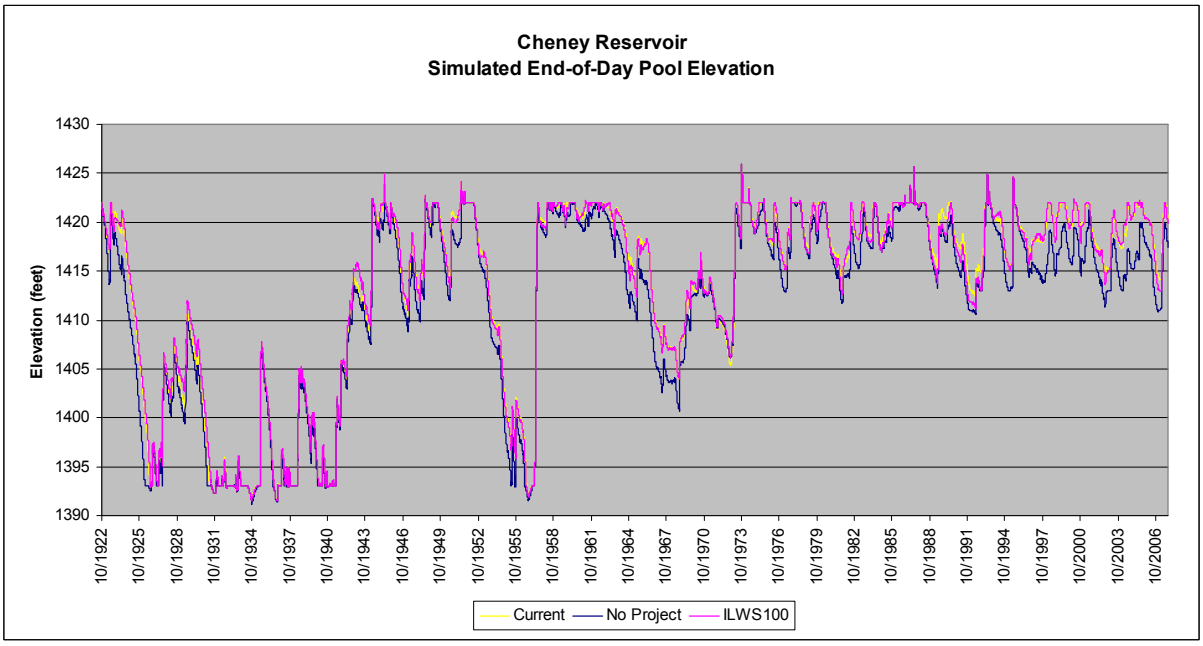
Arkansas River at Wichita												
Median Water Surface Elevation by Month (feet)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No Project	1266.3	1266.6	1266.8	1266.9	1267.2	1267.5	1267.0	1266.6	1266.4	1266.3	1266.4	1266.4
ILWSP100	1266.4	1266.6	1266.8	1266.9	1267.1	1267.4	1267.0	1266.6	1266.5	1266.4	1266.5	1266.5
Difference	0.1	0.1	0.0	0.0	-0.1	-0.1	0.0	0.0	0.1	0.1	0.0	0.1

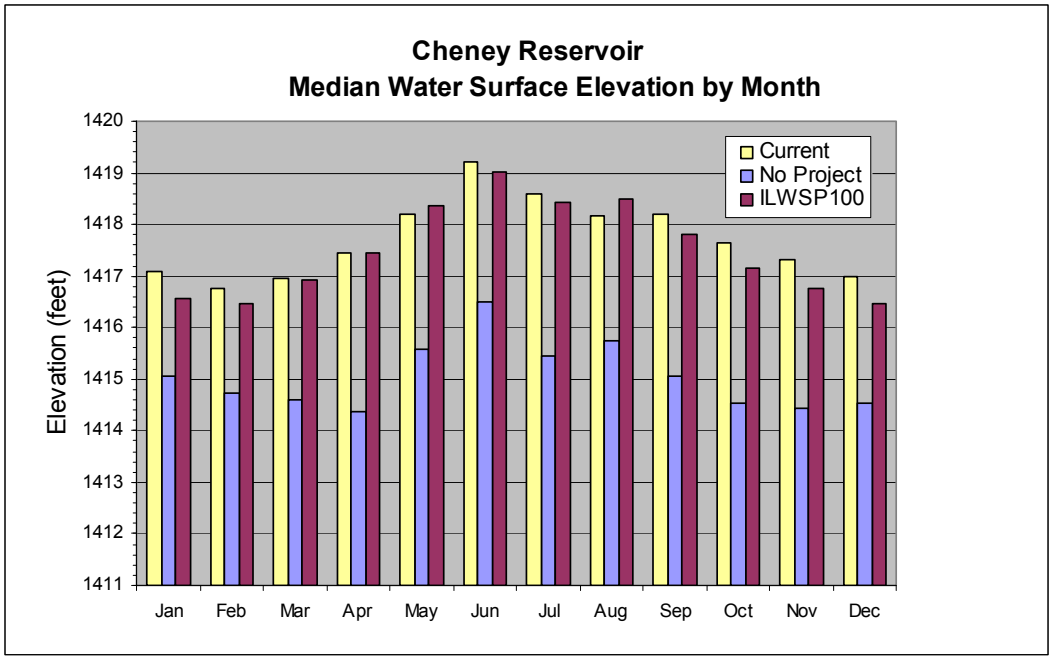


Cheney Reservoir -

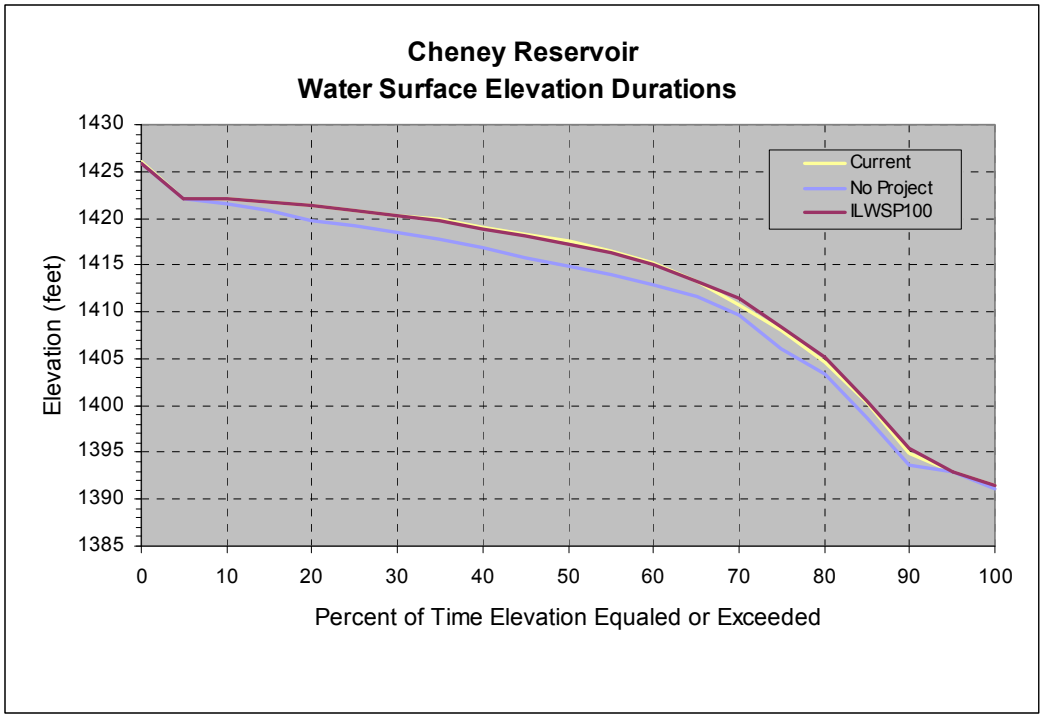
The primary purpose of Cheney Reservoir is to provide a supply of water to Wichita. Without the project, increasing future demands will incur the operation of the reservoir at lower elevations. During drought

periods, the demands on the reservoir will deplete the usable supply. With project implementation, there will be, generally, less of a demand on the reservoir as more of the demand can be shifted to aquifer storage. This will result in higher pool elevations of 1.5 to 3 feet over no-project conditions.



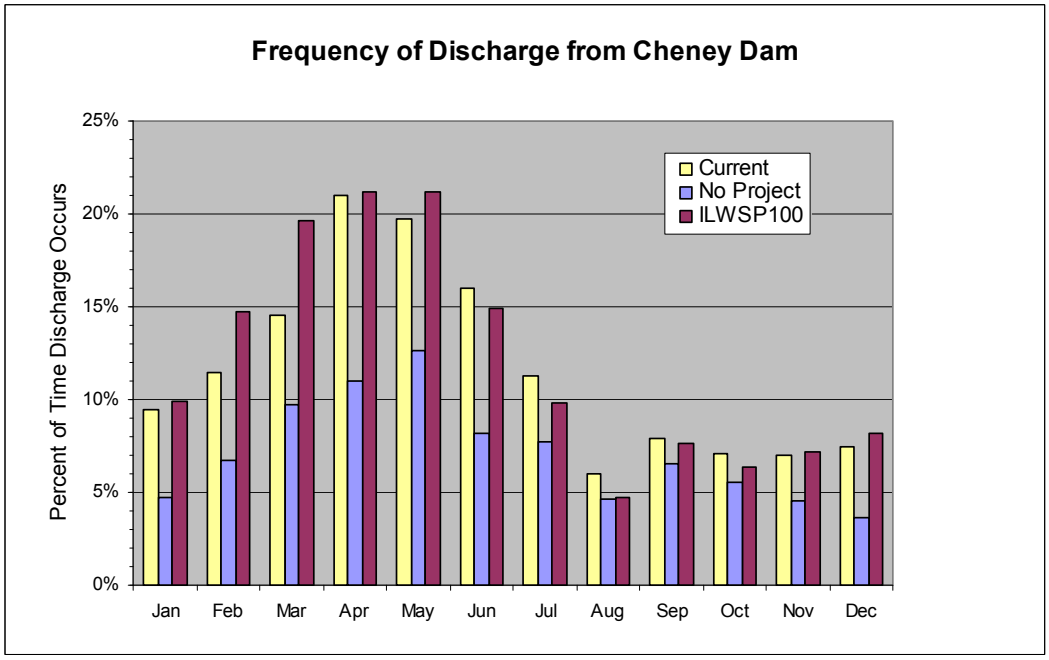


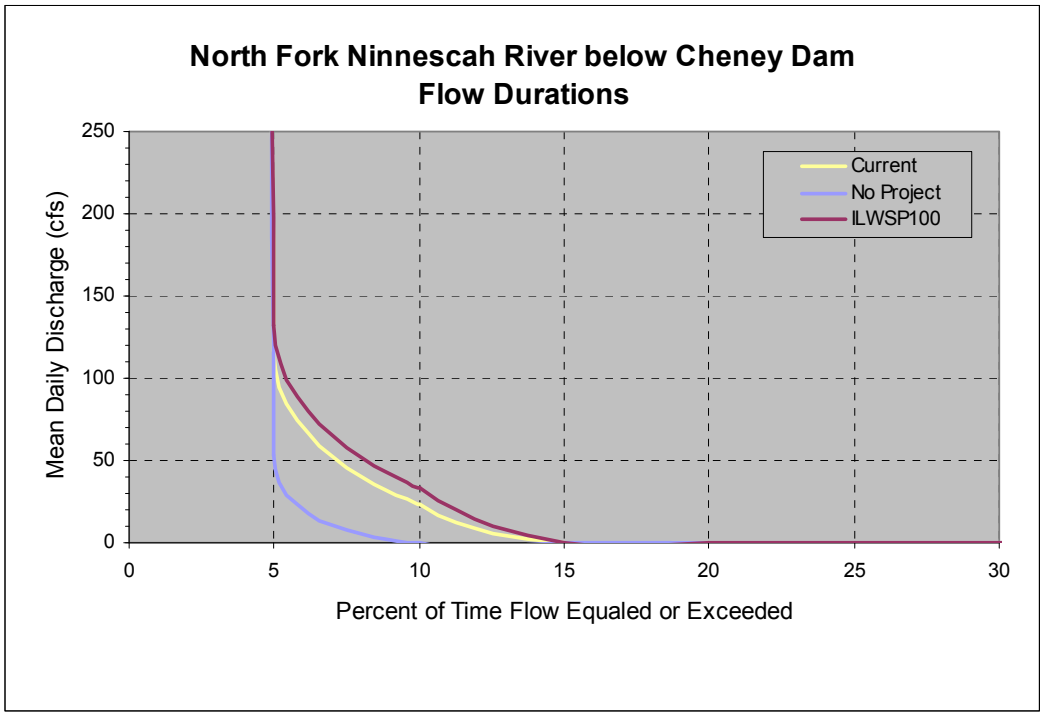
Cheney Reservoir												
Median Pool Elevation by Month (feet)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No Project	1415.1	1414.7	1414.6	1414.4	1415.6	1416.5	1415.5	1415.8	1415.1	1414.5	1414.4	1414.5
ILWSP100	1416.6	1416.5	1416.9	1417.4	1418.4	1419.0	1418.4	1418.5	1417.8	1417.1	1416.8	1416.5
Difference	1.5	1.8	2.3	3.1	2.8	2.5	3.0	2.7	2.8	2.6	2.3	1.9



North Fork Ninnescah River below Cheney Reservoir -

There are no minimum release requirements from Cheney Reservoir. Therefore, releases generally only occur after significant runoff events and when the conservation pool in the reservoir is full (elevation 1421.6 feet). Without the implementation of the project, releases and spills from Cheney Reservoir will occur less frequently since Wichita will be utilizing more of the conservation storage in the reservoir. Will the project in place, there will be less demand on Cheney, resulting in greater storage in the reservoir and more frequent release events to the North Fork Ninnescah River.





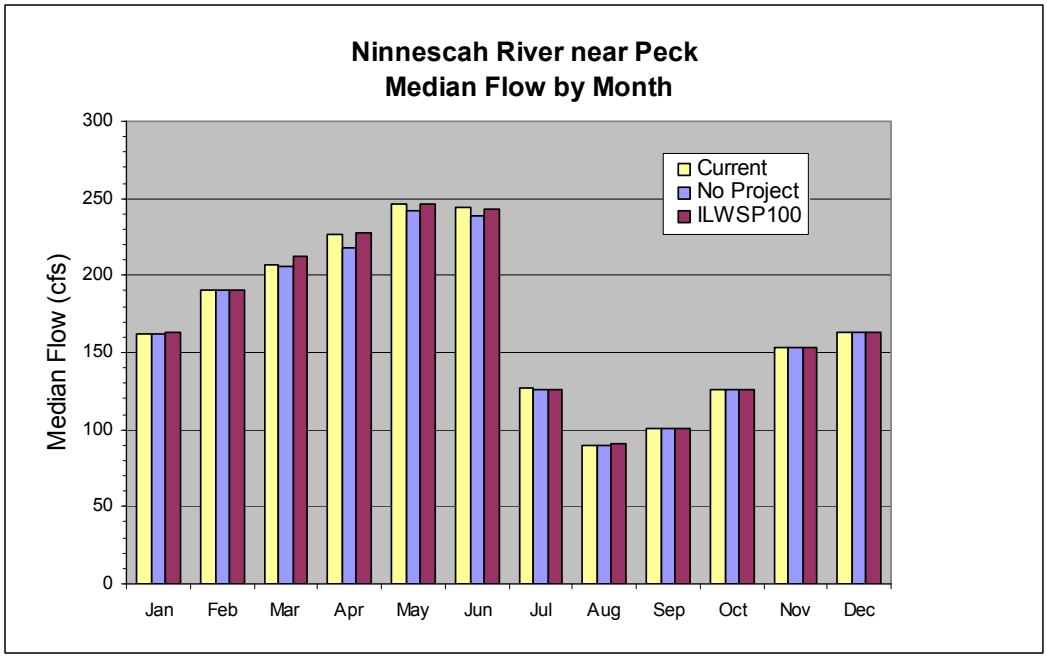
Ninnescah River near Peck -

Project impacts to stream discharge at this location are those produced by changes in releases from Cheney Reservoir. The releases from Cheney make up only a small portion of the total stream discharge at this location. Therefore, project impacts are relatively small compared to total discharge. Implementation of the project may result in increases in discharge of up to 9 cfs created by increasing spills from the reservoir over no-project conditions. But for a majority of the time, discharge would be about the same as without project.

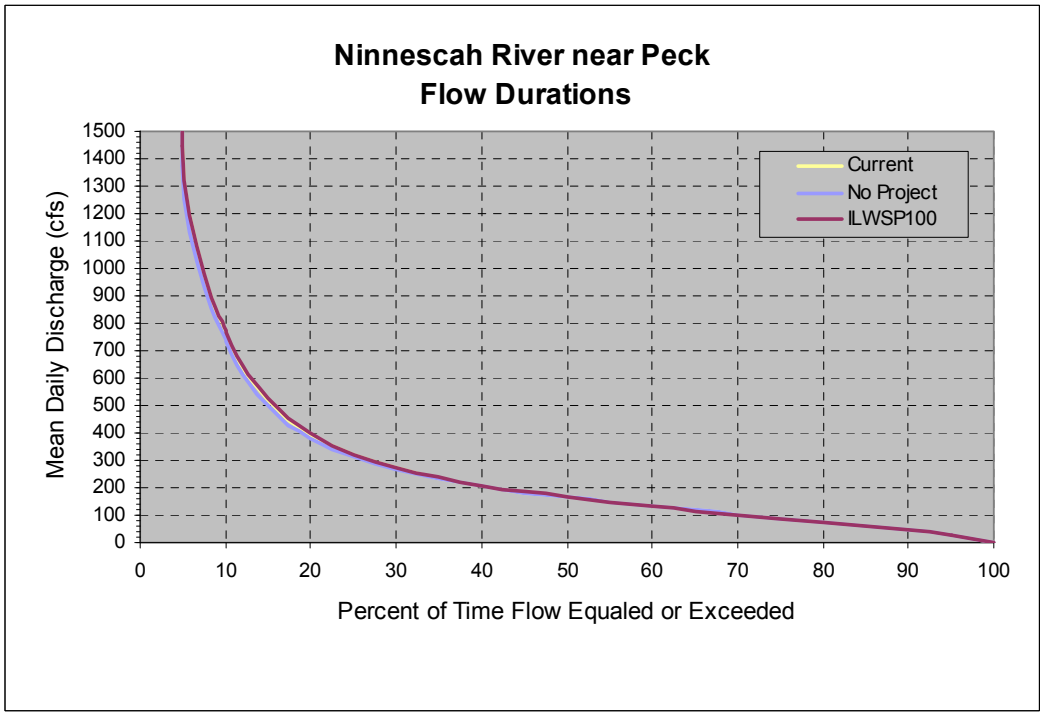
The KWO has established the MDS at this location to be:

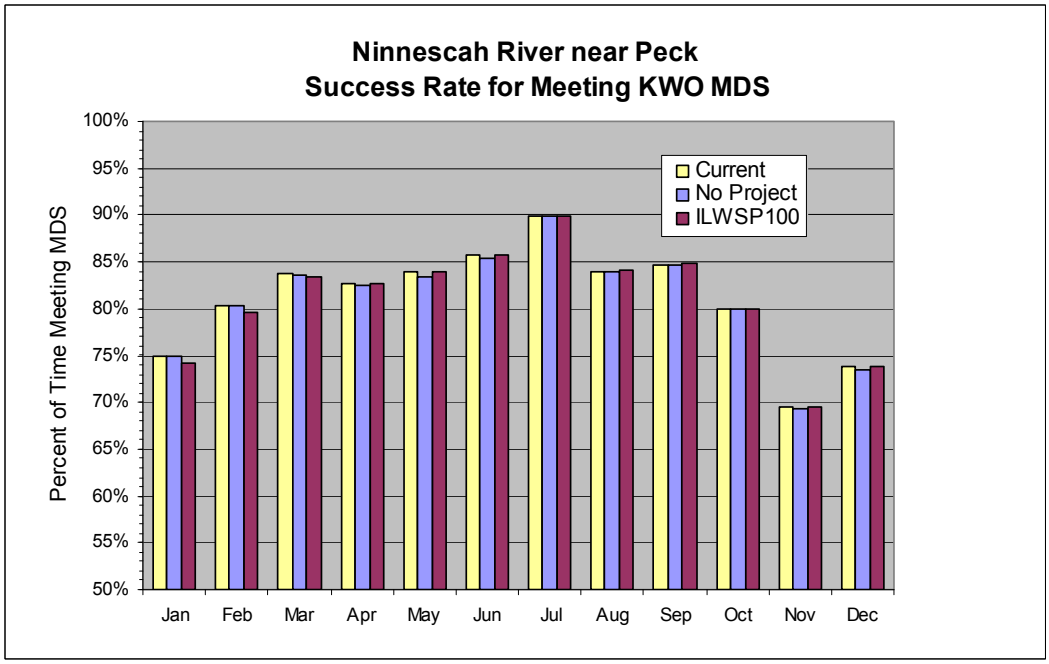
- 100 cfs in November through May
- 70 cfs in June
- 30 cfs in July through September
- 50 cfs in October

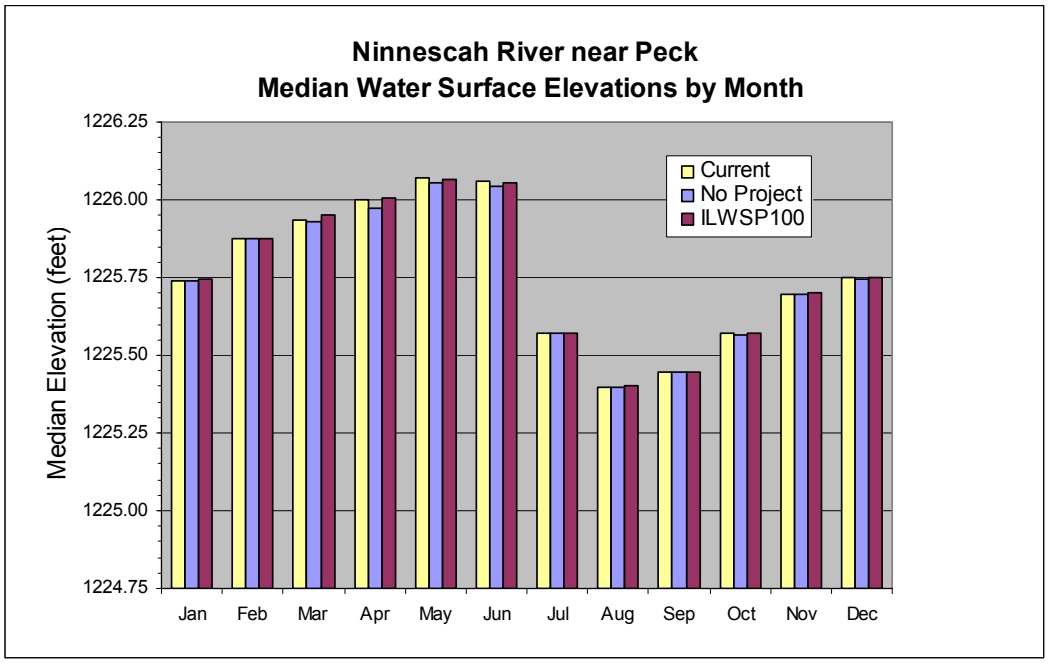
The percentage of time that these MDS values will be met will vary little between with or without project conditions.



Ninnescah River near Peck												
Median Flow by Month (cfs)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No Project	161.7	190.0	206.1	218.4	241.5	238.5	126.2	90.1	100.4	125.7	153.2	163.4
ILWSP100	162.6	190.8	212.3	227.2	245.9	242.7	126.4	90.7	100.5	126.1	153.7	163.7
Difference	0.9	0.9	6.2	8.8	4.4	4.2	0.2	0.6	0.2	0.4	0.5	0.3



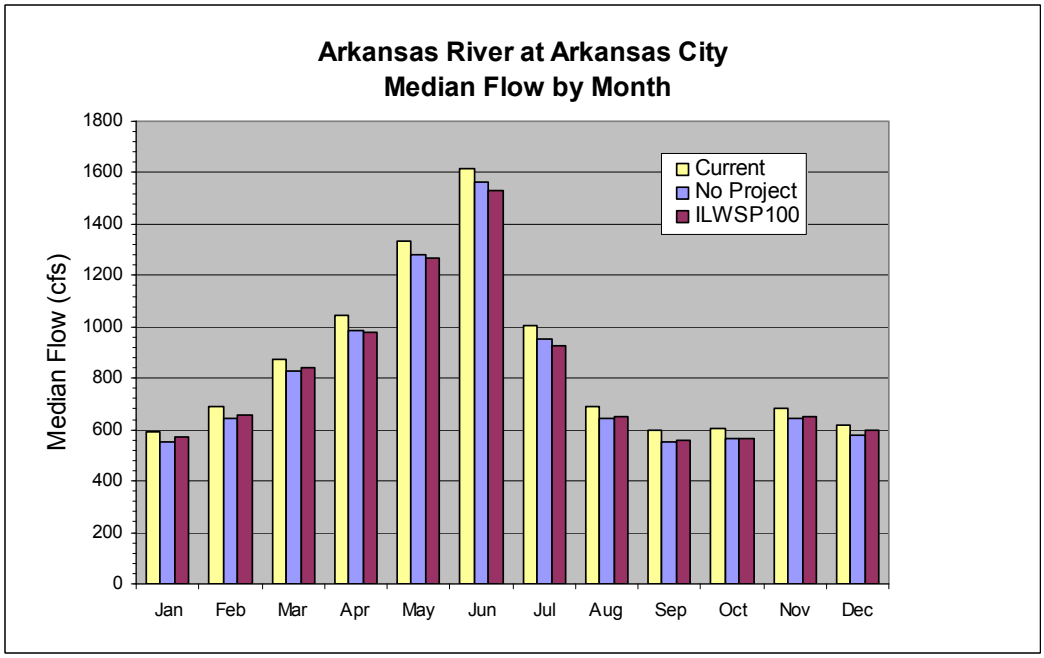




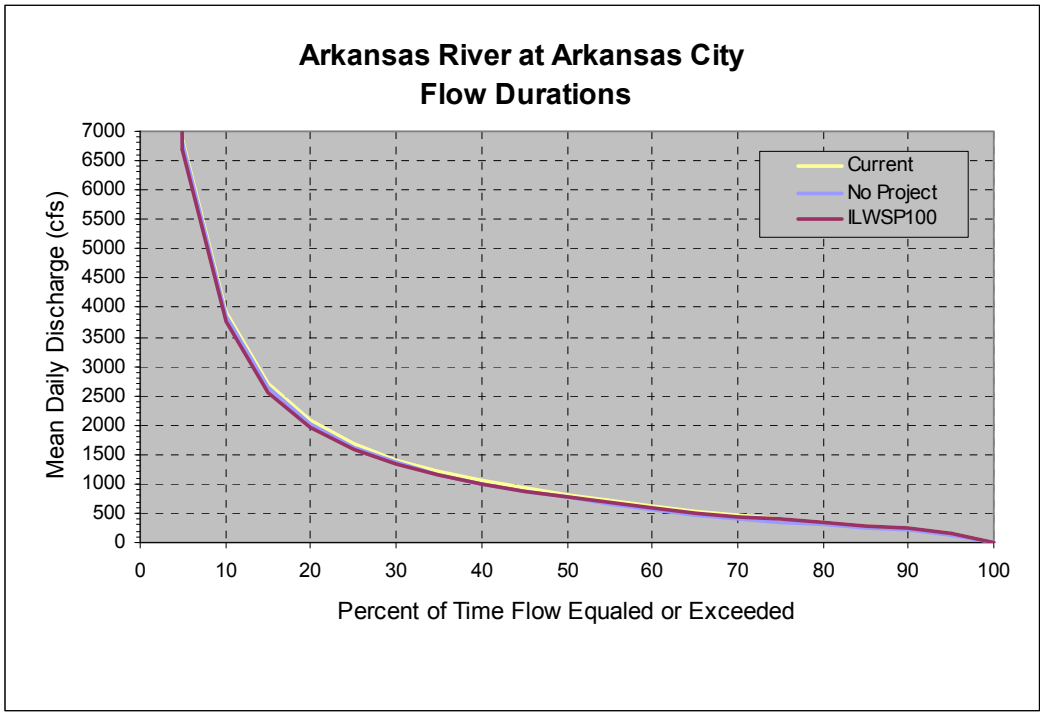
Arkansas River at Arkansas City -

This station is located near the Kansas- Oklahoma state line, approximately 24 miles downstream from the confluence of the Ninnescah and Arkansas Rivers. Discharge at this location would reflect the net impacts from the total ILWS project.

Due to its distance from the project area, and the intervening streamflow gains, the effects of the project on total discharge at this location are relatively small. Simulated median monthly flows suggest that during the peak flow month of June, discharge at this location could be 36 cfs less with implementation of project versus without project. This is approximately 2 percent of the median discharge for that month.



Arkansas River at Arkansas City												
Median Flow by Month (cfs)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No Project	551.8	646.4	827.1	986.2	1284.1	1564.2	952.1	642.9	552.3	562.3	641.0	577.1
ILWSP100	572.6	659.6	841.6	978.9	1267.3	1528.5	927.1	650.0	561.0	567.8	648.7	598.3
Difference	20.8	13.2	14.5	-7.3	-16.7	-35.7	-25.1	7.2	8.7	5.5	7.7	21.2



Attachment A

Supplemental Information on RESNET Operations Model

OPERATIONS MODEL

This appendix documents the computer model that has been developed to simulate operation of the City of Wichita's Integrated Local Water Supply (ILWS) Plan. This operations model was used initially to help with the conceptual design of the ILWS system; it was later used to quantify potential hydrologic impacts for the project's environmental impact statement (EIS).

The operations model for the ILWS system was developed using Burns & McDonnell's Reservoir Network (RESNET) simulation model (Foster, 1989). This computer model represents the stream/reservoir system being simulated as a circulating network. This network representation allows the RESNET model to efficiently determine an optimum solution for each daily time step using least-cost network optimization techniques. This architecture makes it possible for RESNET to simulate systems of virtually unlimited complexity. The optimum network solution determined by the model each day represents a water balance for the ILWS system. This process is repeated for each day during the 85-year model simulation period (water years [WY] 1923–2007). Discussed below are the model's setup and input data, operating assumptions, and output data.

1 Model Setup and Input Data

The ILWS operations model uses the following types of hydrologic data:

- Historical mean daily stream discharge estimates at selected points within the project area
- Historical monthly reservoir evaporation rates
- Available storage and other physical data for Cheney Reservoir and the Equus Beds Aquifer
- City's current and projected water demands
- Irrigation demands for agriculture in the Equus Beds Well Field area
- Minimum desirable streamflow requirements
- Supply capability, operating parameters, and preferred allocation order for all current and potential water supply sources

These input data and operating assumptions are discussed in later sections. The ILWS system is represented in the operations model as a network of nodes with connecting links. A schematic of the overall operations model network is shown in Figure 1. Each of the components of the ILWS model is described further below.

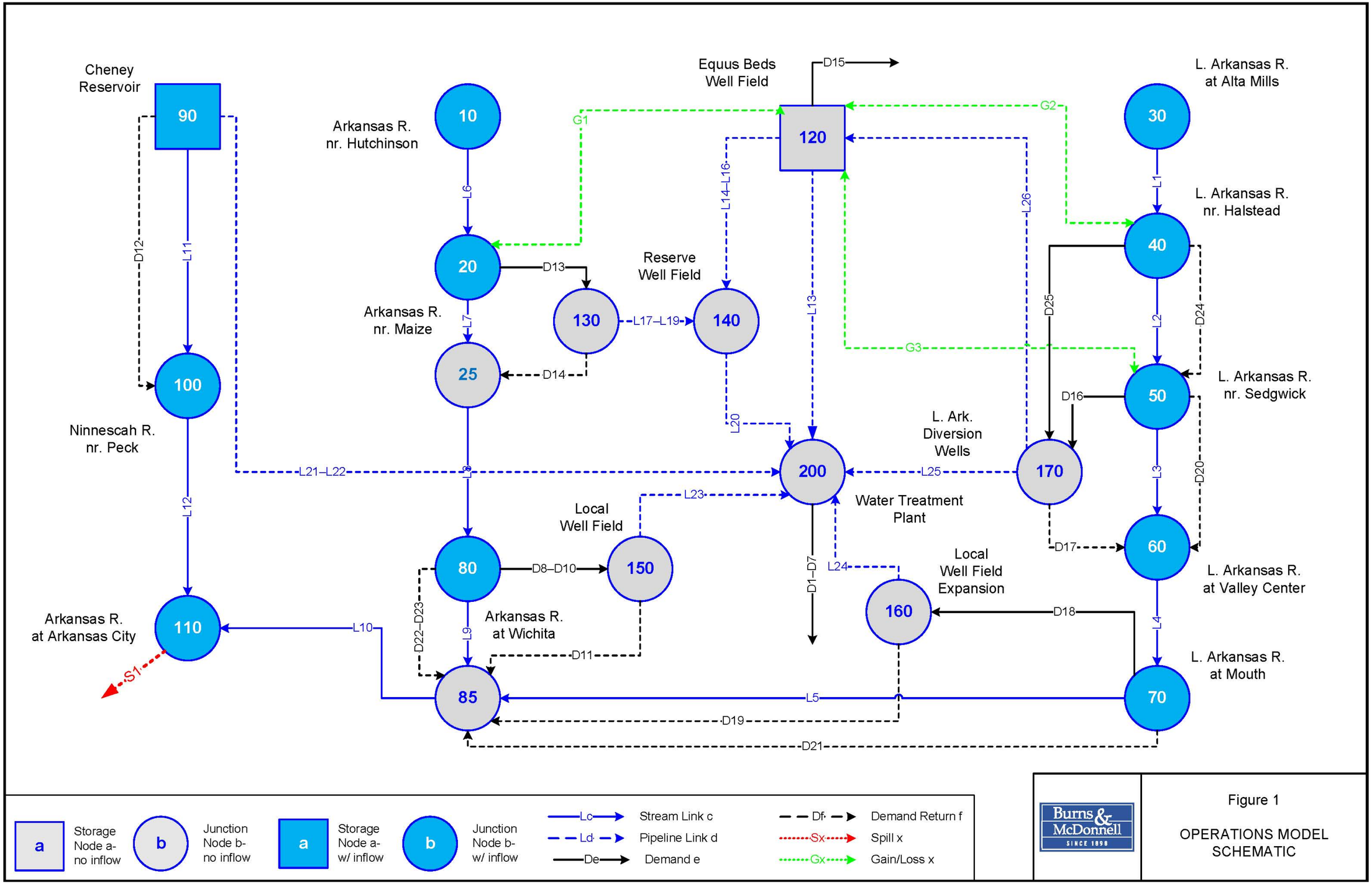


Figure 1

OPERATIONS MODEL SCHEMATIC

The RESNET model utilizes a Microsoft Access database file for storage of all model input and output data. The individual data tables used by the model are listed below in alphabetical order along with a brief description of their contents.

- tblRnAreaCapacity — Elevation-area-storage-leakage rate data for each model reservoir
- tblRnDemand — Input data for each model demand
- tblRnDemandData — Annual distribution data for applicable demands
- tblRnDemandOperations — Daily demand volumes and other related output data
- tlbRnDischargeSummary — Daily discharge below selected stream nodes
- tblRnError — RESNET error messages
- tblRnEvapData — Daily net evaporation data for applicable reservoirs
- tblRnEvapStation — Station identification for evaporation data in tblRnEvapData table
- tblRnFlowData — Daily unregulated inflow data for applicable model nodes
- tblRnFlowStation — Station identification for flow data in tblRnFlowData
- tblRnGageRating — Rating table data for stream nodes located at USGS gages
- tblRnImport — Data for each model import
- tblRnImportData — Annual distribution data for applicable imports
- tblRnLink — Input data for each model link
- tblRnLinkOperations — Daily link flow rates and other related output data
- tblRnModel — Base data that identifies each unique model alternative
- tblRnNetworkArcDump — Dump of network arc data when RESNET cannot find a feasible solution
- tblRnNetworkNodeDump — Dump of network node data when RESNET cannot find a feasible solution
- tblRnNode — Input data for each model node
- tblRnNodeOperations — Daily water balance for each node
- tblRnReservoir — Input data for each model reservoir
- tblRnReservoirLevel — Level/priority data for each model reservoir
- tblRnReservoirOperations — Daily storage and related output data for each reservoir
- tblRnSpill — Input data for each model spill node
- tblRnStorageSummary — Daily end-of-day storage in Cheney Reservoir and Equus Beds aquifer
- tblRnSupplySummary — Daily summary of each supply source's contribution toward meeting City's raw water demand
- tblRnWSElevSummary — Estimates of mean daily water surface elevations at four stream nodes plus daily end-of-day pool elevation and area for Cheney Reservoir

1.1 Model Data

Each unique ILWS alternative is represented by a single record in the model table (tblRnModel). The fields in this table are described below. In Table 1 and similar tables that follow, spaces have been added to the field names to improve readability.

Table 1: Data Fields in Model Table (tblRnModel)

Field Name	Description
ID	Unique record identifier assigned by system. This field contains the model ID that is used to identify each alternative model run.
Name	Short descriptive name for each alternative model run

Description	Description of model run
Start Date	Start date for model run (mm/dd/yyyy)
End Date	End date for model run (mm/dd/yyyy)
No Decimals	Requested precision for model results. The RESNET model uses acre-feet as its base volumetric unit so if this value is one the model will estimate volumes to nearest one tenth of an acre-foot.
Save Operations	True/false flag that indicates if detailed daily output data should be stored
No Zones	Should be zero for all ILWS model runs
Failure Probability	Not used by ILWS model
Primary Dmd Shortages	Number of days during simulation period with shortage in any primary demand
Source Model ID	Used for model cloning only

1.2 Model Nodes

The majority of the model nodes used in the operations model represent locations on project area streams, which include the Arkansas, Little Arkansas, North Fork Ninnescah and Ninnescah rivers. The remainder of the model nodes represent off-stream features, such as well fields, treatment plants and pipeline junctions. Each of these nodes is listed in Table 2.

Table 2: ILWS Model Nodes

Node Nos.	Name	Description	Unregulated Inflow?
10	Arkansas R. near Hutchinson	Located at USGS stream gage of same name. In model domain, most upstream node on Arkansas River.	Yes
20	Arkansas R. near Maize	Located at USGS stream gage of same name. Assumed supply source for Reserve Well Field and gains/losses to Equus Beds aquifer.	Yes
25	Arkansas R. below Maize	Located immediately downstream of Node No. 20	No
30	L. Arkansas R. at Alta Mills	Located at USGS stream gage of same name. In model domain, most upstream node on Little Arkansas River.	Yes
40	L. Arkansas R. near Halstead	Located at approximate position of Phase 1 intake. Assumed supply source for half of recharge diversion wells.	Yes
50	L. Arkansas R. near Sedgwick	Located at USGS stream gage of same name. Assumed supply source of surface water intake and balance of recharge diversion wells.	Yes
60	L. Arkansas R. at Valley Center	Located at USGS stream gage of same name.	Yes
70	L. Arkansas R. at Mouth	Located at mouth of Little Arkansas River.	Yes

80	Arkansas R. at Wichita	Located at USGS stream gage of same name. Assumed supply source for existing Local (E&S) Well Field.	Yes
85	Arkansas R. below Wichita	Located immediately downstream of Node No. 80	No
90	Cheney Reservoir	A storage node located on the North Fork Ninnescah River at Cheney Dam.	Yes
100	Ninnescah R. near Peck	Located at USGS stream gage of same name.	Yes
110	Arkansas R. at Arkansas City	Located at USGS stream gage of same name. Most downstream node in model domain.	Yes
120	Equus Beds Aquifer/Well Field	Storage node that represents Equus Beds Aquifer.	No
130	Reserve Well Field	Node that represents the total supply available from the Bentley Reserve Well Field. This well field is modeled as a direct surface water diversion (that is, aquifer storage is ignored and pumping is assumed to induce immediate and equal infiltration from the Arkansas River).	No
140	Reserve Well Field Junction	Junction node for supplies from Equus and Reserve Well Fields.	No
150	Local Well Field	Located along Arkansas River in downtown Wichita. This node represents the combined supply available from the existing Local (E&S) Well Fields. This well field is modeled like a direct, surface water diversion from the Arkansas River.	No
160	Local Well Field Expansion	Located along the Little Arkansas River in downtown Wichita. This node represents the combined supply available from the proposed Local Well Field Expansion. This well field is modeled as a direct, surface water diversion from the Little Arkansas River.	No
170	L. Arkansas R. Intake/Diversion Wells	Located along the Little Arkansas River. This node represents the combined supply available for aquifer recharge from the proposed surface intake and alluvial diversion wells. Pumping at the diversion wells is assumed to induce immediate infiltration from the Little Arkansas River.	No
200	Water Treatment Plant	Located at Wichita's main water treatment plant near the confluence of the Arkansas and Little Arkansas rivers. All raw water supplied to the City is assumed to flow through this node.	No

As noted in Table 2, slightly more than half of these nodes have unregulated inflow. These nodes are shown in blue in Figure 1. Unregulated inflow is surface runoff that enters tributary stream(s) above a node but below any upstream nodes. The methodology used to estimate unregulated inflow is described in a separate appendix (Burns & McDonnell, 2008c).

The node data for each model run is stored in an Access table named tblRnNode. The data fields in this table are listed in Table 3.

1.3 Model Storage Nodes

Two of the nodes in the operations model are storage nodes, or reservoirs: Cheney Reservoir (Node No. 90) and Equus Beds Aquifer (Node No. 120). Unlike non-storage nodes, these nodes have the ability to retain water from one time step to the next. In RESNET, a reservoir's storage is divided into levels with each level having a defined storage priority. Levels with the highest priority are filled first when water is

Table 3: Data Fields in Node Table (tblRnNode)

Field Name	Description
ID	Unique record identifier assigned by system. This field contains the node IDs that are used to identify the nodes in each alternative model run.
Model ID	Identifier (ID) for corresponding model in Model table (tblRnModel)
Number	Node number. Used as shorthand identifier for each node only.
Name	Short node name
Description	Description of node
Flow Station ID	If this node has unregulated inflow, the applicable flow station ID. Otherwise, this field will be null.
Source Node ID	Used for cloning only

available and used last when water from storage is required to meet demands. These priorities define the unit benefit of having water stored in each level. The defined reservoir levels for Cheney Reservoir and the Equus Beds Aquifer are listed in Table 4.

Table 4: ILWS Reservoir Storage Levels

Level No.	Cheney Reservoir		Equus Beds Aquifer	
	Storage (acre-feet)	Storage Priority	Storage Deficit (acre-feet)	Storage Priority
1	1,140	999	-643,000	999
2	2,000	990	-200,000	770
3	4,000	980	-114,000	760
4	8,000	960	-103,200	750
5	10,000	950	-92,400	740
6	15,476	900	-81,600	730
7	24,817	750	-70,800	720
8	37,170	725	-60,000	710
9	53,265	700	-50,000	700
10	73,356	675	-41667	675
11	97,645	650	-33,333	650
12	125,842	350	-25,000	625

13	152,222	300	-16,667	500
14	170,575	100	-8,333	575
15	247,931	1	0	550

When both reservoirs are relatively full, water will be withdrawn from Cheney Reservoir first because it has a lower storage priority (for example, level 12 has a priority of only 350 for Cheney Reservoir but 625 for the Equus Beds Aquifer). This bias attempts to preserve the water stored in the Equus Beds because this water is relatively more expensive. However, once both reservoirs are drawn down further during a prolonged dry period, the storage priorities are coordinated so that both are drawn down at about the same rate.

There are three Access tables that apply to each model reservoir. The data fields for these tables are described in Tables 5, 6 and 7.

Table 5: Data Fields in Reservoir Table (tblRnReservoir)

Field Name	Description
ID	Unique record identifier assigned by system. This field contains the reservoir IDs that are used to identify the reservoirs in each alternative model run.
Node ID	ID for corresponding node in Node table (tblRnNode)
Initial Storage	Initial storage in the reservoir at start of model run (acre-feet)
Evap Station ID	If this reservoir has evaporation losses, the corresponding evaporation station ID in tblRnEvapStation
Loss Node ID 1	For leaky reservoir, the first loss node ID. Null if not applicable.
Loss Node ID 2	For leaky reservoir, the second loss node ID. Null if not applicable
Loss Node ID 3	For leaky reservoir, the third loss node ID. Null if not applicable
BOC Storage	Reservoir storage at bottom of conservation pool (acre-feet). Not used for ILWS operations model
TOC Storage	Reservoir storage at top of conservation pool (acre-feet). Not used for ILWS operations model
Base Water Right	Base annual water right (acre-feet). Applicable for Equus Beds only.
Max Recharge	Maximum value for recharge credit account (acre-feet). Applicable for Equus Beds only.
Initial Recharge	Initial value of recharge credit account (acre-feet). Applicable for Equus Beds only.
Min Storage	Output field that reports minimum reservoir storage during model run (acre-feet)
Source Reservoir ID	Used for model cloning only.

Table 6: Data Fields in Reservoir Area-Capacity Table (tblRnAreaCapacity)

Field Name	Description

ID	Unique record identifier assigned by system.
Reservoir ID	ID for corresponding reservoir in Reservoir table (tblRnReservoir)
Elevation	Reference pool or aquifer elevation for current reservoir (feet NGVD)
Area	Reservoir pool area for current reservoir at specified elevation (acres)
Storage	Reservoir storage for current reservoir at specified elevation (acre-feet)
Loss Rate 1	Reservoir loss rate to loss node 1 (acre-feet/day)
Loss Rate 2	Reservoir loss rate to loss node 2 (acre-feet/day)
Loss Rate 3	Reservoir loss rate to loss node 3 (acre-feet/day)

Table 7: Data Fields in Reservoir Level Table (tblRnReservoirLevel)

Field Name	Description
ID	Unique record identifier assigned by system.
Reservoir ID	ID for corresponding reservoir in Reservoir table (tblRnReservoir)
Level Num	Sequential level number. Used only for more convenient reference
Level Volume	Storage volume for current reservoir at top of specified level (acre-feet)
Priority	Storage priority for specified level

Additional data for the two system reservoirs are described in the following sections.

1.3.1 Cheney Reservoir

Cheney Reservoir is located on the North Fork Ninnescah River near Cheney, Kansas. This reservoir has the following defined storage pools:

- Dead pool: 979 acre-feet between elevation 1,367 and 1,378.5 feet NGVD
- Fish & wildlife pool: 14,310 acre-feet between elevation 1,378.5 and 1,392.9 feet NGVD
- Conservation pool: 151,800 acre-feet between elevation 1,392.9 and 1,421.6 feet NGVD
- Flood pool: 80,860 acre-feet between elevation 1,421.6 and 1,429 feet
- Surcharge pool: 451,347 acre-feet between elevation 1,429 and 1,453.4 feet NGVD

Table 8 lists the elevation-area-storage data for Cheney Reservoir.

Table 8: Cheney Reservoir Elevation-Area-Storage Data

Pool Elevation (feet NGVD)	Pool Area (acres)	Pool Storage (acre-feet)
1,367	0	0
1,370	14	13
1,375	107	272
1,380	445	1,545
1,385	808	4,535

1,390	1,504	10,241
1,395	2,333	19,793
1,400	3,291	33,761
1,405	4,530	53,265
1,410	5,785	78,987
1,415	7,293	111,602
1,420	8,976	152,222
1,425	10,788	201,557
1,430	12,835	260,557
1,435	14,949	330,019
1,440	17,466	411,058
1,445	20,631	506,303
1,450	23,387	616,350

As a conventional surface reservoir, Cheney Reservoir is also subject to evaporation losses. The estimated net evaporation rates from Cheney Reservoir are described in a separate appendix (Burns & McDonnell, 2008a). These rates account for the net evaporation losses each day (gross evaporation loss less direct precipitation gain).

1.3.2 Equus Beds Aquifer

The Equus Beds aquifer is modeled similar to a surface water reservoir except it does not have evaporation losses. Natural aquifer recharge was estimated to be 3.2 inches per year by the U.S. Geological Survey. This natural recharge is represented in the operations model as an import to this node (No. 120) of 18,800 acre-feet/year.

The interaction between the Equus Beds aquifer and local streams was evaluated in the MODFLOW groundwater model. Generally, aquifers receive their recharge from precipitation and streams serve as aquifer drains. The outflow from aquifers supports the baseflow in these streams. The Equus Beds aquifer has two streams that are major components of the hydrogeological system. The Arkansas River is generally parallel to the pre-development groundwater flow gradient so the interaction between the aquifer and this river was relatively minor. In contrast, the Little Arkansas River is at the down-gradient edge of the Equus Beds aquifer and generally perpendicular to the predominant groundwater flow direction. Changes in the aquifer groundwater level impact the differential head between the aquifer and streams and can result in significant changes in the volume of flow between the aquifer and streams.

The water budget summary feature in MODFLOW provides an accounting of the total water flow from aquifer to stream and stream to aquifer. These total aquifer-stream interaction flows are discussed in the accompanying groundwater appendix (Burns & McDonnell, 2008b) and repeated in Table 9.

Table 9: Equus Beds Storage Deficit-Gain-Loss Data

Index Well 886 Elevation (feet NGVD)	Storage Deficit (acre-feet)	Total Gain from Rivers (cfs)	Total Loss to Rivers (cfs)	Net Equus Beds Loss Rates (cfs)	
				To Arkansas River	To Little Arkansas River
1,342	429,700	133	23	-116.6	6.6
1,360	289,400	100	38	-72.8	10.8
1,366	242,700	89	43	-58.3	12.3
1,370	211,500	82	44	-50.5	12.5
1,375	172,600	73	48	-38.7	13.7
1,380	133,600	62	53	-24.1	15.1
1,385	94,700	54	60	-11.1	17.1
1,389	63,500	48	68	0.6	19.4
1,390	55,700	46	70	4.1	20.0
1,395	16,800	38	82	20.6	23.4
1,396	9,000	36	85	24.8	24.2
1,402	0	29	99	41.8	28.2

Table 9 lists the total gain and loss data for the Equus Beds aquifer as a function of water level. Initially, it was assumed that all aquifer gains come from the Arkansas River and all losses accrue to the Little Arkansas River but subsequent analyses proved this assumption to be too simplistic. In the ILWS plan and operations model the Arkansas and Little Arkansas rivers are treated as two distinct sources. Therefore, the flow between the aquifer and Arkansas River must be differentiated from the flow between the aquifer and Little Arkansas River. These flows were differentiated through an analysis that is described in the Streamflow Appendix (Burns & McDonnell, 2008c). The last two columns in Table 9 show the resulting distribution of these aquifer losses.

With recognition of this aquifer interaction, the RESNET model was customized for development of the ILWS system operations model by adding the ability to model a leaky reservoir. Leakage rates are entered into the model for each destination node as a function of reservoir storage. These reservoir leakage or loss rates can be negative, indicating an actual gain.

1.4 Model Links

The nodes described above are interconnected in the operations model by a series of model links. These links, which are listed in Table 10, represent both natural stream reaches, and pipelines and other man-made conveyance facilities. These stream and pipeline links are shown respectively as solid or dashed blue lines in Figure 1. Each model link has only one origin node and one terminal node. The flow in these links can travel in only one direction from their origin node to their terminal node. Each link also has a specified minimum and maximum flow rate, expressed in acre-feet/day. Generally, the minimum flow rate for these links is zero but the maximum flow rate is dependent on the link type; natural streams are assigned an arbitrarily large flow rate and pipelines are assigned maximum flow rates based on their flow capacity. The RESNET model uses a least-cost algorithm to find the best solution in each time step. Therefore, each link also has an assigned unit flow cost, which is expressed in arbitrary cost units per acre-foot.

Table 10: ILWS Model Links

Link No.	Origin→ Terminal Node Nos.	Description	Minimum Flow Rate (ac-ft/day)	Maximum Flow Rate (ac-ft/day)	Unit Cost/ ac-ft
L1	30→40	L Arkansas R: Alta Mills–Halstead	0	1,000,000	0
L2	40→50	L Arkansas R: Halstead–Sedgwick	0	1,000,000	0
L3	50→60	L Arkansas R: Sedgwick–Valley Center	0	1,000,000	0
L4	60→70	L Arkansas R: Valley Center–Mouth	0	1,000,000	0
L5	70→80	L. Arkansas R: Mouth–Arkansas R	0	1,000,000	0
L6	10→20	Arkansas R: Hutchinson–Maize	0	1,000,000	0
L7	20→25	Arkansas R: Maize–below Maize	0	1,000,000	0
L8	25→80	Arkansas R, below Maize–Wichita	0	1,000,000	0
L9	80→85	Arkansas R: Wichita–below Wichita	0	1,000,000	0
L10	85→110	Arkansas R: below Wichita–Arkansas City	0	1,000,000	0
L11	90→100	North Fork/Ninnescah R: Cheney Reservoir–Peck	0	1,000,000	0
L12	100→110	Ninnescah/Arkansas R: Peck–Arkansas City	0	1,000,000	0
L13	120→200	Pipeline: Equus Beds WF–WTP	0	349	10
L14	120→140	Pipeline: Equus Beds WF–RWF Junction	0	33	-75
L15	120→140	Pipeline: Equus Beds WF–RWF Junction	0	33	-50
L16	120→140	Pipeline: Equus Beds WF–RWF Junction	0	33	-25
L17	130→140	Pipeline: Reserve WF–RWF Junction	0	11	510
L18	130→140	Pipeline: Reserve WF–RWF Junction	0	11	535
L19	130→140	Pipeline: Reserve WF–RWF Junction	0	11	560
L20	140→200	Pipeline: RWF Junction–WTP	0	132	10
L21	90→200	Pipeline: Cheney Reservoir–WTP	0	144	10
L22	90→200	Pipeline: Cheney Reservoir–WTP	0	101	10
L23	150→200	Pipeline: Local WF–WTP	0	113	30
L24	160→200	Pipeline: Local WF Expansion–WTP	0	138	10
L25	170→200	Pipeline: Intake–WTP	0	0	20
L26	170→120	Pipeline: Intake/Diversion Wells–Equus Beds	0	306.9	30

The data for these model links is stored in an Access table named tblRnLink. The fields in this table are described in Table 11. For most model links, their intended purpose is self explanatory; however, there are a few exceptions that warrant additional explanation. These special cases are discussed below.

1.4.1 Bentley Reserve Well Field

The Bentley Reserve Well Field is located in the alluvium of the Arkansas River so pumping from this well field will induce infiltration of relatively saline water from the Arkansas River. To avoid excessive quality impacts to the City's water supply, the operations model is configured to provide mandatory blending of this Reserve Well Field water with better-quality water from the Equus Beds Well Field at a ratio of three to one (that is, three parts Equus Beds water for each one part Reserve Well Field water). The RESNET model does not have the direct capability to regulate the flow in one link based on the flow in a parallel link; therefore, this blending process is approximated by using three links each from the Equus Beds to RWF Junction (L14, L15 and L16) and three links from the Reserve Well Field to the RWF Junction (L17, L18 and L19).

Table 11: Data Fields in Link Table (tblRnLink)

Field Name	Description
ID	Unique record identifier assigned by system. This field contains the link IDs that are used to identify the links in each model run.
Number	Sequential link number. Used for more convenient reference only.
Name	Short link name
Origin Node ID	Identifier corresponding to origin node in tblRnNode
Terminal Node Id	Identifier corresponding to terminal node in tblRnNode
Minimum Flow	Minimum allowable flow in this link (acre-feet/day)
Maximum Flow	Maximum allowable flow in this link (acre-feet/day)
Cost	Unit cost of flow in this link (per acre-foot)
Loss Node ID	For leaky stream segment, ID for node where losses accrue. Not utilized in ILWS model.
Link Loss Percent	For leaky stream segments, percent of flow loss in link (percent). Not used in ILWS model.
Link Loss Max	Maximum loss in link (acre-feet/day). Not used in ILWS model.
Limit Link ID	Link ID used to limiting flow for this link. Not used in ILWS model.
Limit Demand ID	Demand ID used to limit flow in this link. Not used in ILWS model.
Source Link ID	Used for cloning only

When water is available from the Reserve Well Field and there is sufficient water supply demand to utilize this water, the operations model will first use up to 33 acre-feet/day of water from the Equus Beds Well Field via link L14 before then using up to 11 acre-feet/day of water from the Reserve Well Field through link L17. If there is additional water available from the Reserve Well Field, this process will continue with the model using in order links L15, L18, L16 and finally L19.

1.4.2 Cheney Reservoir Supply Pipeline

Deliveries from Cheney Reservoir to the City's water treatment plant are modeled using two parallel links even though there is only one physical supply pipeline. The first link (L21) has a maximum flow based on the City's original water right for Cheney Reservoir (47 million gallons per day [MGD] or 144 acre-feet/day). Water can be supplied to the City through this link whenever there is water available in the reservoir's conservation pool. The second link from Cheney Reservoir (L22) represents the balance of the

capacity in this supply pipeline (80 MGD less 47 MGD = 33 MGD or 101 acre-feet/day). This additional supply capability is available only when the reservoir's conservation pool is full or near full.

1.5 Model Demands

In the ILWS operations model, system demands are used to accomplish a variety of purposes. The most obvious purpose is to satisfy actual water demands, such as the required raw water supply to the City's water treatment plant. The water extracted from the Equus Beds aquifer by farmers for irrigation is a similar consumptive water demand. All other model demands are termed flow-through demands because all of the water withdrawn at the given node is returned to the system at another node. These flow-through demands are used to represent minimum streamflow requirements and also the available supplies to pump stations.

In the RESNET model, each demand has a source node, annual demand volume and demand priority. Optionally, these demands can also have a return node and return percentage, and a specified annual demand distribution. If no demand distribution is provided, the annual demand volume is distributed evenly across each day of the year.

Demands with the highest priority yield the highest benefit per unit when satisfied. For example, a demand for 10 acre-feet/day with a priority of 500 will yield 5,000 benefit units when satisfied. Benefits are treated as negative costs (with the same units) in the RESNET model. Therefore, in order to minimize costs the model will try to satisfy the demands with the highest priorities first.

The model demands included in the ILWS operations model are described in Table 12.

Table 12: ILWS Model Demands

Demand No.	Origin Node No.	Annual Demand (ac-ft/yr)	Dmd Dist?	Priority	Return		Description
					Node No.	Per-cent	
D1	200	87,563.1	Yes	806	---	---	Wichita: 0-70%
D2	200	6,254.5	Yes	805	---	---	Wichita: 70-75%
D3	200	6,254.5	Yes	804	---	---	Wichita: 75-80%
D4	200	6,254.5	Yes	803	---	---	Wichita: 80-85%
D5	200	6,254.5	Yes	802	---	---	Wichita: 85-90%
D6	200	6,254.5	Yes	801	---	---	Wichita: 90-95%
D7	200	6,254.5	Yes	800	---	---	Wichita: 95-1000%
D8	80	5,604	No	850	150	100	E Wells: 0-5MGD
D9	80	5,604	No	800	150	100	E Wells: 5-10MGD
D10	80	22,418	No	750	150	100	S Wells: 20MGD
D11	150	33,627	No	10	85	100	Local WF Excess Return
D12	90	1,448,000	No	10	100	100	Cheney spillway drawdown
D13	20	5,000	No	875	130	100	Reserve WF supply
D14	130	11,209	No	10	25	100	RWF excess return

D15	120	26,500	Yes	900	---	---	Equus Beds irrigation
D16	50	56,044	No	825	170	100	Sedgwick recharge supply
D17	170	112,088	No	10	60	100	Excess recharge return
D18	70	50,440	No	825	160	100	Local WF Expansion supply
D19	160	50,440	No	10	85	100	Local WF Expansion excess return
D20	50	28,960	No	850	60	100	L Arkansas R minimum flow at Sedgwick
D21	70	14,480	No	850	85	100	L Arkansas R minimum flow at mouth
D22	80	362,000	No	825	85	100	Arkansas R minimum flow: 500 cfs
D23	80	724,000	No	775	85	100	Arkansas R minimum flow: 500-1500 cfs
D24	40	28,960	No	850	50	100	L Arkansas R minimum flow at Halstead
D25	40	56,044	No	825	170	100	Halstead recharge supply

The data for these model demands is stored in two Access tables: tblRnDemand and tblRnDemandData. The data fields in these tables are described in Tables 13 and 14.

Table 13: Data Fields in Demand Table (tblRnDemand)

Field Name	Description
ID	Unique record identifier assigned by system. This field contains the demand IDs that are used to identify the demands in each model run.
Node ID	Identifier for node where this demand originates
Number	Sequential demand number. Used for more convenient reference only.
Name	Short demand name
Description	Description of demand
Demand	Desired annual quantity for the current demand (acre-feet/year)
Priority	Priority for current demand
Return Node ID	Node ID for return node. Null if not applicable
Return Percent	Percentage of volume in this demand that is returned to system at specified node
Primary Demand	True/false flag that indicates if current demand is considered to be a primary demand.
Shortage Days	Output field that accumulates number of days during simulation period with shortages at current demand
Source Demand Id	Used for cloning only.

Table 14: Data Fields in Demand Distribution Table (tblRnDemandData)

Field Name	Description
ID	Unique record identifier assigned by system.
Demand ID	Identifier for corresponding demand in tblRnDemand
Month	Month number (1=Jan, 2=Feb, etc.)
Day	Day of month
Demand Percent	Portion of the annual demand volume that is desired on this day of year (percent of annual)

The model demands listed in Table 12 are discussed further below.

1.5.1 Wichita Raw Water Demands

The total raw water demand for the City of Wichita was segregated into seven parts for modeling purposes. These seven individual demands (D1-D7) were included to show the potential impact of additional water conservation measures on system reliability. The demand quantities listed in Table 3 for these demands total to 125,090 acre-feet/year, which is equivalent to an average of 111.8 MGD. This is the City's estimated average-day demand in 2050. For current conditions, a total City water demand of 78,768 acre-feet, or 70.4 MGD, was used. These demand estimates include the impact of typical conservation measures, such as existing City ordinances that require use of low-flow showerheads and toilets in new construction, but not additional conservation measures during dry periods, such as restrictions on lawn watering and vehicle washing. None of these additional conservation measures were implemented in the model runs used in the EIS, but they can be simulated by progressively reducing the demand priorities of demands D7, D6, etc. The distribution of the City's water demand was derived from actual usage data for calendar year 1991 (Burns & McDonnell, 2003).

1.5.2 Local Well Field

Demands D8–D11 and D22–D23 are used to model the City's existing Local Well Field, which is a combination of the Emergency and Sims well fields and, therefore, often referred to as the E&S well fields. The "E" wells have a total capacity of 10 MGD and the "S" wells a total capacity of 20 MGD. Demand D8 represents the first 5 MGD of supply from the "E" wells, with D9 the second half. Demand D10 represents the 20 MGD available from the "S" wells. Demand D11 is a low-priority demand that returns "excess" diversions to the Local Well Field back to the Arkansas River when not needed to satisfy the City's water demands. Demands D22 and D23 are flow-through demands (that is, in-stream flow requirements) that restrict when the Local Well Field can operate because of the lower-quality water available from the Arkansas River.

Among these five demands, D8 has the highest priority (850) so up to 5 MGD is assumed to be available from the "E" wells whenever there is flow in the Arkansas River at Node No. 80. The demand with the next lower priority is D22 (825) so the model will attempt to satisfy this demand next. This demand represents an in-stream flow requirement of 500 cfs. The water quality of the Arkansas River tends to improve at higher flow rates so demand D22 prevents the balance of the "E" wells (demand D9 with priority 800) from operating unless the flow in the Arkansas River is greater than 500 cfs. In a similar manner, demand D23, which has an average rate of 1,000 cfs, prevents the "S" wells from operating unless the flow in the Arkansas River totals over 1,500 cfs.

1.5.3 Local Well Field Expansion

In the model runs completed for the EIS, the Local Well Field was assumed to be expanded by 45 MGD with a series of alluvial wells along the Little Arkansas River. The supply and excess return from this new source is represented by demands D18 and D19. Demand D21 is a flow-through demand that also originates at Node No. 70. This demand, with a priority of 850, prevents the local well field expansion (demand D18 with priority 825) from operating unless the flow in the Little Arkansas River exceeds 20 cfs at its mouth.

1.5.4 Cheney Drawdown

The RESNET model attempts to put all available water to beneficial use. That is, it attempts to minimize spills (Section 1.5). In Cheney Reservoir, the elevation-storage data includes the flood control and surcharge pools. Without some means to evacuate these upper pools, the model would try to keep this water in storage if its release would contribute to a spill. Demand D12 mimics the reservoir's spillway to provide a means to draw the reservoir back down to the top of its conservation pool.

1.5.5 Reserve Well Field

The Bentley Reserve Well Field has a planned capacity of 10.8 MGD. This water source is represented in the operations model by a supply demand (D13) and an excess return demand (D14). Pumping at this well field is assumed to induce infiltration from the Arkansas River so this source is assumed available whenever there is sufficient flow in the Arkansas River. As discuss above (Section 1.3.1), the water withdrawn from this source must be blended with three times as much better-quality water from the Equus Beds Well Field.

1.5.6 Equus Beds Irrigation Demand

Within the Equus Beds Well Field area, agriculture is the dominate land use. Many of the farmers in this area irrigate with groundwater withdrawn from the Equus Beds aquifer. The demand for irrigation withdrawals from the aquifer is represented in the operations model by demand D15. This demand has an annual quantity of 26,500 acre-feet, which was derived from review of reported water usage records for the entire aquifer. These records are collected by the Kansas Division of Water Resources. Generally, only annual water usage data are available so these irrigation withdrawals are assumed to occur at a constant rate over the entire growing season (mid-May through mid-September).

1.5.7 Equus Beds Recharge

Recharge to the Equus Beds aquifer is represented in the operations model by demands D16, D17, D25, D20 and D24. Demands D20 and D24 are flow-through demands that restrict withdrawals from the Little Arkansas River to periods when the flow exceeds 40 cfs. The potential recharge supply is represented by demands D16 and D25, which total to either 100 or 150 MGD, depending on alternative. Fifty percent of these withdrawals are assumed to occur above Halstead (D25) and the balance between Halstead and Sedgwick. The operations model makes no distinction between withdrawals via a surface water intake or through alluvial wells. The supply demands (D16 and D25) will withdraw water from the Little Arkansas River whenever conditions permit. If the Equus Beds aquifer is fully recharged, demand D17 provides a means to return this water back to the river.

1.6 Model Imports

In RESNET an import is a fixed quantity of water that accrues at a specified node each year. Only one import is used in the ILWS operations model. This import represents the average annual natural recharge

to the Equus Beds aquifer. Imports and their corresponding annual distribution data are stored in two Access tables: tblRnImport and tblRnImportData. The data fields for these two tables are listed in Tables 15 and 16.

Table 15: Data Fields in Import Table (tblRnImport)

Field Name	Description
ID	Unique record identifier assigned by system. This field contains the import IDs that are used to identify the imports in each model run.
Node ID	Identifier for node where this import accures
Import	Annual quantity for the current import (acre-feet/year)
Source Import ID	Used for cloning only.

Table 16: Data Fields in Import Distribution Table (tblRnImportData)

Field Name	Description
ID	Unique record identifier assigned by system.
Import ID	Identifier for corresponding import in tblRnImport
Month	Month number (1=Jan, 2=Feb, etc.)
Day	Day of month
Import Percent	Portion of the annual import volume that is received on this day of year (percent of annual)

1.7 Model Spills

A spill is a final sink for any water in the system that is left over after all possible demands are met and reservoirs filled. In the ILWS model, there is only one designated spill (S1), which is located at the most downstream node in the system, the Arkansas River at Arkansas City (Node No. 110). This spill is assigned a very high unit cost (15,000 per acre-foot) so the model will minimize spill quantities to the extent practicable in finding the least-cost network solution for each time step.

In RESNET, spill data is stored in an Access table named tblRnSpill. The data fields in this table are described in Table 17.

Table 17: Data Fields in Spill Table (tblRnSpill)

Field Name	Description
ID	Unique record identifier assigned by system. This field contains the spill IDs that are used to identify the spills in each model run.
Node ID	Identifier for node where this spill originates
Cost	Unit cost of water lost to system through this spill (per acre-foot). Spill costs are usually relatively high such a 10,000 or more.
Source Import ID	Used for cloning only.

2 Operations Model Output Data

Execution of the operations model generates data that depicts the daily water balance calculated for each day during the 85-year simulation period. These data are stored as four separate data streams, with one stream each for nodes, reservoirs, links and demands. These four data streams are described below.

2.1 Node Operations Data

The ILWS operations model will output a water balance for each node in the model for each day. These data are stored in an Access table named tblRnNodeOperations. The individual fields in this table are described in Table 18.

Table 18: Data Fields in Node Operations Table (tblRnNodeOperations

Field Name	Description
ID	Unique record identifier assigned by system
Node ID	Identifier for corresponding node from tblRnNode table. These node IDs are unique to each alternative model run.
Date	Date for these data (mm/dd/yyyy)
Inflow	The unregulated inflow (if any) to this node on specified date (acre-feet).
Upstream Release	The total flow on specified date in all links that terminate at this node (acre-feet). For example, at Node No. 110, this field would include the total flow in links L10 and L12.
Import	The import to this node on specified date (acre-feet). This field will be zero for all nodes except Node No. 120.
Demand Return	If the current node is a return node for any flow-through demand, this field will contain the total return flow at this node (acre-feet). If this node is the return node for multiple demands (for example, Node No. 85 is the return node for demands D11, D19, D21, D22 and D23), this field will contain the total for all return flows.
Downstream Release	The total flow on specified date in all links that originate at the current node (acre-feet).
Demand	The total for all demands that originate at the current node satisfied on specified date (acre-feet).
Spill	Total spills on specified date from this node (acre-feet). This field will be zero except at Node No. 110.
Losses	Total reservoir losses on specified date from this node (acre-feet). This field will be zero for all nodes except Node No. 120.

2.2 Reservoir Operations Data

The data included in the node operations table shows a complete water balance at each node except for storage nodes. At these storage nodes or reservoirs, the additional data needed to complete the water balance are listed in the reservoir operations data table. These data are stored in an Access table named tblRnReservoirOperations. The individual fields in this table are described in Table 19.

Table 19: Data Fields in Reservoir Operations Table (tblRnReservoirOpeations)

Field Name	Description
ID	Unique record identifier assigned by system
Reservoir ID	Identifier for corresponding reservoir from tblRnReservoir table. These reservoir IDs are unique to each alternative model run.
Date	Date for these data (mm/dd/yyyy)
Evap Rate	The net evaporation loss rate from this reservoir on specified date (inches). On date with net gain from precipitation, this rate will be negative.
Evap Volume	The net evaporation volume from the current reservoir on specified date (acre-feet). Evaporation volumes are calculated as the product of the evaporation rate and average reservoir surface area [BOPArea+EOPArea)/2].
BOP Area	Estimated pool area for current reservoir at start of specified day (acres).
BOP Storage	Storage contents of current reservoir at start of specified day (acre-feet).
EOP Area	Estimated pool area for current reservoir at end of specified day (acres).
EOP Storage	Storage contents of current reservoir at end of specified day (acre-feet).
EOP Pool Elev	Pool elevation of current reservoir at end of specified day (feet).
Loss 1	Net losses from current reservoir to first loss node on specified date (acre-feet).
Loss 2	Net losses from current reservoir to second loss node on specified date (acre-feet).
Loss 3	Net losses from current reservoir to third loss node on specified date (acre-feet).
BOP Recharge	Balance in recharge credit account for current reservoir at start of specified day (acre-feet). Applies only to Node No. 120.
EOP Recharge	Balance in recharge credit account for current reservoir at end of specified day (acre-feet). Applies only to Node No. 120.
BOP Water Right	Balance in annual water right account for current reservoir at start of specified day (acre-feet). Applies only to Node No. 120.
EOP Water Right	Balance in annual water right account for current reservoir at end of specified day (acre-feet). Applies only to Node No. 120.

2.3 Link Operations Data

The flow in each model link on each day is summarized in the link operations table, which is named tblLinkOperations in the Access database. The individual fields in this table are described in Table 20.

Table 20: Data Fields in Link Operations Table (tblRnLinkOperations)

Field Name	Description
ID	Unique record identifier assigned by system
Link ID	Identifier for corresponding link from tblRnLink table. These link IDs are unique to each alternative model run.
Date	Date for these data (mm/dd/yyyy)
Flow	The flow in the current link on specified date (acre-feet).
Loss	Flow loss from current link on specified date (acre-feet). This model option is not used for the ILWS model so this field will always be zero.

2.4 Demand Operations Data

The final operation table used in the RESNET model is the demand operations data table (tblRnDemandOperations). The individual fields in this table are described in Table 21.

Table 21: Data Fields in Demand Operations Table (tblRnDemandOpearations)

Field Name	Description
ID	Unique record identifier assigned by system
Demand ID	Identifier for corresponding demand from tblRnDemand table. These demand IDs are unique to each alternative model run.
Date	Date for these data (mm/dd/yyyy)
Demand	Actual volume for current demand satisfied on specified date (acre-feet).
Demand Shortage	Difference between desired and actual volume for current demand on specified date (acre-feet).
Return Flow	Portion of current demand that is returned to system on specified date (acre-feet).

2.5 Post-processing Data

Execution of the RESNET model generates the four output tables described above. To aid in subsequent analysis, several Access routines have been developed that generate auxiliary data tables from the data contained in the four primary output tables. These routines are available in the main RESNET model database file and will generate the following summary tables:

2.5.1 Discharge Summary Data

In the RESNET model, minimum required streamflow and deliveries to pump stations are modeled as flow-through demands. For this reason, the flow in a stream below a given model node is often a combination of terms at some locations. The process for calculating these flows is outlined below.

- Arkansas River near Hutchinson (Node No. 10): Flow in Link L6 only
- Arkansas River near Maize (Node No. 25): Flow in Link L8 only
- Arkansas River below Wichita (Node No. 85): Flow in Link L10 only
- Little Arkansas River at Alta Mills (Node No. 30): Flow in Link L1 only
- Little Arkansas River at Halstead (Node No. 40): Flow in Link L2 plus Demand D24 plus lesser of Demands D17 and D24
- Little Arkansas River at Sedgwick (Node No. 50): Flow in Link L3 plus Demands D20 and D17
- Little Arkansas River at Valley Center (Node No. 60): Flow in Link L4 only
- Little Arkansas River at Mouth (Node No. 70): Flow in Link L5 plus Demands D19 and D21
- North Fork Ninnescah River (Node No. 90): Flow in Link L11 plus Demand D12
- Ninnescah River near Peck (Node No. 100): Flow in Link L12 only
- Arkansas River at Arkansas City (Node No. 110): Spill at Node 110 (sum of flows in Links L10 and L12)

A post-processing routine has been developed that generates a discharge summary table (tblRnDischargeSummary) that combines the various link and demand flows listed above for each day during the model simulation period. The individual fields in this table are listed in Table 22.

Table 22: Data Fields in Discharge Summary Table (tblRnDischargeSummary)

Field Name	Description
ID	Unique record identifier assigned by system
Model ID	Identifier for corresponding model run in tblRnModel table.
Date	Date for these data (mm/dd/yyyy)
Halstead	Mean daily flow in Little Arkansas River near Halstead (cfs).
Sedgwick	Mean daily flow in Little Arkansas River near Sedgwick (cfs).
Valley Center	Mean daily flow in Little Arkansas River at Valley Center (cfs).
L Ark Mouth	Mean daily flow in Little Arkansas River at it mouth in Wichita (cfs)
Wichita	Mean daily flow in Arkansas River at Wichita (cfs)
Below Cheney	Mean daily flow in North Fork Ninnescah River below Cheney Reservoir (cfs)
Peck	Mean daily flow in Ninnescah River near Peck (cfs)
Ark City	Mean daily flow in Arkansas River at Arkansas City (cfs)

2.5.2 Storage Summary Data

The daily end-of-day storage in Cheney Reservoir and storage deficits in the Equus Beds aquifer are available in the storage summary table (tblRnStorageSummary). The fields in this table are described in Table 23.

Table 23: Data Fields in Storage Summary Table (tblRnStorageSummary)

Field Name	Description
ID	Unique record identifier assigned by system
Model ID	Identifier for corresponding model run in tblRnModel table.
Date	Date for these data (mm/dd/yyyy)
Cheney	End-of-day storage in Cheney Reservoir on this date (acre-feet).
Equus Beds	End-of-day storage deficit in Equus Beds aquifer (acre-feet).

2.5.3 Water Supply Summary Data

The City's total raw water demand each day is determined by the related demand and demand distribution data described above (Section 1.5.1). The supply summary table (tblRnSupplySummary) shows where the water to meet this demand comes from each day. This table also summaries the water delivered to the Equus Beds for recharge and aquifer gains and losses from the Arkansas and Little Arkansas rivers. The fields in the supply summary table are listed in Table 24

Table 24: Data Fields in Supply Summary Table (tblRnSupplySummary)

Field Name	Description
ID	Unique record identifier assigned by system
Model ID	Identifier for corresponding model run in tblRnModel table.
Date	Date for these data (mm/dd/yyyy)
Cheney	Water supplied from Cheney Reservoir on this date (acre-feet).
Equus Beds	Water supplied from Equus Beds well field on this date (acre-feet).
Bentley Reserve	Water supplied from the Bentley Reserve well field (acre-feet).
Local WF	Water supplied from the existing local (E&S) well fields (acre-feet)
Local Expansion	Water supplied from the planned expansion of the local well field (acre-feet).
L Ark Diversion	Water supplied by direct diversion from the Little Arkansas River (acre-feet)
Equus Beds Recharge	Water diverted from the Little Arkansas River for recharge of the Equus Beds aquifer (acre-feet)
Ark Losses	Net losses from Equus Beds aquifer to Arkansas River (acre-feet)
L Ark Gains	Net losses from Equus Beds aquifer to Little Arkansas River (acre-feet)

2.5.4 Water Surface Elevation Summary Data

The water surface elevations at four locations in the model area are estimated from the modeled daily discharges at these locations. These locations are as follows:

- Little Arkansas River at Valley Center
- Arkansas River at Wichita
- Ninnescah River near Peck
- Arkansas River at Arkansas City

These four locations are all located at active USGS stream gages. The water surface elevations at these locations are calculated using rating tables obtained from the USGS. The rating table data for these gages are stored in a database table named tblRnGageRating. The fields in the gage rating table are described in Table 25.

Table 25: Data Fields in Gage Rating Table (tblRnGageRating)

Field Name	Description
ID	Unique record identifier assigned by system
Number	Station number for USGS stream gage
Gage Height	Gage height reading (feet)
WS Elev	Water surface elevation corresponding to this gage height (feet NGVD). Equivalent to gage height plus gage datum elevation.
Discharge	Estimate stream discharge at this gage height (cfs)

The estimated water surface elevations at the four stream nodes are written to a summary table named tblRnWSElevSummary. This table also contains the end-of-day pool elevation and pool area for Cheney Reservoir. The fields in the water surface elevation summary table are listed in Table 26.

Table 26: Data Fields in Water Surface ElevationSupply Summary Table (tblRnSupplySummary)

Field Name	Description
ID	Unique record identifier assigned by system
Model ID	Identifier for corresponding model run in tblRnModel table.
Date	Date for these data (mm/dd/yyyy)
Valley Center	Estimated water surface elevation in Little Arkansas River at Valley Center (feet NGVD).
Wichita	Estimated water surface elevation in Arkansas River at Wichita (feet NGVD).
Cheney	End-of-day pool elevation in Cheney Reservoir (feet NGVD).
Peck	Estimated water surface elevation in Ninnescah River near Peck (feet NGVD)
Ark City	Estimated water surface elevation in Arkansas River at Arkansas City (feet NGVD).
Cheney Area	End-of-day pool area for Cheney Reservoir (acres)

3 References

Complete citations for the references cited in this document are listed below:

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Attachment B

Supplemental Information on Development of Equus Beds Groundwater Elevation and Storage Deficit/Stream Gain and Loss Relationships

Equus Beds Groundwater Elevation and Storage Deficit/Stream Gain and Loss Relationship

prepared for

City of Wichita
Wichita, Kansas

November 2008

Project No. 49305

prepared by

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TABLE OF CONTENTS

Page No.

1.0 INTRODUCTION 1-1

2.0 GROUNDWATER-SURFACE WATER INTERACTION 2-1
2.1 General 2-1
2.2 Groundwater Model 2-2
2.2.1 Initial USGS Model 2-2
2.2.2 USBR Model 2-2
2.2.3 Current Model 2-5

3.0 GROUNDWATER ELEVATION - STREAM GAIN AND LOSS 3-1
3.1 Infiltration from Streams 3-1
3.2 Groundwater Discharge to Streams 3-2

4.0 GROUNDWATER ELEVATION - STORAGE DEFICIT 4-1
4.1 USGS Storage Volume Estimates 4-1
4.2 Detailed Storage Volume Estimates 4-2
4.2.1 Groundwater Model Storage Volume – Groundwater Level Relationship 4-2

5.0 REFERENCES 5-1

APPENDIX A - GROUNDWATER MODEL INFORMATION

* * * * *

LIST OF TABLES

Table No. **Page No.**

2.1 2003 Annual Rainfall Totals 2-6

4.1 Storage-volume changes in Equus Beds aquifer near Wichita, South-central Kansas, August 1940-January 2006. 4-4

LIST OF FIGURES

Figure No. **Page No.**

2.1 Wichita Well Field Conceptual Model 2-3
2.2 Wichita Well Field Revised Model Grid 2-4

3.1 Modeled Groundwater Elevation at Monitoring Well 886 vs. Aquifer Loss/Gain to Streams 3-1

4.1 Hydrograph of Water Levels in Monitoring Well 886 4-2
4.2 Modeled Groundwater Elevation/Storage Deficit Relationship 4-3

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1.0 INTRODUCTION

The *Equus* bed aquifer, located northwest of Wichita, supplies municipal and industrial water for the City and for agricultural irrigation. Development for municipal use began in the 1930's. The City owns water rights for up to 40,000 acre-feet per year (AFY) in the *Equus* beds aquifer, one of its major sources of municipal and industrial water.

Equus beds groundwater use for irrigation developed in the 1970's and 1980's with additional water rights granted for an additional amount of about 50,000 AFY. Combined municipal and irrigation pumping is greater than the estimated safe yield of the aquifer; accelerated water level declines resulted, with the greatest decline or deepest groundwater level being recorded in October 1992.

The City has maintained water level measurements from over 100 monitoring wells since before pumping began in 1940. The U.S. Geological Survey (USGS) has been analyzing the data and publishing reports of water-level altitude maps periodically since 1949. More recently, the USGS has been publishing reports of groundwater levels and storage volume in the *Equus* beds aquifer under contract with the City of Wichita.

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2.0 GROUNDWATER-SURFACE WATER INTERACTION

2.1 GENERAL

Many studies have addressed the interaction of the *Equus* beds aquifer with the Arkansas and Little Arkansas rivers, including investigations by the U.S. Bureau of Reclamation (USBR) and USGS as reported by Pruitt in 1993 and Myers in 1995.

Prior to groundwater development in the *Equus* beds, there was little exchange of water between the aquifer and the Arkansas River because the groundwater gradient was approximately parallel to the river. The Little Arkansas River, extending from the northern portions of the aquifer to the east and south and paralleling the eastern aquifer boundary, serves as a drain to the aquifer. A relatively large amount of annual precipitation, estimated to be about 20 percent, recharges the aquifer and moves downgradient; that which is not intercepted by pumping ultimately discharges to the Little Arkansas River and lower reaches of the Arkansas River.

With groundwater development, the potentiometric head of the aquifer was lowered; this created a gradient from the Arkansas River toward the aquifer and induced infiltration of saline river water into the aquifer. Additionally, the reduced head in the aquifer reduced the gradient of flow from the aquifer to the Little Arkansas River causing a decline in the river's baseflow.

Concerns that high-chloride water was moving into the aquifer and degrading its excellent water quality led to studies by both the USGS and the USBR. These studies used groundwater modeling to estimate future impacts to the aquifer under various pumping, recharge and management scenarios. The groundwater models used by the agencies were also used to evaluate the feasibility for the Wichita Equus beds aquifer recharge project.

For this analysis, groundwater modeling was used to establish a relationship between water elevation at a representative target well and aquifer-stream interaction. To develop the relationship, the model was run at various pumping stresses to determine aquifer inflow from streams and losses to streams at different elevations at the target well.

2.2 GROUNDWATER MODEL

MODFLOW, a three-dimensional, finite-difference groundwater flow model, was used to simulate the *Equus* Beds aquifer in the vicinity of the City of Wichita well field. MODFLOW is a well-documented groundwater model that is widely used and accepted by many regulatory agencies. The groundwater model currently in use was originally developed by the USGS office in Lawrence, Kansas (Myers et al 1996). The model was refined by the USBR for analysis of chloride migration in the Burrton, Kansas area. The model was later further refined by Burns & McDonnell Engineering Company, Inc. (Burns & McDonnell) and used to evaluate the City's Aquifer Storage and Recovery (ASR) Project and later to track recharge credits for the accounting reports required by the Kansas Department of Agriculture Division of Water Resources (DWR).

2.2.1 Initial USGS Model

The USGS groundwater flow model was developed to study the stream-aquifer interaction between the Arkansas River and the *Equus* Beds aquifer and to help evaluate chloride migration into the aquifer. The USGS model area includes the current study area along the Little Arkansas River. The original USGS model grid consists of 34 rows, 42 columns, and 3 layers, and covers an area of approximately 950 square miles. Row spacing varied from 1000 feet to 10,000 feet; column spacing was 5000 feet. A conceptual depiction of the model construction is shown in Figure 2.1. The location and extent of the model area is shown in Figure 2.2.

The model uses constant-head nodes along the margins of the model boundary to represent areas where the aquifer extends beyond the model boundary. No-flow boundaries represent areas where shale provides a natural barrier to groundwater flow. The model includes areal recharge, evapotranspiration, stream flow and well pumpage.

More extensive details of the USGS model including information regarding model set-up, calibration, sensitivity analysis, and model results are contained in Myers et al (1996).

2.2.2 USBR Model

The USBR modified the USGS model for a contaminant transport study for the *Equus* Beds Groundwater Management District No. 2 (GMD2). To improve the accuracy of the transport modeling, the USBR reduced model grid spacing and adjusted the grid cells to a more uniform dimension. This resulted in a

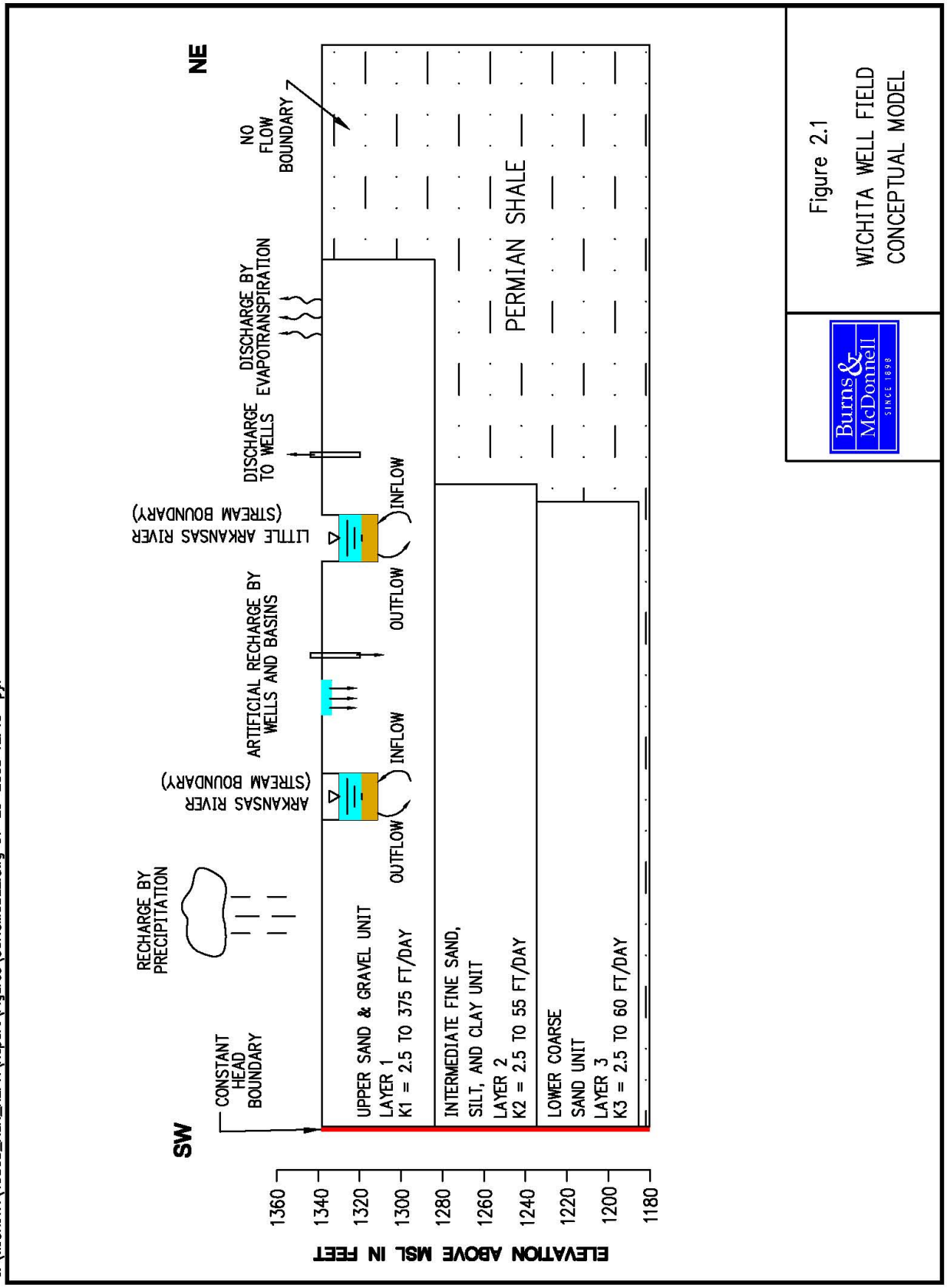
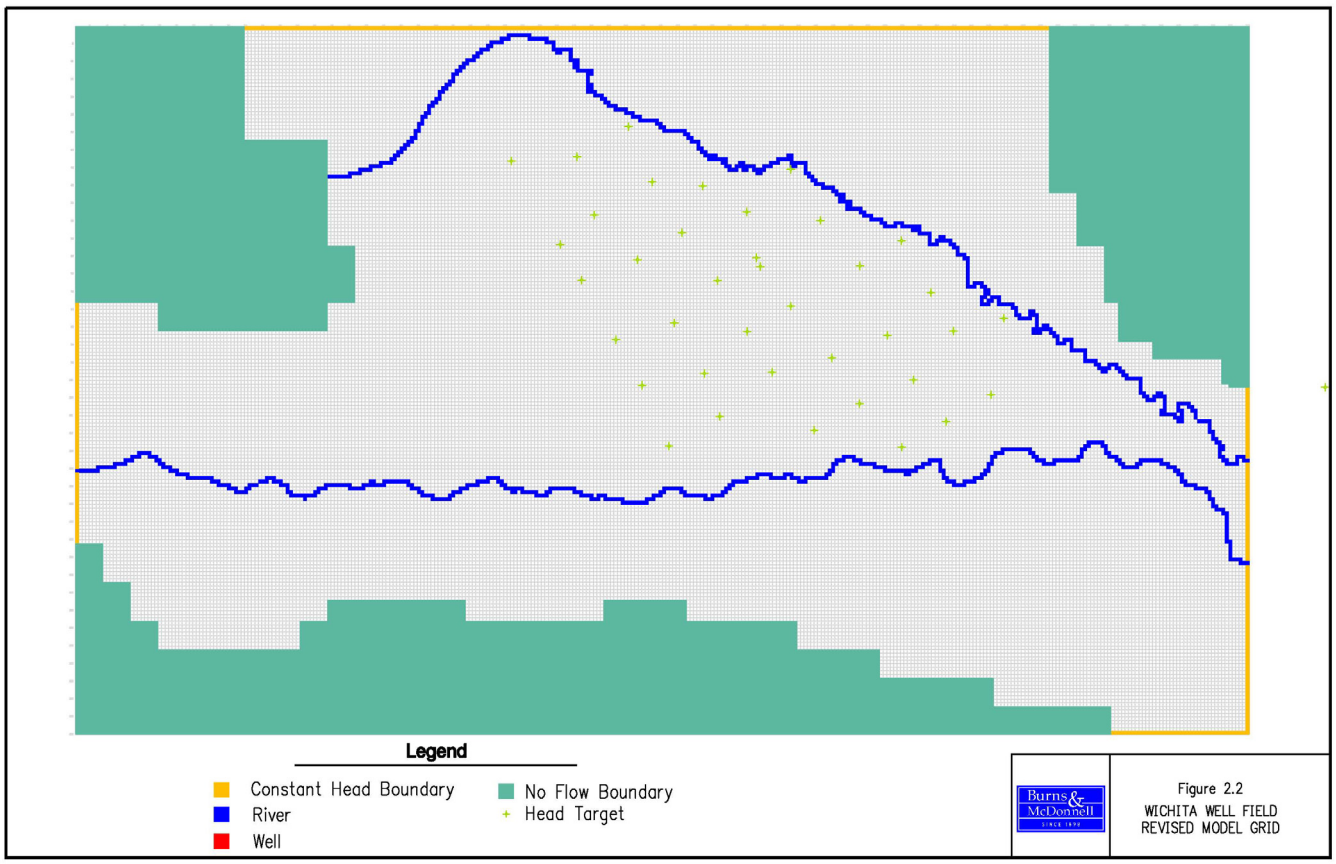


Figure 2.1
WICHITA WELL FIELD
CONCEPTUAL MODEL


Legend
Constant Head Boundary
River
Well
No Flow Boundary
Head Target
Burns & McDonnell
Figure 2.2
WICHITA WELL FIELD
REVISED MODEL GRID

model grid consisting of 54 rows and 84 columns. Details of the USBR modeling are given in Pruitt (1993).

The primary area of interest during the initial investigation for the ASR Project was the Wichita well field. As a result, the USBR model grid spacing in the well field area was too great for proper analysis, and the model was re-gridded to provide better resolution in this area. The finest grid spacing was 1000 feet by 1000 feet and resulted in a model domain with 84 rows and 120 columns.

2.2.3 Current Model

2.2.3.1 Setup and Implementation

The groundwater model used currently for the Wichita ASR accounting has been upgraded and refined with data acquired during various phases of investigation for the ASR project. Basic model refinements include reducing model cell size to a uniform 632.5 feet by 617.6 feet, resulting in a grid with 200 rows and 340 columns. The reduced cell size required repair of stream parameters. Additionally, some adjustments were made to aquifer parameters in areas where additional data was available.

The original model received from USBR was translated into a pre- and post-processing software program (Groundwater Vistas, V 3.0) and the simulations were performed using MODFLOW 98. The current version of the Wichita *Equus* Beds model was recently upgraded to a newer version of Groundwater Vistas (V 4.0) and is run using MODFLOW 2000.

2.2.3.2 Model Aquifer Parameters

2.2.3.2.1 Hydraulic Conductivity

The current versions of the model used for recharge credit accounting uses a large number of monitoring wells for calibration; however, the calibration at the target well 886 was not particularly good. Well 886 was established by USGS as representative of aquifer heads in the area of greatest historical drawdown in numerous USGS reports describing water level changes and estimate storage volumes (Hansen, 2007). Well 886 was used in the original EIS operation model to identify storage volumes available. Model hydraulic conductivity was reduced by one-half compared to the value used in the USGS model (Myers et al, 1996) to improve calibration at target well 886 for this application. Some pumping test results in the general area suggest that a reduction in hydraulic conductivity is appropriate.

Although these modifications resulted in slight changes to modeled heads, stream gain and loss, and aquifer storage compared to the previous EIS results, the current results are relatively close to the original EIS results. Table A-2 in Appendix A compares stream gain and loss for the two models, and Figure A-4 compares storage deficits calculated from each model and the USGS storage depletion estimates.

2.2.3.2.2 Storativity

Specific yield has been reduced from 0.15 to 0.1, and specific storage for the middle and lower layers was reduced by one-half from 0.0001 ft^{-1} to 0.00005 ft^{-1} compared to the original EIS Model and the USGS transient model (Myers et al, 1996). It should be noted that when computing storage volume changes for the dewatered portions of the aquifer, the USGS has typically used a specific yield value of 0.2 (Hansen, 2007).

2.2.3.2.3 Streambed Conductance and Streambed Roughness

Streambed conductance has been reduced from 50 feet/day to 40 ft/d for the Arkansas River, and from 5.0 ft/d to 4.0 ft/day for the Little Arkansas River compared to the original EIS Model and the USGS transient model (Myers et al). Several model runs varying the streambed conductance showed that the model is not very sensitive to this parameter.

Streambed roughness was not modified in the current version of the model.

2.2.3.3 Area Stresses for Model Input

2.2.3.3.1 Precipitation and Recharge

A percentage of annual precipitation contributes to natural recharge. The USGS used average precipitation from three area weather stations and then distributed the recharge across the model area based on soil type, ground cover, and model calibration. The current model employs data from the same locations used by USGS, plus an additional station added at Newton, Kansas.

2.2.3.3.2 Stream Flow

Stream flow can contribute to aquifer recharge depending on river stage, river bed conductivity, and elevation of the underlying groundwater table. Variations in river stage and flow are considered in the groundwater model using the MODFLOW stream package. In this package, a starting flow is assigned to the upstream river node with MODFLOW assigning river flow and stage in all downstream nodes. The

USGS determined that the appropriate starting river flow was that flow with a 70 percent return interval within the modeled stress period.

The 2007 river flows were used for this model evaluation. At the Alta Mills gage on the Little Arkansas River, a value of 8.5 cubic feet per second (cfs) was determined for the 70 percent return interval. The flow for the Arkansas River was determined to be 263 cfs at Hutchinson.

2.2.3.3.3 Groundwater Pumping

Groundwater pumping data for GMD2 has been from Kansas Department of Agriculture Division of Water Resources (DWR) from the early 1990s. Water use reported in acre-feet by DWR was converted to average daily pumping rates, and well locations reported in geographic coordinates (latitude and longitude) were converted to model coordinates. The converted data was then imported into the model. For this evaluation, pumping data from 2003 was used as the base case. Pumping rates for the stress periods were then set at 0, 10, 30, 50, 70, 90, 115, 130 and 145 percent of the base case to stress the aquifer. The stress period using a pumping rate of 145 percent of the 2003 rates simulated water levels lower than or approximately equal to those recorded in 1992.

2.2.3.3.4 Natural Recharge

The amount of natural recharge entering an aquifer system is based on many factors including the amount of precipitation, the surface conditions of soil texture and slope, and the type and amount of groundcover. The GMD2 has determined that approximately 20 percent of rainfall is recharged to the aquifer. The USGS groundwater model used average rainfall from Wichita, Hutchison, and Mount Hope for model input and distributed recharge based on soil type, slope, and land use. Actual values used in the model are increased or decreased with a ratio of the base case to the precipitation for the current year. Since that time, an additional weather station in Newton has become available. Recharge is distributed across the model based on soil type and other factors. Recharge for 2003 is based on the annual rainfall totals shown in Table 2.1.

2.2.3.3.5 Evaporation and Transpiration

Evapotranspiration is estimated in the model. Earlier USGS studies estimated maximum evapotranspiration to be approximately 3.5 inches per year. The USGS model incorporated a maximum

Table 2.1
2003 Annual Rainfall Totals

Station	2003 Precip. (in.)
Hutchinson E.	35.42
Mount Hope	27.64
Wichita	32.60
Newton	36.05
Average	32.93

value of 3.5 inches per year when the water table is at the surface. The rate is reduced with deeper groundwater levels and is equal to 0 when the water table is 10 feet or more below the surface.

2.2.3.4 Model Calibration

Modeled pumping rates were based on the period (2003) in which the highest observed pumping rates in recent history occurred (where more complete records are available).

Calibration was performed by comparing modeled heads at the end of the 100% stress period (2003) to the observed heads at well 886 at the end of 2003 (actually measured in early 2004).

Reductions in the values for hydraulic conductivity and storage were required to simulate aquifer heads at the target well 886, established by USGS as representative of aquifer heads in the area of greatest historical drawdown (Hansen, 2007). This essentially results in calibrating to a single point as opposed to multiple points in previous versions of the model.

Final calibration resulted in difference of 5.4 feet between the model and observed values (modeled elevation 1384.7 vs. observed 13794 feet).

The current model has a water budget mass balance discrepancy of -0.08 percent, a residual mean of -9.44 feet, and an absolute residual mean (compared to observed January 2004 water level measurements in 38 index monitoring wells) of 9.50 feet. The absolute residual mean is the average absolute difference between measured water levels and computed water levels at the same location. Differences are due to seasonal variations in local weather (recharge), timing of local pumping, and other operations factors.

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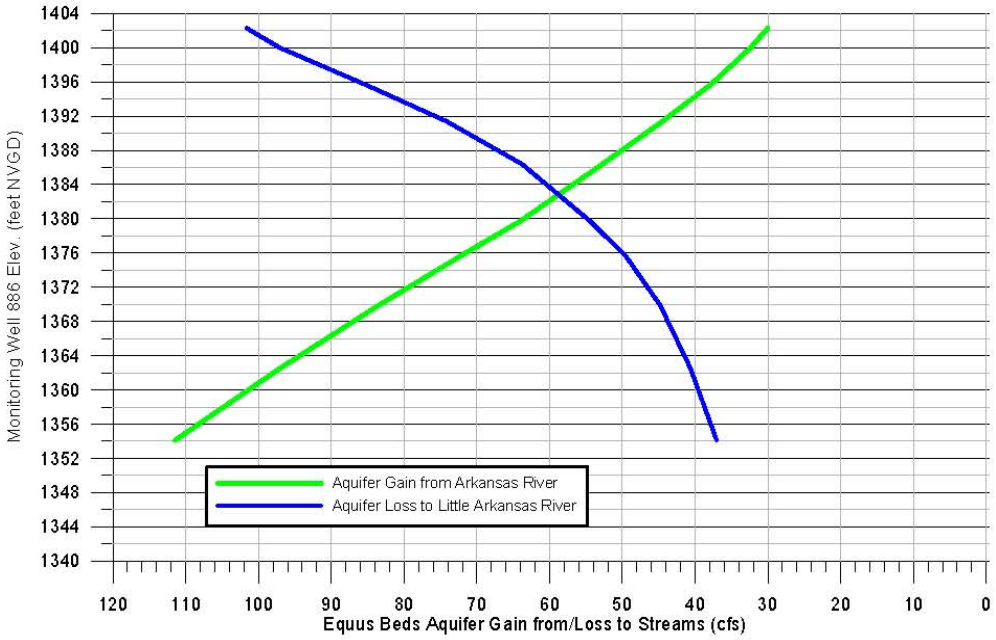
3.0 GROUNDWATER ELEVATION - STREAM GAIN AND LOSS

3.1 INFILTRATION FROM STREAMS

When aquifer levels are lower than water levels in a stream, there is a potential for water inflow or infiltration from the stream to the aquifer. The amount of flow depends on the difference in water levels and the permeability of the streambed. The rate of infiltration from streams is reported in the model water budget for each time and stress period. For this evaluation it is assumed that the infiltration is from the Arkansas River. Minor amounts may actually infiltrate from the Little Arkansas River; however, the amount reported in the model is the net impact on the aquifer. The data from the ten stress periods are graphed with the calculated water level at Monitoring Well 886 to illustrate the change in river inflow dynamics with changes in groundwater elevation (Figure 3.1).

Figure 3.1

Modeled Groundwater Elevation at Monitoring Well 886 vs. Aquifer Loss/Gain to Streams



3.2 GROUNDWATER DISCHARGE TO STREAMS

When aquifer levels are higher than water levels in a stream, there is a potential for water inflow or infiltration from the aquifer to the stream. The amount of flow depends on the difference in water levels and the permeability of the streambed. The rate of aquifer loss to streams is reported in the model water budget for each time and stress period. For this evaluation, it is assumed that aquifer losses are to the Little Arkansas River. Minor amounts may actually be lost to the Arkansas River; however, the amount reported in the model is the net impact on the aquifer. Data from the ten stress periods are graphed with the calculated water level at Monitoring Well 886 to illustrate the change in river inflow dynamics with changes in groundwater elevation (Figure 3.1).

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4.0 GROUNDWATER ELEVATION - STORAGE DEFICIT

The City of Wichita, GMD2, and the USGS collect water level data in over 100 monitoring wells on a quarterly basis to monitor groundwater level changes. The USGS identified four noteworthy periods of water-level changes. They include the initial period of pumping, the severe drought conditions of the mid-1950's, a period of relatively stable levels from 1958 to 1977, and a period of declines due to increased irrigation pumping from 1978 to 1992. Subsequent to these identified periods, the City has adopted its Integrated Local Water Supply Plan Project (Project) which calls for greater use of water from Cheney Reservoir when available and reduced pumping from the Equus beds aquifer. The reduced withdrawal from the aquifer has resulted in recent rebound of water levels.

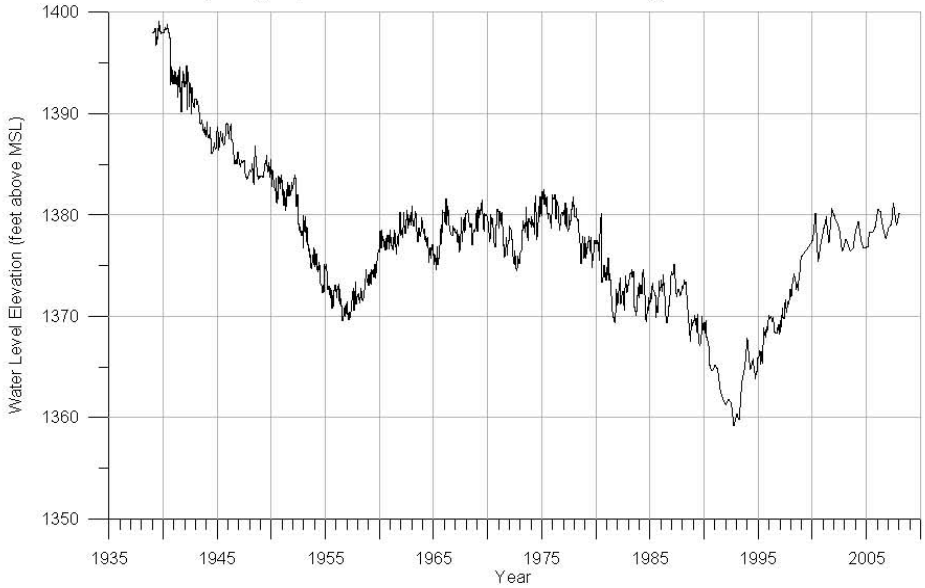
4.1 USGS STORAGE VOLUME ESTIMATES

In the current USGS report (Hansen, 2007), three water-level altitude maps of the water level data are presented. These include 1940 (pre-development), 1992 (lowest levels recorded), and current (2006) levels. Additionally, a number of water level change maps showing the difference in water levels for several periods are presented.

The USGS selected monitoring well 886 as a representative descriptor of historical water-level changes in the area of maximum water-level declines which occur in the central part of the study area near the historic center of pumping by the City. Figure 4.1 is a hydrograph of water levels recorded in monitoring well 886.

The USGS has calculated the storage-volume changes for several time periods covering the recorded well field data (Hansen, 2007). USGS defines the changes in storage volume as the change in saturated aquifer volume multiplied by the specific yield of the aquifer; a specific yield of 0.2 has been used by the USGS as representative of the *Equus* beds aquifer. Volume calculations were computed using computer-generated Thiessen polygons based on the measured water-level changes at wells and manually drawn lines of equal water-level change (Hansen, 2007). Table 4.1, developed by the USGS, lists the calculated storage-volume changes in acre-feet and percent for various time periods for the complete study area and the central part of the study area which is the immediate areal extent of the Wichita municipal wells.

Figure 4.1
Hydrograph of Water Levels in Monitoring Well 886



4.2 DETAILED STORAGE VOLUME ESTIMATES

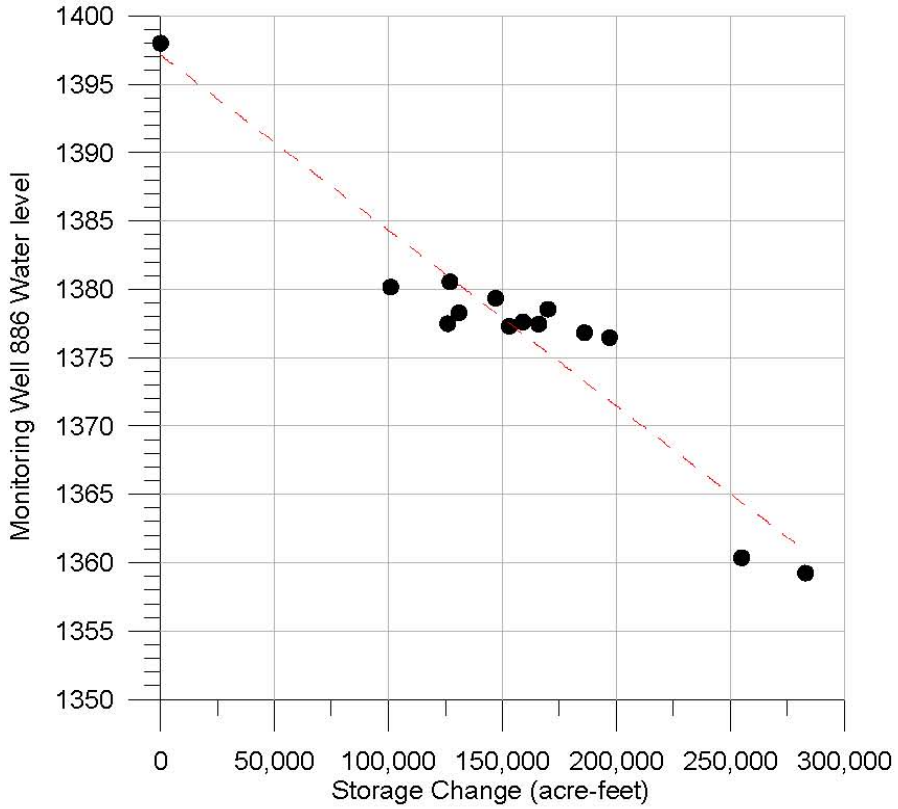
Storage volumes were determined by Burns & McDonnell for each section in the immediate study area, based on drilling and geophysical logs obtained for this project. The total thickness of coarse- and fine-grained material within the allowable vertical ASR zone was determined and storage factors were applied to calculate the total available volume within each section. The calculated total available volume for the immediate study area is about 200,000 acre-feet. This is comparable to the USGS evaluation for a slightly larger study area. Details of the evaluation, drill logs, cross-sections and methods are described in the Concept Design Report (Burns & McDonnell, 2000).

4.2.1 Storage Volume – Groundwater Level Relationship

A relationship between water levels in target well 886 and storage volumes calculated by the USGS is shown in Figure 4.2. The Figure shows the USGS calculated changes in storage from 1940 levels with well 886 elevations for the time of the calculations.

Table A-1 shows the modeled aquifer-stream losses and gains with groundwater elevations at target well 886 and the storage-volume deficit based on the USGS calculations as shown in Figure 4.2. The

Figure 4.2
Well 886 Elevation - Storage Change
USGS SIR 2006-5321



relationship between the storage-volume deficit and the aquifer-stream losses and gains is used directly in the operation model. Table A-2 compares the current model values with the original EIS estimates.

Table 4.1
Storage-volume changes in *Equus* Beds Aquifer near Wichita, South-central Kansas, August 1940-January 2006.

	Change in storage volume in the study area				Change in storage volume in the central part of the study area			
End date of time period	Since August 1940 (acre-feet)	Since October 1992 (acre-feet)	Since October 1992 (percent)	Since January 2003 (acre-feet)	Since August 1940 (acre-feet)	Since October 1992 (acre-feet)	Since October 1992 (percent)	Since January 2003 (acre-feet)
October 1992	[1]-283,000	--	--	--	[1]-159,000	--	--	--
January 1993	[2]-255,000	+28,000	+10	--	[2]-154,000	+5,000	+3	--
January 2000	[1]-126,000	[3]+157,000	+55	--	[1]-70,600	[3]+88,400	[3]+56	--
April 2000	[3]-101,000	[3]+182,000	[3]+64	--	[3]-74,500	[3]+84,500	+53	--
January 2003	[3]-159,000	[3]+124,000	+44	--	[3]-83,400	[3]+75,600	+48	--
April 2003	-153,000	+130,000	+46	+6,000	-84,400	+74,600	+47	-1,000
July 2003	-197,000	+86,000	+30	-38,000	-89,300	+69,700	+44	-5,900
October 2003	-186,000	+97,000	+34	-27,000	-92,300	+66,700	+42	-8,900
January 2004	-170,000	+113,000	+40	-11,000	-89,900	+69,100	+43	-6,500
April 2004	-147,000	+136,000	+48	+12,000	-83,600	+75,400	+47	-200
July 2004	-166,000	+117,000	+41	-7,000	-86,900	+72,100	+45	-3,500
October 2004	-158,000	+125,000	+44	+1,000	-86,200	+72,800	+46	-2,800
January 2005	-143,000	+140,000	+49	+16,000	-82,700	+76,300	+48	+700
April 2005	-131,000	+152,000	+54	+28,000	-80,500	+78,500	+49	+2,900
July 2005	-137,000	+146,000	+52	+22,000	-74,300	+84,700	+53	+9,100
October 2005	-131,000	+152,000	+54	+28,000	-74,300	+84,700	+53	+9,100
January 2006	-127,000	+156,000	+55	+32,000	-68,900	+90,100	+57	+14,500

[1] Storage-volume change previously reported by Hansen and Aucott (2001).

[2] Storage-volume change previously reported by Aucott and Myers (1998).

[3] Storage-volume change previously reported by Hansen and Aucott (2004).

(Table from USGS Scientific Investigations Report 2006-5321)

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APPENDIX A - GROUNDWATER MODEL INFORMATION

Table A-1

Equus Beds Elevation-Storage-Gain-Loss Data

Elevation (feet)*	Storage Deficit (acre-feet)**	Gain from Arkansas River (cfs)	Loss to Little Arkansas River (cfs)
1342	NA	NA	NA
1360	290,000	100	38
1366	245,000	89	43
1370	212,000	82	44
1375	173,000	73	48
1380	135,000	62	53
1385	95,000	54	60
1390	55,000	48	70
1395	20,000	38	82
1396	10,000	36	85
1402	0	29	99

* Aquifer head at monitoring well 886
** Storage deficit read directly from graph and rounded to nearest 1000 ac-ft

Table A-2

Equus Beds Elevation-Storage-Gain-Loss Data

	Original EIS Model		EIS Model Update	
Elevation (feet)*	Gain from Streams (cfs)	Loss to Streams (cfs)	Gain from Streams (cfs)	Loss to Streams (cfs)
1342	138.2	-2.0	NA	NA
1360	90.5	8.2	100	38
1366	74.5	11.6	89	43
1370	63.9	13.9	82	44
1375	57.3	19.8	73	48
1380	50.2	29.2	62	53
1385	40.3	41.9	54	60
1390	29.1	56.3	48	70
1395	17.7	72.0	38	82
1396	15.1	75.2	36	85
1402	NA	NA	29	99

* Aquifer head at monitoring well 886

Figure A-1. Hydraulic Conductivity Zones in Layer 1

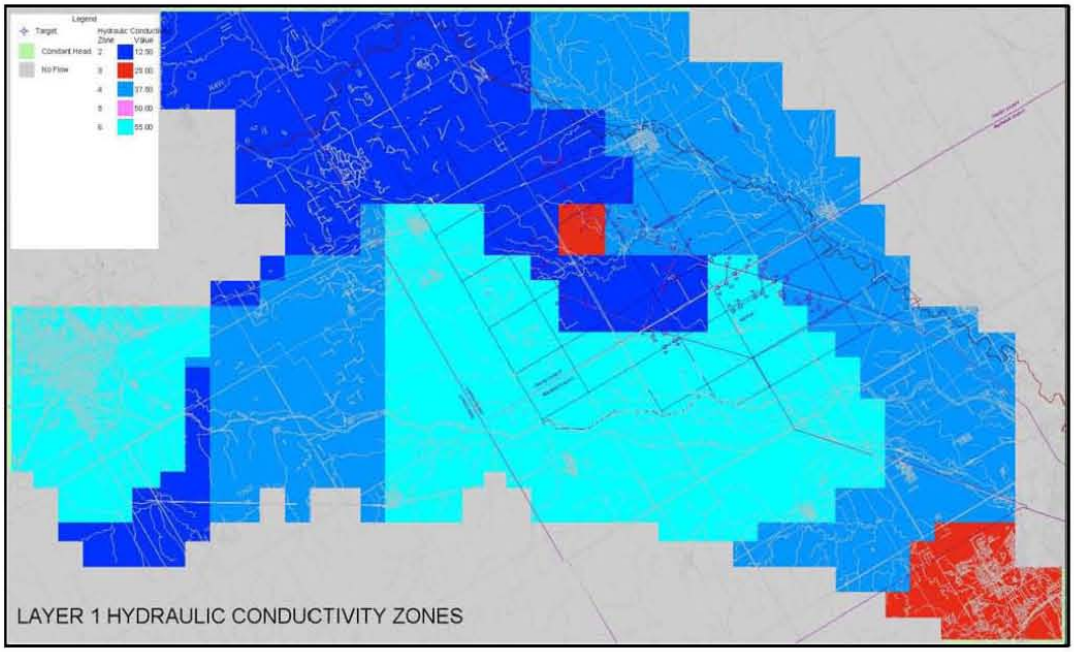


Figure A-2. Hydraulic Conductivity Zones in Layer 2

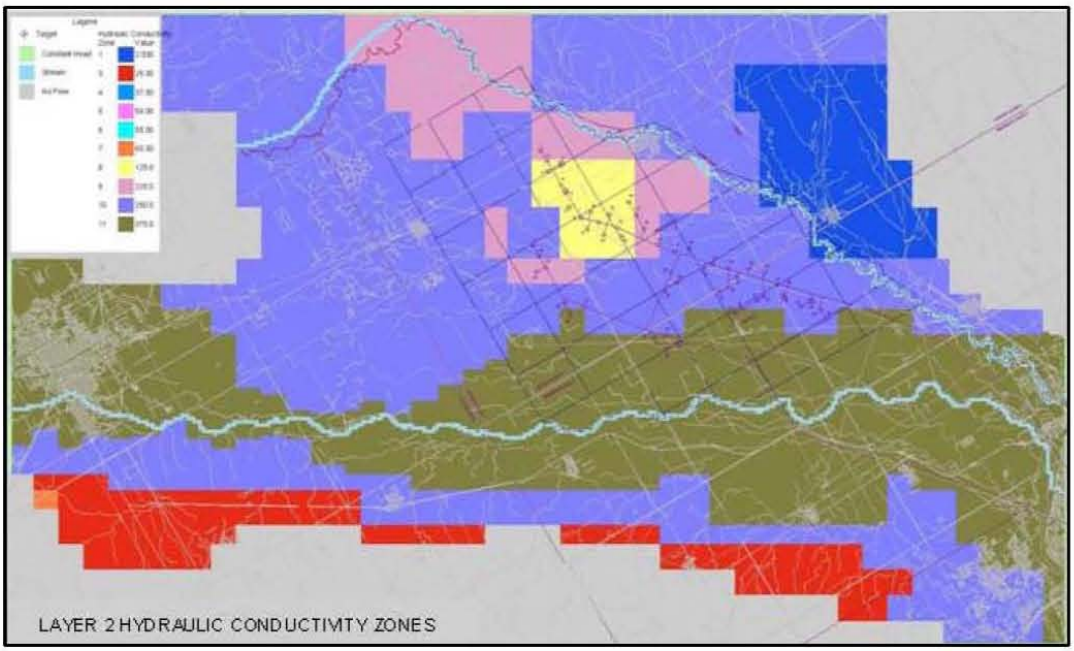


Figure A-3. Hydraulic Conductivity Zones in Layer 3

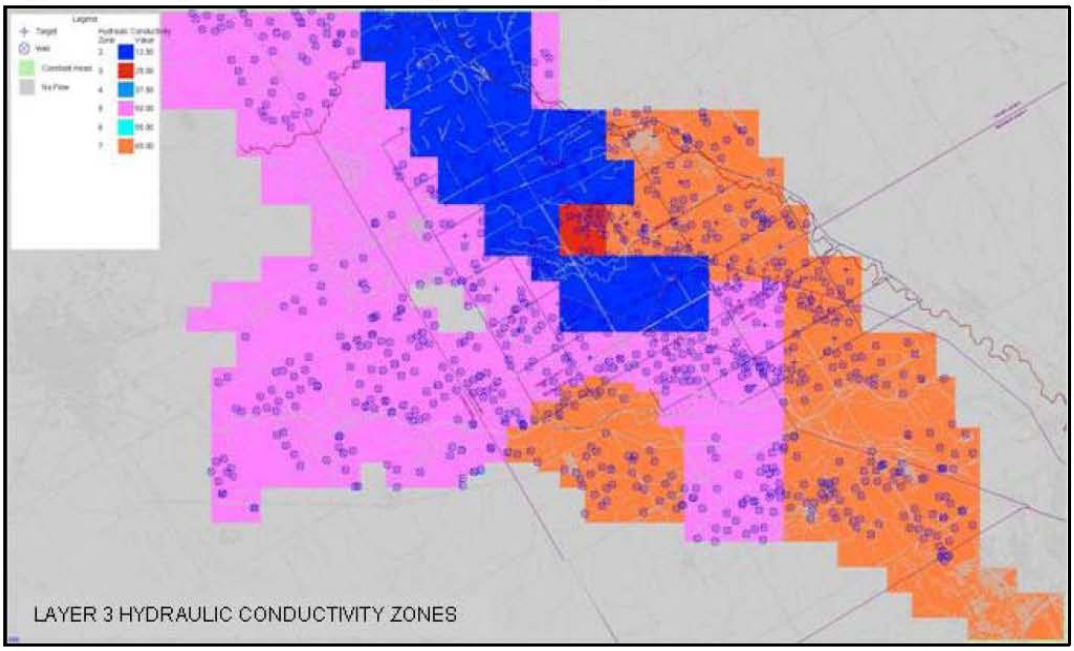
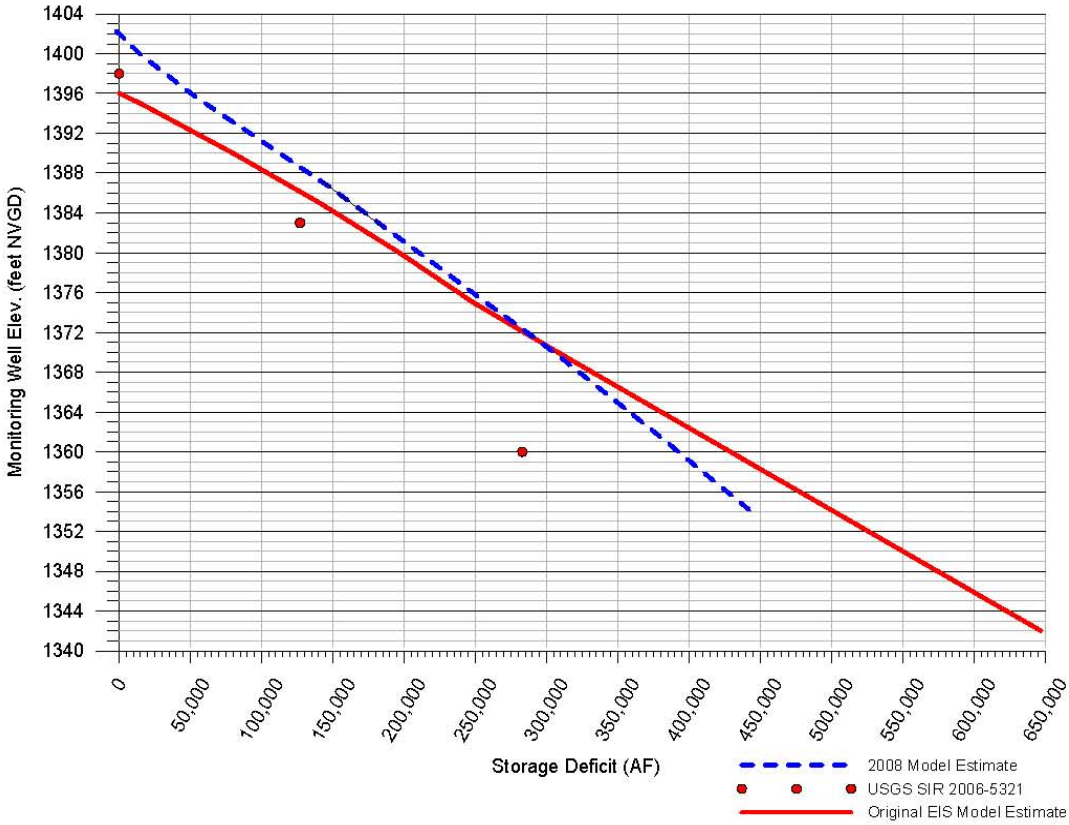


Figure A-4. Comparison of Storage Deficit vs Aquifer Head



Attachment C

Supplemental Information on Cheney Reservoir Evaporation Rates

RESERVOIR EVAPORATION RATES

This appendix documents the reservoir evaporation rate estimates that have been developed for use in planning studies for the City of Wichita's Integrated Local Water Supply (ILWS) Plan. Discussed below are the base climatic and hydrologic data, the methodology used to develop the evaporation estimates and the resulting estimates.

Background

A computer model was developed to simulate operation of the ILWS system under various scenarios. This operations model was used initially to help with the conceptual design of the ILWS system and later to quantify potential hydrologic impacts for the project's environmental impact statement (EIS). The operations model calculates a water balance for the ILWS system each day during the 85-year model simulation period (water years [WY] 1923–2007) using the following hydrologic data:

- Historical mean daily stream discharge at selected points within the project area
- Historical monthly reservoir evaporation rates
- Available storage and other physical data for Cheney Reservoir
- Available storage, natural recharge and other parameters for the Equus Beds aquifer
- City's current and projected water demands
- Irrigation demands for agriculture in the Equus Beds Well Field area
- Minimum desirable streamflow requirements
- Supply capability and other operating parameters for all current and potential water supply sources
- Preferred allocation order for each water supply source

The City's existing Cheney Reservoir is one of the principal supply sources in the ILWS system. This reservoir is located on the North Fork Ninnescah River (North Fork) about 26 miles west of downtown Wichita. Simulating the operation of this reservoir requires estimates of all significant inflow to and outflow from the reservoir, including the net evaporation from the reservoir surface. The evaporation rate estimates discussed below were used to estimate the net evaporation losses from this reservoir.

Climatic Data

The evaporation rate estimates are based directly or indirectly on recorded climatic data. The climatic data utilized in this analysis are described below:

Pan Evaporation Data

The City of Wichita has collected pan evaporation data at Cheney Reservoir since shortly after the reservoir was placed in service. These data were provided to Burns & McDonnell in the form of monthly pan evaporation rates. The period of record for these data is September 1965 through August 2008; however, there are frequent missing values during the winter months prior to 1975.

Pan evaporation data for two other stations in the vicinity of Cheney Reservoir were also collected for comparison purposes. These data are described below:

- Wichita Weather Service Office: The National Weather Service has developed estimates of average monthly pan evaporation at the Weather Service Office (WSO) in Wichita for the period 1956–1970 (NOAA, 1982b). This office is located near the Wichita airport, which is about 21 miles east-southeast of Cheney Reservoir.

- Fall River Dam: Pan evaporation data were collected at Fall River Dam from 1948–1978. This dam is located approximately 95 miles east of Cheney Reservoir.

The pan evaporation data available from these sources were converted into estimates of lake, or free water surface, evaporation by multiplying by a pan coefficient of 70 percent (NOAA, 1982a). Table 1 and Figure 1 present the average monthly lake evaporation rates calculated from these data. Review of this table and graph show that the recorded monthly evaporation at Cheney Reservoir is typically higher than at the other two locations. This condition is not unexpected because evaporation in Kansas tends to increase in a westerly direction as the climate becomes more arid.

Other Climatic Data

Other types of monthly climatic data were also collected for use in these evaporation rate estimates. These additional data were all collected at the National Weather Service office in Wichita. The available types of climatic data, along with their respective units and periods of record, are listed below:

Table 1: Average Monthly Lake Evaporation Rates (inches)

Month	Cheney Reservoir[a,b]	Wichita WSO[a,c]	Fall River Dam[a,d]
Jan	1.32	1.14	0.71
Feb	1.48	1.47	1.65
Mar	2.58	2.90	3.12
Apr	4.52	4.12	4.92
May	5.46	5.25	5.40
Jun	7.11	6.13	6.08
Jul	8.41	6.76	7.22
Aug	7.61	6.42	6.98
Sep	5.14	4.20	4.50
Oct	3.84	3.28	3.41
Nov	2.03	1.84	1.88
Dec	1.53	1.39	0.75
Annual	51.03	44.90	46.62
May-Oct	37.57	32.04	33.59

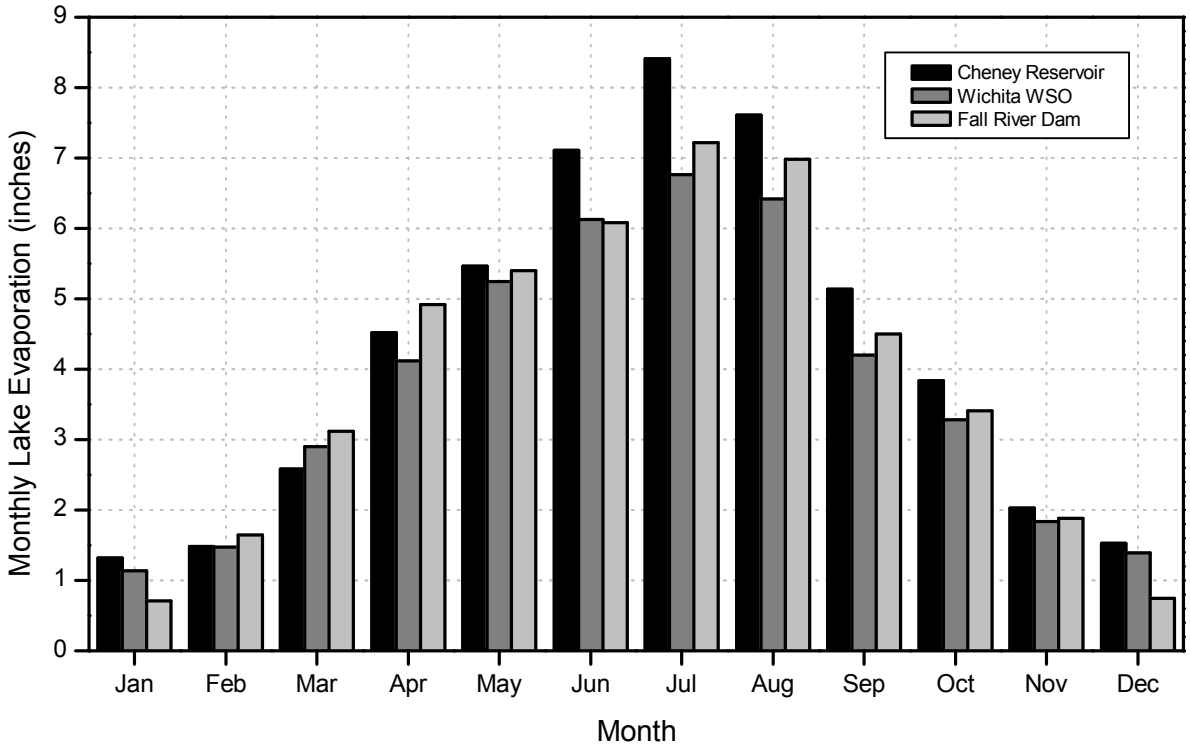
a. Calculated from recorded or estimated pan evaporation data using pan coefficient of 70 percent.

b. Pan evaporation data collected by City for period Sep 1965-Aug 2007.

c. National Weather Service estimates of pan evaporation for period 1956–1970.

d. Pan evaporation data collected for period 1948–1978.

Figure 1: Average Monthly Lake Evaporation Rates



- Average monthly temperature (degrees F.) — Jan 1922–Dec 2007
- Total monthly precipitation (inches) — Jan 1930–Dec 2007
- Average monthly relative humidity (percent) — Jan 1954–Dec 1997
- Average monthly wind speed (miles/hour) — Jan 1954–Dec 1997
- Average monthly barometric pressure (millibars) — Jan 1954–Dec 1997
- Average monthly sunshine (percent of possible sunshine) — long-term averages by month only
- Average solar radiation (megajoules/square meter) — long-term averages by month only

Average monthly values for these data are listed in Table 2. Appendix A contains a complete listing of the data types that have long periods of record: temperature, precipitation, relative humidity, wind speed and barometric pressure. As noted above, many of these data types are only available starting in 1954. For earlier periods when these data types are missing, long-term average monthly values were used as a substitute for actual monthly data.

Table 2: Average Monthly Climatic Data[a]

Month	Temper-ature	Precip-itation	Percent Sunshine	Relative Humidity	Solar Radiation	Wind Speed	Baro. Pressure

	(deg. F.)	(inches)		(percent)	(MJ/m^2)	(mph)	(millibars)
Jan	31.3	0.88	61	74.4	9.29	10.0	971.5
Feb	36.5	1.03	61	72.8	11.97	10.9	970.2
Mar	45.0	2.07	61	69.4	15.99	11.6	966.7
Apr	56.2	2.67	64	69.4	19.76	11.8	965.7
May	65.6	4.04	65	74.4	22.78	10.3	965.4
Jun	75.7	4.47	70	72.8	25.20	10.2	965.7
Jul	81.1	3.42	76	67.8	22.12	9.3	967.4
Aug	81.0	3.25	75	68.8	19.32	9.1	967.8
Sep	71.1	3.21	68	72.6	18.71	9.7	968.6
Oct	59.3	2.48	65	71.5	14.40	9.9	969.4
Nov	44.9	1.50	59	73.4	10.26	10.2	969.4
Dec	34.7	1.16	58	75.2	8.29	9.8	970.8

a. All of these data were collected at the Wichita Weather Service Office. The period of record for these data varies. Percent sunshine and solar radiation available only as long-term averages by month.

Evaporation Model

The pan evaporation data collected by the City at Cheney Reservoir are considered to provide the best possible estimates of reservoir evaporation when available (Table B-1 in Appendix B). However, these data start in the mid-1960s when the reservoir was placed in operation and do not cover the entire simulation period used in the operations model (WY1923–2007). For the period prior to 1965, reservoir evaporation rate estimates were calculated for Cheney Reservoir using Burns & McDonnell's ETCALC computer model. This model uses a form of the Penman Equation to estimate evaporation depths. In general, the ETCALC model uses the following procedure to estimate evaporation rates.

- Advective Losses: The ETCALC model contains a number of relationships to estimate advective, or aerodynamic, losses from the reservoir surface. Advective losses occur as water evaporates from the reservoir into the air immediately over the water surface. This process will occur whenever this air is unsaturated with water vapor (that is, has a relative humidity less than 100 percent). Wind that flows across the reservoir surface will then carry this "wetter" air away and replaces it with air that is

relatively drier, allowing the process to continue. Advective losses are primarily a function of air temperature, relative humidity and wind speed.

- Energy Budget: A substantial amount of heat energy is required to transform water in liquid form into water vapor. The ETCALC model also contains relationships to estimate the amount of evaporation that would occur using an energy budget, or heat balance, methodology. The principal source of heat energy that controls evaporation is the Sun. Incident solar radiation at the reservoir varies seasonally, based on the inclination of the Earth's axis and its distance from the Sun, and with the amount of cloud cover (percent possible sunshine).

- Weighting Function: The Penman Equation uses a weighting function to estimate potential evapotranspiration from the separate advective loss and energy balance estimates. This weighting function is based on the slope of the saturation-vapor-pressure versus temperature curve at the given air temperature. (Linsley, et. al., 1982).

The relationships build into the ETCALC model — the relationships that estimate the advective loss, energy budget and weighting function terms described above — use the types of climatic data listed in the previous section as inputs. For the most accurate evaporation estimates, these inputs should be daily data. However, records of daily climatic data have become widely available only in recent years. Therefore the ETCALC model was designed to use monthly inputs and generate monthly evaporation rate estimates.

Model Calibration

The ETCALC model must be calibrated to yield accurate evaporation estimates. There are two calibration coefficients available in the model that can be used to adjust the resulting evaporation rate estimates. The model was calibrated using the available pan evaporation data collected by the City at Cheney Reservoir, which start in September 1965. When available, the ETCALC model will use recorded evaporation data to calculate a goodness-of-fit statistic based on the differences between monthly recorded and estimated evaporation rates (sum of the squares of the residuals). For calibration, the ETCALC model was executed for a period September 1965–December 1996. The calibration coefficients were adjusted by trial and error until a minimum value for this goodness-of-fit statistic was obtained.

Evaporation RATE Estimates

Once the ETCALC model was successfully calibrated, it was re-executed to estimate monthly evaporation rates for the entire simulation period, WY1923–2007. The evaporation rates estimated in the ETCALC model are gross rates for Cheney Reservoir. These estimated evaporation rates were combined with the data recorded by the City to yield a composite record. That is, whenever recorded evaporation data were available, they were used in preference to values estimated by the ETCALC model. The resulting gross evaporation rate estimates are listed in Table B-2.

Precipitation that falls directly on the surface of Cheney Reservoir will tend to offset some of the gross evaporation from the reservoir. The resulting evaporation — gross evaporation less direct precipitation — is referred to as net reservoir evaporation. Not all of the precipitation that strikes the surface of a reservoir is considered to reduce evaporation. In the absence of the reservoir, some of this precipitation would have run off from the portion of the watershed that is covered by the reservoir itself and contribute to the discharge in the North Fork. This direct runoff was accounted for in the reservoir's inflow estimates. Therefore, to avoid double counting this water, monthly net evaporation estimates (N) were calculated using the following formula:

$$N = G - P + R$$

In this equation, G is the estimated monthly gross evaporation and P is the estimated total monthly precipitation at Cheney Reservoir. The direct runoff component (R) is also a function of precipitation and was estimated to be 30 percent of direct precipitation. Substituting this relationship for direct runoff ($R = 0.3P$) into the above equation yields the following equation for net evaporation:

$$N = G - 0.7\ P$$

Substituting the values of gross evaporation (G) (Table B-2) and precipitation (P) (Table A-2), yields the monthly net evaporation rates estimates. These net evaporation rates are listed in Table B-3. These net evaporation rates can be negative in months when precipitation exceeds evaporation.

Summary

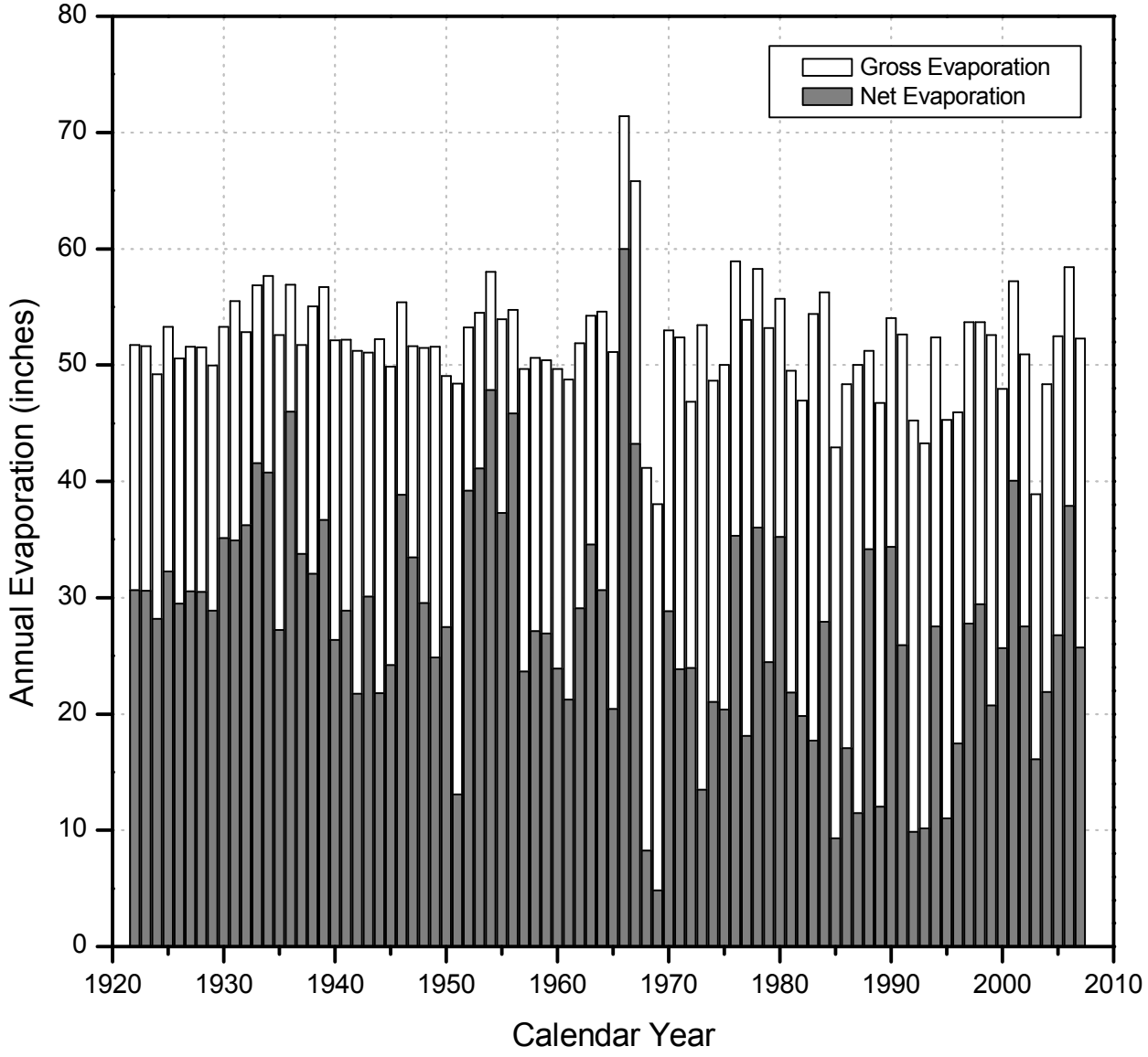
Table 3 is a summary that lists average monthly rates for gross and net evaporation. Figure 2 is a graph of estimated annual gross and net evaporation rates that shows how these rates vary from year to year.

Table 3: Average Monthly Evaporation Rates at Cheney Reservoir

Month	Gross Evaporation (inches)	Net Evaporation (inches)
Jan	1.53	0.85
Feb	1.71	0.92
Mar	2.66	0.94
Apr	4.18	2.04
May	5.25	2.01
Jun	6.88	3.26
Jul	8.31	5.57
Aug	7.86	5.26
Sep	5.47	2.90
Oct	4.08	2.10
Nov	2.27	1.06
Dec	1.68	1.06
Annual	51.88	27.67

Review of Figure 2 shows that annual gross evaporation ranged from a low of 38.02 inches in 1969 to a high of 71.42 inches in 1966; annual gross evaporation averages 51.88 inches. Annual net evaporation is more variable than gross evaporation because it is influenced by precipitation, which can vary significantly from year to year. The range in annual net evaporation was from about 5 to 60 inches, with an average of nearly 28 inches.

Figure 2: Annual Gross and Net Reservoir Evaporation (inches)



The operations model uses a daily time step so it requires estimates of daily evaporation. The daily evaporation rates used in the operations model were estimated from these monthly data by simply dividing the monthly totals by the number of days in each month to yield average daily values by month.

References

Complete citations for the references cited in this document are listed below:

Linsley, R., Kohler, M. & Paulhus, J. (1982). *Hydrology for engineers.* NewYork: McGraw-Hill Book Company

National Oceanic and Atmospheric Administration (NOAA). (1982a, July). *Evaporation Atlas for the Contiguous United States* [Technical Report NWS 33]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service: Washington, DC.

NOAA. (1982b, December). *Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States* [Technical Report NWS 34]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service: Washington, DC.

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Attachment D

Supplemental Information on Streamflow Discharge Development for RESNET Model

STREAMFLOW ESTIMATES

This appendix documents the streamflow estimates that have been developed for use in planning studies for the City of Wichita's Integrated Local Water Supply (ILWS) Plan. Discussed below are the base historical streamflow data, the methodology used to synthesize flow estimates, and the resulting estimates.

Background

A computer model was developed to simulate operation of the ILWS system under various scenarios. This operations model was used initially to help with the conceptual design of the ILWS system; it was later used to quantify potential hydrologic impacts for the project's environmental impact statement (EIS). The operations model calculates a water balance for the ILWS system each day during the 85-year model simulation period (water years [WY] 1923–2007) using the following hydrologic data:

- Historical mean daily stream discharge at selected points within the project area
- Historical monthly reservoir evaporation rates
- Available storage and other physical data for Cheney Reservoir
- Available storage, natural recharge and other parameters for the Equus Beds aquifer
- City's current and projected water demands
- Irrigation demands for agriculture in the Equus Beds Well Field area
- Minimum desirable streamflow requirements
- Supply capability and other operating parameters for all current and potential water supply sources
- Preferred allocation order for each water supply source

The ILWS system is represented in the operations model as a network of nodes with connecting links. The majority of the model nodes represent locations on project area streams; the remaining nodes represent off-stream features, such as well fields, treatment plants and pipeline junctions. A schematic of the overall operations model network is shown in Figure 1. The nodes shown in Figure 1 with dark shading are stream nodes that receive unregulated surface runoff. These stream nodes are listed in Table 1 along with their corresponding node numbers.

Figure 1: Operations Model Schematic

(see Page A4 of Attachment A)

Table 1: Model Stream Nodes with Unregulated Inflow

Model Stream Node (Node Number)	Model Stream Node (Node Number)
Arkansas River near Hutchinson (10)	Little Arkansas River at Mouth (70)
Arkansas River near Maize (20)	Arkansas River at Wichita (80)
Little Arkansas River at Alta Mills (30)	NF Ninnescah River at Cheney Reservoir (90)
Little Arkansas River at Halstead (40)	Ninnescah River near Peck (100)
Little Arkansas River near Sedgwick (50)	Arkansas River at Arkansas City (110)
Little Arkansas River at Valley Center (60)	

To maintain a daily water balance for the ILWS system, the operations model requires estimates of mean daily streamflow at each of these stream nodes. As there is no practicable method available that can predict future hydrologic conditions with any certainty, these streamflow estimates are based on historical data. These historical data are used as a surrogate for possible future streamflow. The historical streamflow estimates developed for the operations model are described below.

Recorded Stream Discharge Data

In the United States, stream discharge data are collected primarily by the U.S. Geological Survey (USGS). Although the USGS maintains a network of stream gaging stations located throughout the country, it does not operate gaging stations at each of the stream nodes identified above. Therefore, it was necessary to synthesize some of the stream discharge data used in the operations model from those data that were available. The available stream gages of interest in the project vicinity are listed in Table 2 along with other relevant data. A map showing the locations of these gages is included as Figure 2 (USGS, no date). The recorded mean daily discharge for these gages was downloaded from the USGS' National Water Information System (NWIS), an online database system.

Review of Table 2 shows these streamflow records start as early as 1921 for the Arkansas River; however, only two of these gages, the Little Arkansas River at Valley Center (Station 07144200) and Arkansas River at Arkansas City (Station 07146500), have long continuous records. Under the ILWS plan, the Little Arkansas River is the primary new water source, both for direct use and aquifer recharge; therefore, this gage's period of record was used to define the simulation period for the project operations model: WY 1923-2007 (October 1922–September 2007).

Table 2: USGS Stream Gaging Stations[a]

Station Number	Name	Location (Latitude/ Longitude)	Drainage Area[b] (sq. mi.)	Period of Record
07143330	Arkansas River near Huchinson, KS	37°56'47" 97°45'29"	31,724	10/01/59-09/30/07
07143375	Arkansas River near Maize, KS	37°46'53" 97°23'33"	31,924	03/01/87-09/30/07
07143400	Arkansas River near Wichita, KS	37°42'30" 97°21'50"	31,978	10/01/21-03/31/35
07143665	Little Arkansas River at Alta Mills, KS	38°06'44" 97°35'30"	681	06/06/73-09/30/07
07143672	L. Arkansas River at Hwy 50 near Halstead, KS	38°01'43" 97°32'25"	685	05/01/95 09/30/07
07144100	Little Arkansas River near Sedgwick, KS	37°52'59" 97°25'27"	1,165	10/01/93-09/30/07
07144200	Little Arkansas River at Valley Center, KS	37°49'56" 97°23'16"	1,253	06/10/22-09/30/07
07144200	Little Arkansas River Floodway[c]	---	---	---
07144300	Arkansas River at Wichita, KS	37°38'41" 97°20'06"	33,227	10/01/34-09/30/07
07144300	Big Slough-Cowskin Floodway[d]	---	---	---
07144550	Arkansas River at Derby, KS	37°32'34" 97°16'31"	33,567	10/01/68-09/30/07
07144780	N. Fork Ninnescah River above Cheney Res., KS	37°50'41" 97°56'09"	550	07/01/65-09/30/07
07144795	North Fork Ninnescah River at Cheney Dam, KS	37°43'17" 97°47'39"	664	10/01/64-09/30/07
07144800	North Fork Ninnescah River near Cheney, KS	37°40'00"	685	10/01/50-

		97°46’00”		09/30/64
07145500	Ninnescah River near Peck, KS	37°27’26” 97°25’20”	1,785	04/01/38- 09/30/07
07146500	Arkansas River at Arkansas City, KS	37°03’23” 97°03’32”	36,106	10/01/21- 09/30/07

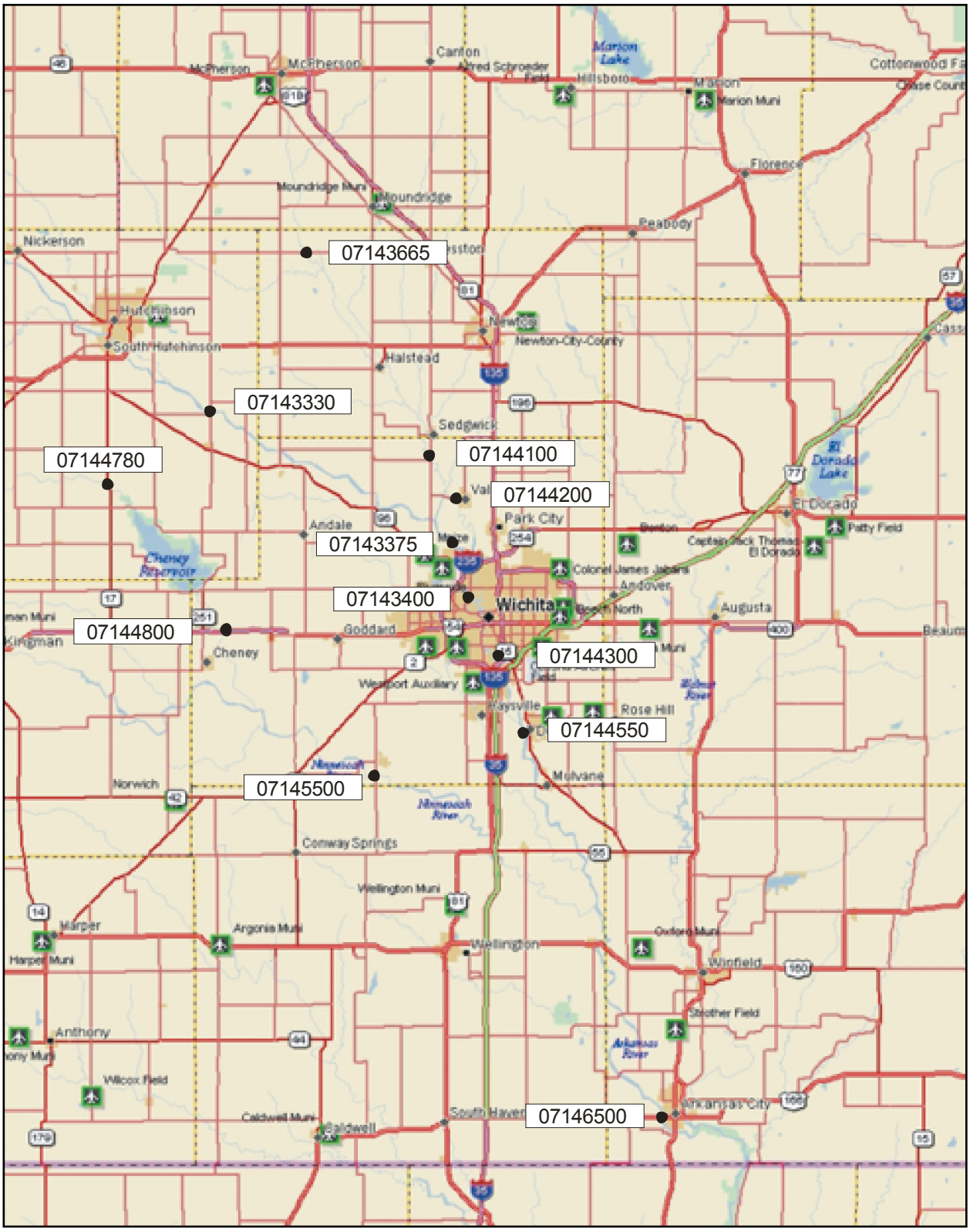
a. The available data at these gaging stations were downloaded from USGS NWIS database system.

b. Contributing drainage area.

c. During periods of high flow, some of the flow in the Little Arkansas River is diverted through the Little Arkansas Floodway into the Arkansas River. Flow data for Station 07144200 is a composite of flow in main stem of Little Arkansas River and Little Arkansas River Floodway.

d. During periods of high flow, some of the flow in the Arkansas River is diverted around Wichita through the Big Slough-Cowskin Floodway. These diverted flows re-enter the Arkansas River downstream of Wichita near Derby, KS. Flow data for Station 07144300 is a composite of flow in main stem of Arkansas River and Big Slough-Cowskin Floodway.

Figure 2: Location Map for USGS Stream Gages



Stream discharge can vary significantly from day to day and year to year based on weather patterns and other factors. On an annual basis, this variability is illustrated in a graph of the annual discharge in the Little Arkansas River at Valley Center (Valley Center gage) (Figure 3). These annual discharges have ranged from a low of approximately 18,000 acre-feet in WY 1934 to 1.23 million acre-feet in WY 1993, a factor of more than 100.

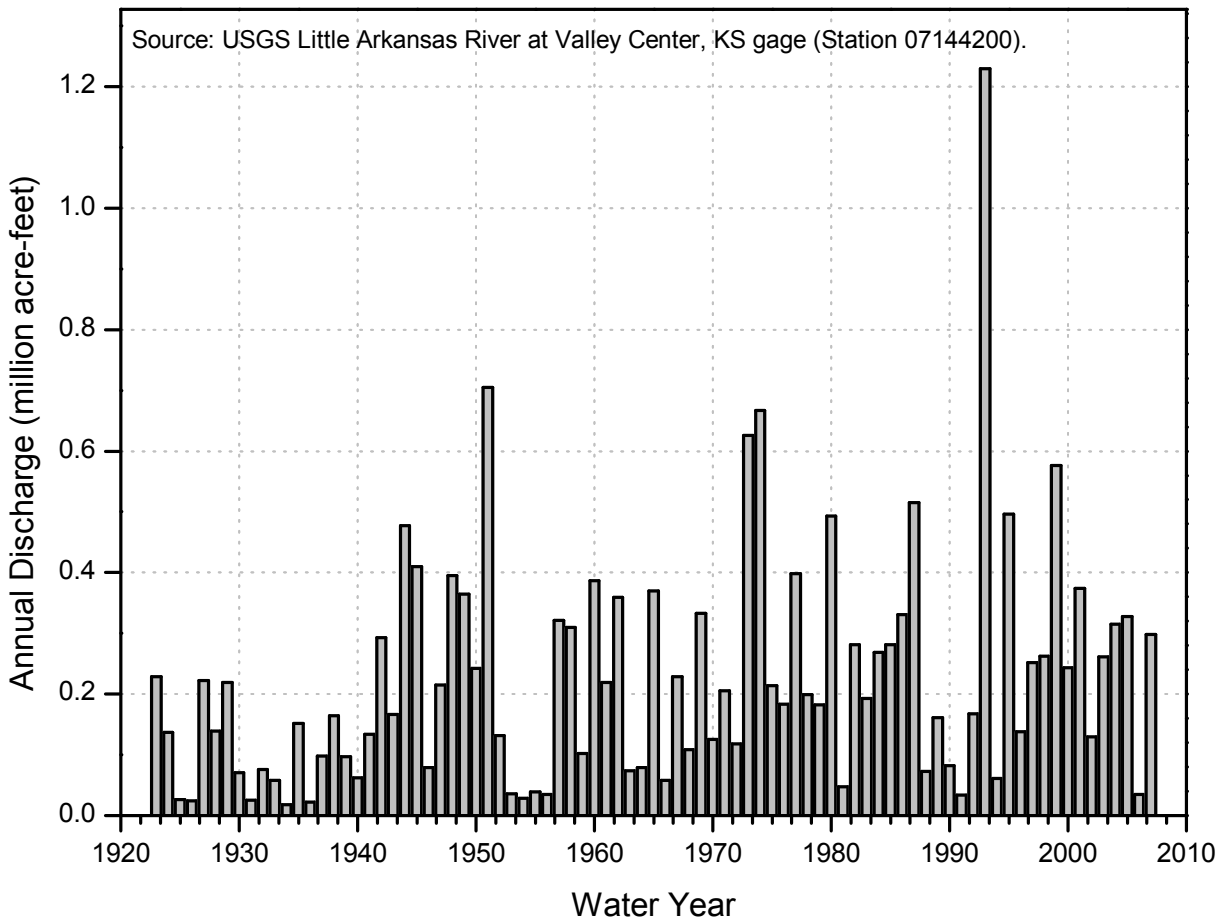


Figure 3: Annual Discharge in Little Arkansas River at Valley Center

For water supply purposes, the most critical periods during the available record are times of drought. In Kansas and much of the central plains region, the drought of record occurred in the mid-1950s. Following widespread flooding in WY 1951 and normal flows in WY 1952, the next four consecutive water years (1953–1956) proved to be exceptionally dry. Individually, there were several water years during the "dust bowl" of the 1920s and 1930s that were drier than these four years (1934, 1936, 1926, 1931, and 1925),

but never more than two in a row. This drought generally ended in February 1957 with heavy rains across the region.

On a daily basis, the mean flow at the Valley Center gage has ranged from 1.1 to 28,600 cubic feet per second (cfs), and averages 315 cfs. Figure 4 is a flow duration curve for this stream gage that shows this daily variability. From this figure, the median (50 percent) discharge in the Little Arkansas River is shown to be 59 cfs, approximately one fifth of the average flow. The 10- and 90-percent flows at this gage are 494 and 21 cfs, respectively.

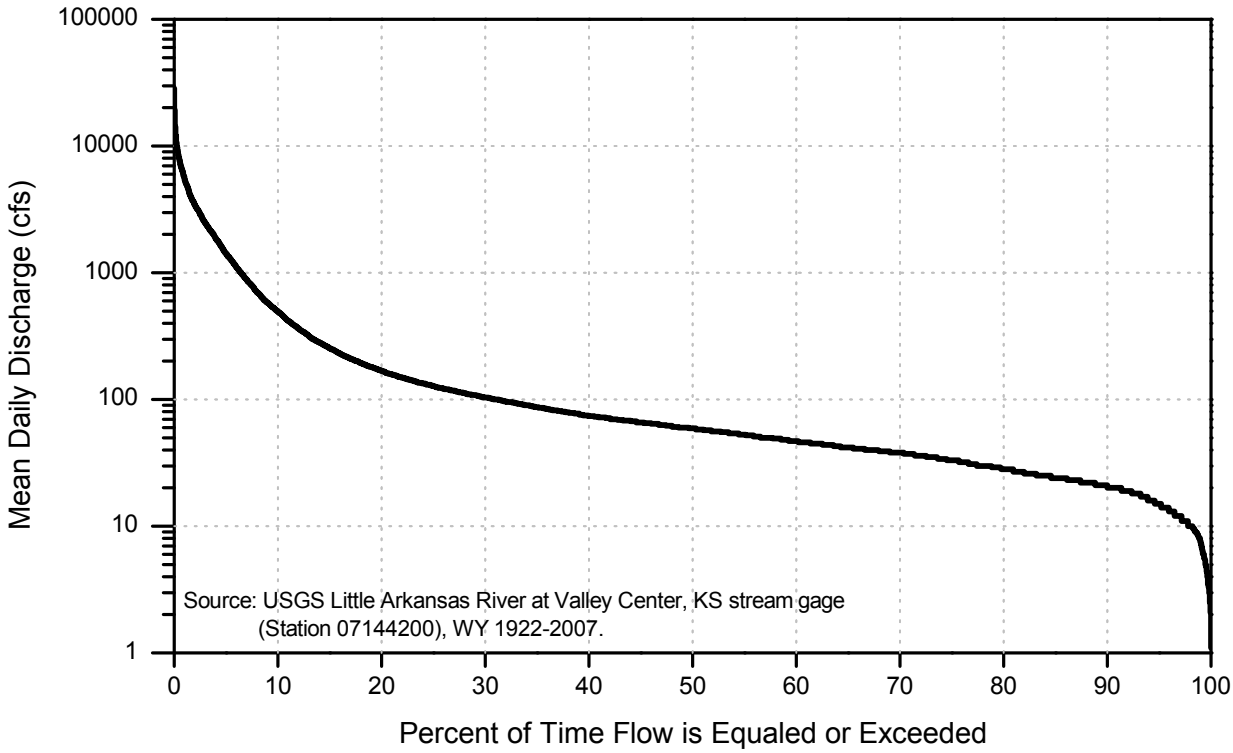


Figure 4: Flow Durations in Little Arkansas River at Valley Center

Natural Stream Discharge

Natural stream discharge is the discharge that would have occurred in a stream without any man-made influences. These influences can include construction of an upstream reservoir, direct withdrawals for water supply or irrigation, or indirect withdrawals caused by groundwater depletions. Over time, these influences tend to become more pronounced as the water resources within a stream's watershed area are developed.

As a typical first step in the development of a computer model for a water supply system, the available recorded streamflow data are naturalized. That is, they are adjusted to reflect estimated natural conditions by attempting to remove the affects of significant man-made influences. Estimating these influences, however, requires detailed records of applicable stream withdrawals and reservoir operations plus estimates of stream-aquifer interactions (discharges from aquifer to stream and depletions from stream to aquifer). Unfortunately, many of the necessary historical data often do not exist. Even where these data do exist, collection of these data can become a daunting task for a watershed the size of the Arkansas River.

Within the ILWSP project area, there are three primary streams of interest: the North Fork Ninnescah, Little Arkansas and Arkansas rivers. Each of these streams is discussed separately below.

North Fork Ninnescah River

The North Fork Ninnescah River is home to Cheney Reservoir. Other than Cheney Reservoir itself, there is little development within this watershed that would significantly impact streamflow volumes. Land use within the watershed upstream of the reservoir is largely agricultural. Some of this cropland is irrigated but this water is supplied from groundwater and not by diversions from the river. The flow in this river and its tributaries is sporadic enough that surface water diversions have limited utility without accompanying storage. The City has relatively senior surface water rights for Cheney Reservoir and a comprehensive watershed protection program is in place for the reservoir's catchment area.

There are two stream gages on this stream that were used to estimate Cheney Reservoir inflow. The gage near Cheney (Station 07144800) is located below Cheney Dam; this gage was discontinued when the reservoir was placed in service. The other gage of interest (Station 07144780) is located above the reservoir. As a result, neither of these flow records requires adjustment because of the reservoir. Therefore, given there has been little other surface water development in this watershed, the recorded flow at these two gages is considered reasonably equivalent to natural flow.

About 15 miles downstream of Cheney Reservoir, the North and South Forks meet to form the main stem of the Ninnescah River. There is another stream gage downstream on the Ninnescah River that was included as a stream node in the operations model: Ninnescah River near Peck (Station 07145500). About 37 percent of this gage's drainage area is located above Cheney Dam and the recorded flow at this gage has been impacted by operation of the reservoir since it went online in 1964. Therefore, the recorded flows at this gage are generally less than natural in recent years. However, this node was included in the

operations model only to show the impacts (discharge differences) of the various alternatives. For this reason, natural flow at this gage was not estimated.

Little Arkansas River

The Little Arkansas River is the major new water source that will be developed under the ILWS plan. The water in this river will be used directly to meet current City water demands and for aquifer recharge. Land use within this river's watershed is mostly agricultural, except at its extreme northern extent where the City of McPherson is located. Water supplies within this area are derived almost exclusively from groundwater. There are a few small surface water rights on the Little Arkansas River but none result in significant depletions.

There are four USGS stream gages on the Little Arkansas River that were used as stream nodes in the operations model: Alta Mills (Station 07143665), Halstead (Station 07143672), Sedgwick (Station 07144100), and Valley Center (Station 07144200). Given the general lack of significant surface water diversions within the Little Arkansas River watershed and the Alta Mills gage's location relatively high in the watershed, no adjustments were made to this gage's record.

Similarly, the flow record at the Sedgwick, Halstead and Valley Center gages has not been significantly influenced by surface water diversions. However, groundwater discharge from the Equus Beds aquifer does contribute to the base flow in the river at these gages. The operations model includes routines to estimate this groundwater discharge so the incremental runoff between these gages was adjusted later to remove the estimated historical groundwater discharge. This process avoids double counting of this groundwater discharge in the operations model and yields more accurate results.

Arkansas River

The Arkansas River runs through Wichita but because of its poor quality characteristics (high saline content), it is not currently a major water source for the City; use of this water source will increase under the ILWS plan but not significantly. Above Wichita, the Arkansas River drains a contributing watershed that covers more than 33,000 square miles, including about one-half of the State of Kansas. The water resources of the Arkansas River have been extensively developed, with the first ditch diversions for irrigation occurring in the late 1800s.

Although these surface water diversions have impacted the flow in this river, the more significant impacts have occurred because of groundwater development. The High Plains and other aquifers of the central plains states have been developed extensively for irrigation, municipal, and industrial use. This groundwater usage exploded beginning in the late 1960s with the development of reliable center pivot irrigation systems, which encouraged farmers to begin irrigating thousands of square miles of cropland in eastern Colorado and western Kansas. The resulting declines in groundwater levels have turned the Arkansas River into a losing stream; historically, the discharge from alluvial aquifers helped maintain the base flow in this river. Figure 5 provides an illustration of just how significant these flow impacts have been. This graph shows the annual flow in the Arkansas River at Dodge City, which is located about 150 miles west of Wichita. Prior to the 1970s, the discharge at Dodge City was typically 40,000 acre-feet or more even in drier years. By the mid-1970s, typical dry-year flows had dropped to zero or nearly zero.

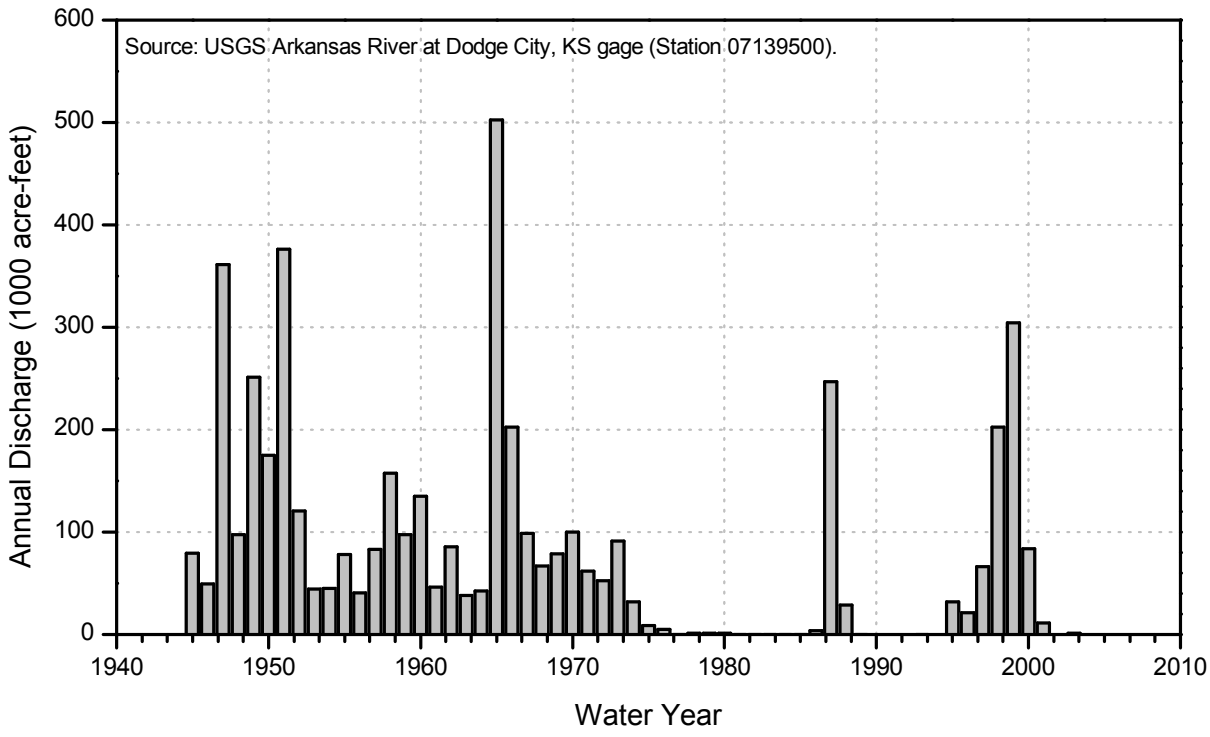


Figure 5: Annual Arkansas River Discharge at Dodge City

Downstream in Wichita, the impacts of stream depletions can be seen when comparing flow durations for periods before and after this groundwater development period. Figure 6 shows two flow duration curves for the Arkansas River at Wichita: one for water years (WY) 1935–1975 and the second for WY 1976–2007. Examination of these graphs show that flows have typically decreased in the midrange, from about 20 to 80 percent. However, the lowest flows — those with durations greater than 85 percent — have

actually increased. This latter observation is counterintuitive but may be a result of increased wastewater or other man-made discharges.

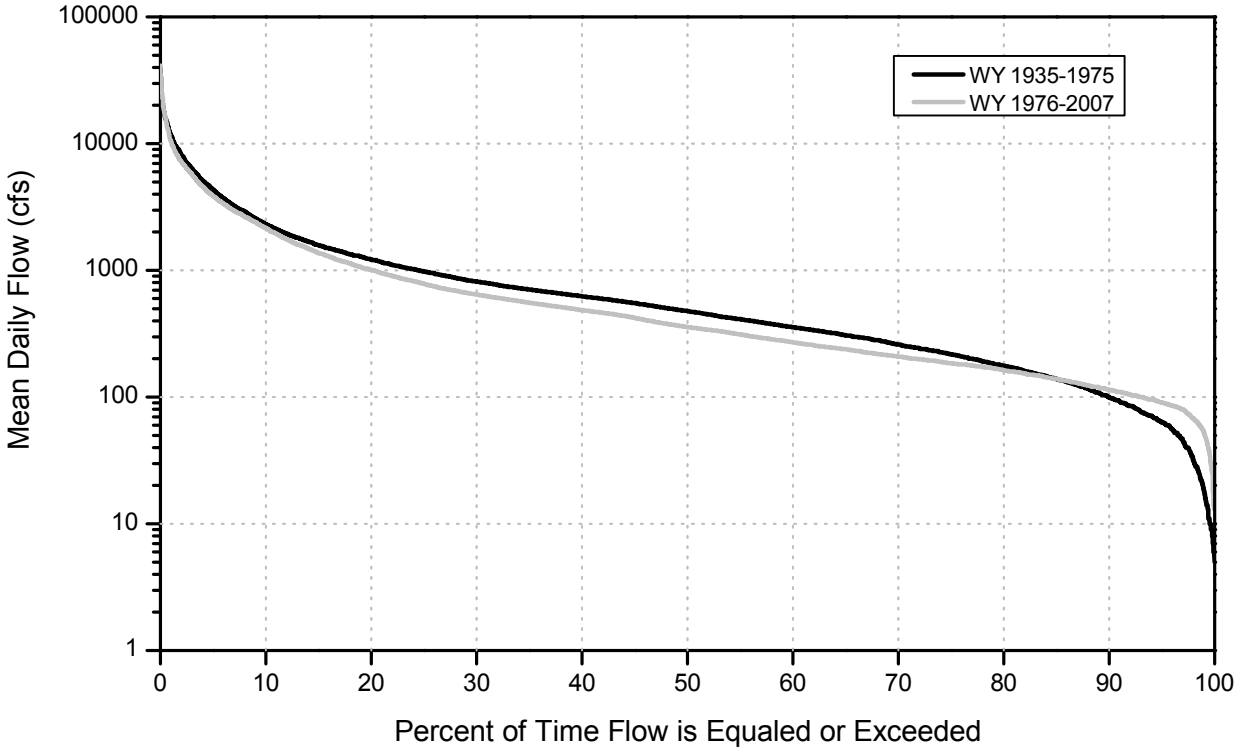


Figure 6: Flow Durations for Arkansas River at Wichita

Naturalizing the flow records for the Arkansas River would require collecting historical data on direct stream diversions from the river and its tributaries, and on groundwater withdrawals plus development of a groundwater model capable of estimating stream-aquifer interactions. Such a major effort was not considered practicable or justifiable given the comparisons presented above and the fact that the Arkansas River is a relatively minor water source for the City of Wichita.

Synthesis of Streamflow Estimates

As mentioned in Section 2, there are only two stream gages in the project vicinity with long continuous records that span the entire model simulation period: the Valley Center and Arkansas River at Arkansas City (Arkansas City) gages. At all other model stream nodes (Table 1), all or portions of the flow data used in the operations model were synthesized. The methods used to synthesize these data are described below:

Methodology

For stream nodes located at stream gages, whether active or discontinued, there are discharge data that cover a portion of the model simulation period. At these locations, it was necessary to fill in the missing data with estimates based on recorded data at other nearby gages. At stream nodes that are not located at an active or discontinued stream gage, a complete 85-year record was generated. In either case, the missing flow data at the target stream node were estimated based on the recorded data at a nearby source gage or gages that have data for the missing period. In selecting source gages, preference was given to gages available on the same stream, located either upstream or downstream of the target stream node, that have comparable drainage areas. For target gages without any nearby upstream or downstream gages, data for a gage on another, nearby stream were used.

For target nodes located at an active or discontinued stream gage, the missing data were estimated by first calculating the average annual unit discharge at the target and source stream gages. Unit discharge was calculated by dividing a gage's flow by its contributing drainage area, yielding values in cfs/square mile. When the target and source gages have an overlapping period of record, regression analyses were used to determine a best-fit line through these data:

$$q_t = a + bq_s$$

Where:

q_t = Recorded average annual unit discharge for target stream node (cfs/square mile)
q_s = Recorded average annual unit discharge for source stream gage (cfs/square mile)
a = Intercept of best-fit line through data
b = Slope of best-fit line through data

When the regression analyses returned a best-fit line with a negative intercept or relatively large positive intercept, an alternate analysis was performed with an intercept forced to go through zero. This adjustment avoided problems later on days when the flow in the source gage was zero or near zero. With a negative intercept, the equation above returns an invalid negative flow estimate. Where the regression analysis returns a large positive intercept, the calculated flows yielded unrealistically high minimum flows. When there is no overlapping period of record for the target and source gages, the intercept and slope were assumed to be zero and one, respectively.

The regression analyses described above were based on average annual flows but later used to develop daily flow estimates. The mean daily discharges at the target stream node were estimated using these regression results in the following equation:

$$Q_t = \left(a + b \times \frac{Q_s}{A_s} \right) * A_t$$

Where:

Q_t = Estimated mean daily discharge at target stream node (cfs)
Q_s = Recorded mean daily discharge at source gage(s) (cfs)
A_s = Contributing drainage area at source gage (square miles)
A_t = Contributing drainage area at target stream node (square miles)

For those source and target gages that have no overlapping period of record, this equation simplifies to a straight drainage area ratio when substituting $a = 0$ and $b = 1$.

Arkansas River near Hutchinson

The uppermost stream node on the Arkansas River is located about 24 miles upstream of Wichita at the USGS' Arkansas River near Hutchinson stream gage (Station 07143330). The period of record at this gage starts in October 1959 and runs through the end of the model simulation period. Prior to October 1959, the flow data for this stream node were estimated from two downstream gages on the Arkansas River: Arkansas River near Wichita and Arkansas River at Wichita. The specifics of these estimates are described below:

- Arkansas River near Wichita gage (Station 07143400): The period of record for this source gage runs from October 1921–March 1934, so it does not overlap the record at the near-Hutchinson gage. Therefore, the flow at this target stream node was estimated from the data at this source gage using a multiplier based on the ratio of the respective drainage areas. The flow estimates derived from this source gage extend from October 1922–September 1934.

- Arkansas River at Wichita gage (07144300): This stream gage began operation in October 1934, replacing the near-Wichita gage discussed in the previous bullet item. This gage has been in continuous operation since that time, so there is an overlapping period of record for the target, near-

Hutchinson stream node and this source gage (October 1959–September 2007). A major tributary, the Little Arkansas River, enters the Arkansas River between the Hutchinson and Wichita gages. The flow in this tributary (as measured at the Valley Center gage) was netted out of the flow at the Wichita gage before making flow comparisons. These comparisons are shown in Figure 7. The best-fit regression line through these points has an intercept of 1.9277E-4 and a slope of 0.80236, with a coefficient of determination (R^2) of about 0.947. For the period October 1934–September 1959, mean daily discharge at the near-Hutchinson stream node was estimated from this source gage using these regression results.

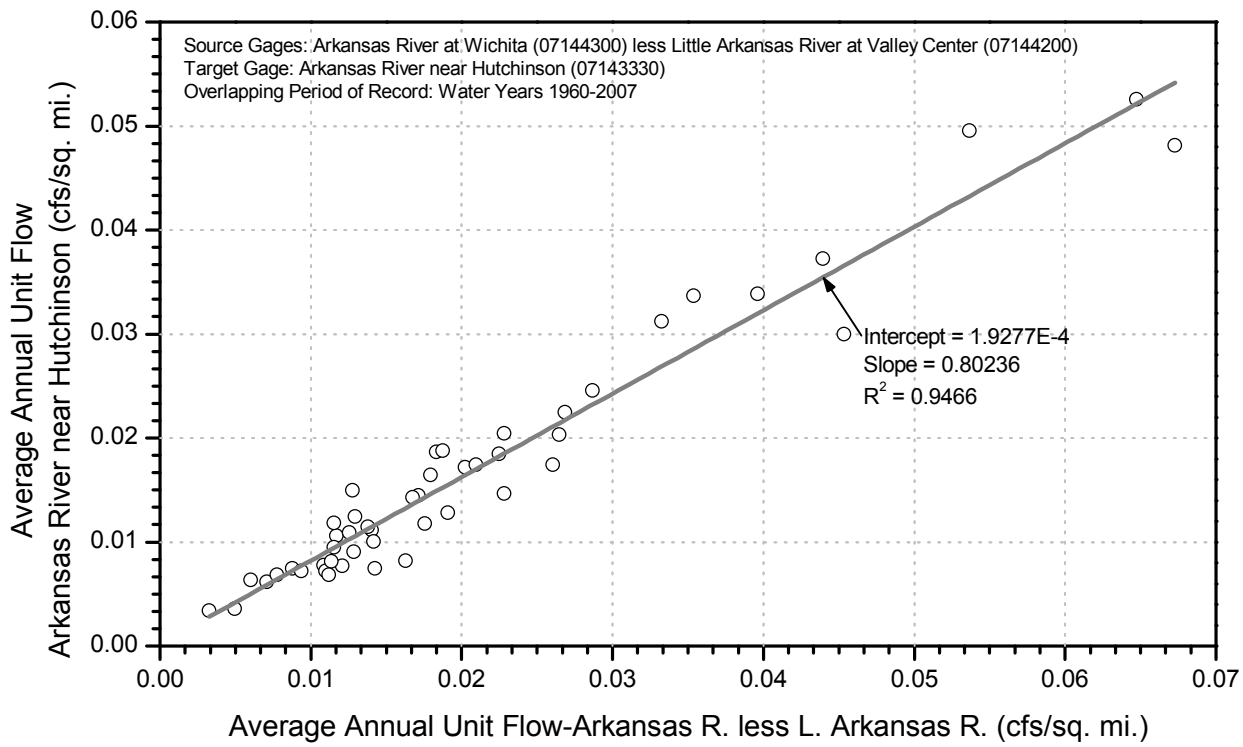


Figure 7: Discharge Comparison–Arkansas River near Hutchinson vs. at Wichita

If the unit runoff at these two Arkansas River gages was equivalent (that is, proportional to their respective drainage areas), the regression line shown in Figure 7 would have an intercept of zero and a slope of one. This seemingly large discrepancy results because the Arkansas River frequently runs dry in central Kansas because of upstream regulation and stream depletions. Therefore, the true effective contributing drainage area for these gages usually starts in central Kansas and not at the continental divide in Colorado.

Starting in October 1959, the actual recorded data at the near-Hutchinson stream gage was used for this stream node.

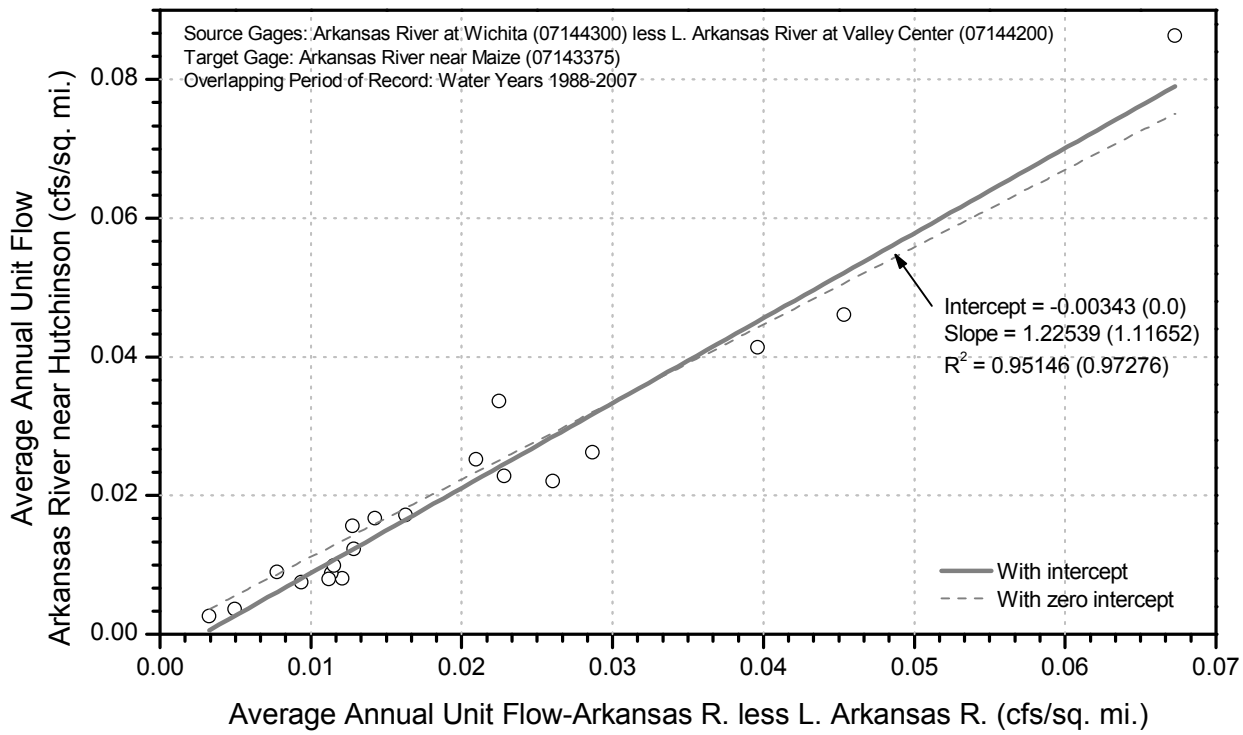
Arkansas River near Maize

The USGS' Arkansas River near Maize, Kansas stream gage (Station 07143375) is located a short distance upstream of the Wichita metropolitan area. The period of record for this gage is March 1987 to present. Prior to March 1987, the flow data for this stream node were estimated using the Arkansas River near Wichita and Arkansas River at Wichita gages. The methods used to estimate the missing flow data at this node are described below:

- Arkansas River near Wichita gage (Station 07143400): The period of record for this source gage runs from October 1921–March 1934; therefore, its record does not overlap that at the near-Maize gage. For this reason, the target node flow estimates derived from this source gage's data were developed using a drainage area ratio. The ratio of the contributing drainage areas at the near-Maize and near-Wichita gages is 0.998 (31,924 square miles/31.978 square miles). The flow estimates developed from this source gage extend from October 1922–September 1934.

- Arkansas River at Wichita gage (Station 07144300): This source gage is the active stream gage on the Arkansas River in Wichita. The period of record for this gage is October 1934 to present. The multiplier used to estimate the flow data at the near-Maize node from this gage's data was derived from regression analyses using average annual unit flow data. Figure 8 is a scatter plot that shows the relationship between the average annual unit flows at the near-Maize gage and the net average annual unit flow at the at-Wichita and Valley Center gages. The best-fit regression line through these points has an intercept of -0.00343 and a slope of 1.22539, with an R^2 of 0.95146. An alternate regression line with a forced intercept of zero yields a slope of 1.11652 and R^2 of 0.97276. These latter regression results were used to generate the flow estimates using this source gage. These estimates start in October 1934 and end in March 1987, when the near-Maize gage became active.

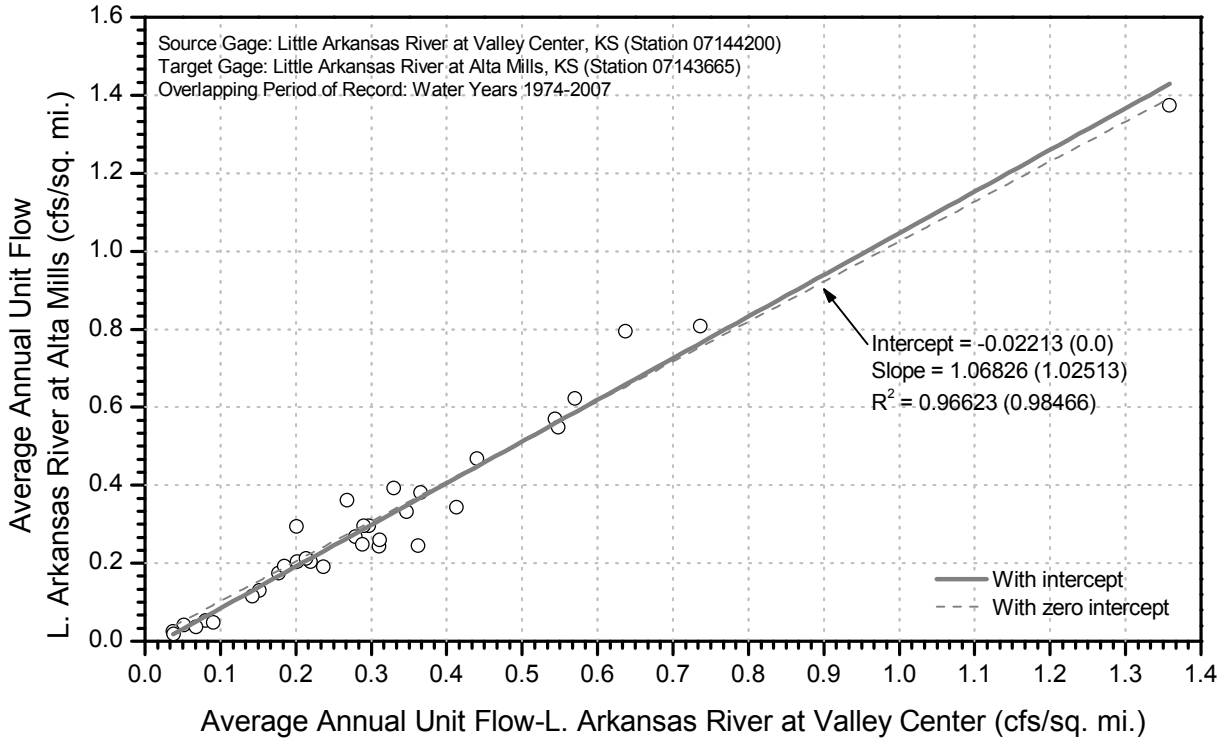
Figure 8: Discharge Comparison-Arkansas River near Maize vs. at Wichita



Little Arkansas River at Alta Mills

The USGS has operated a stream gaging station on the Little Arkansas River at Alta Mills (Station 07143665) since 1973. The location of this gage was selected as the farthest upstream node on the Little Arkansas River. For the balance of the model simulation period, the flow at this gage was estimated from the flow records at the downstream Valley Center gage. A scatter plot that compares the average annual flow at these two gages for the available 34-year overlapping period of record is shown in Figure 9. The best-fit line through these points has an approximate intercept of -0.02213, a slope of 1.06826, and an R^2 of 0.96623. An alternate regression line with a forced intercept of zero was also added to this graph. This line has a slope of 1.02513 and R^2 of 0.98466. The results of this alternate regression analysis were used to estimate the discharge at Alta Mills for the missing period, October 1922–June 1973.

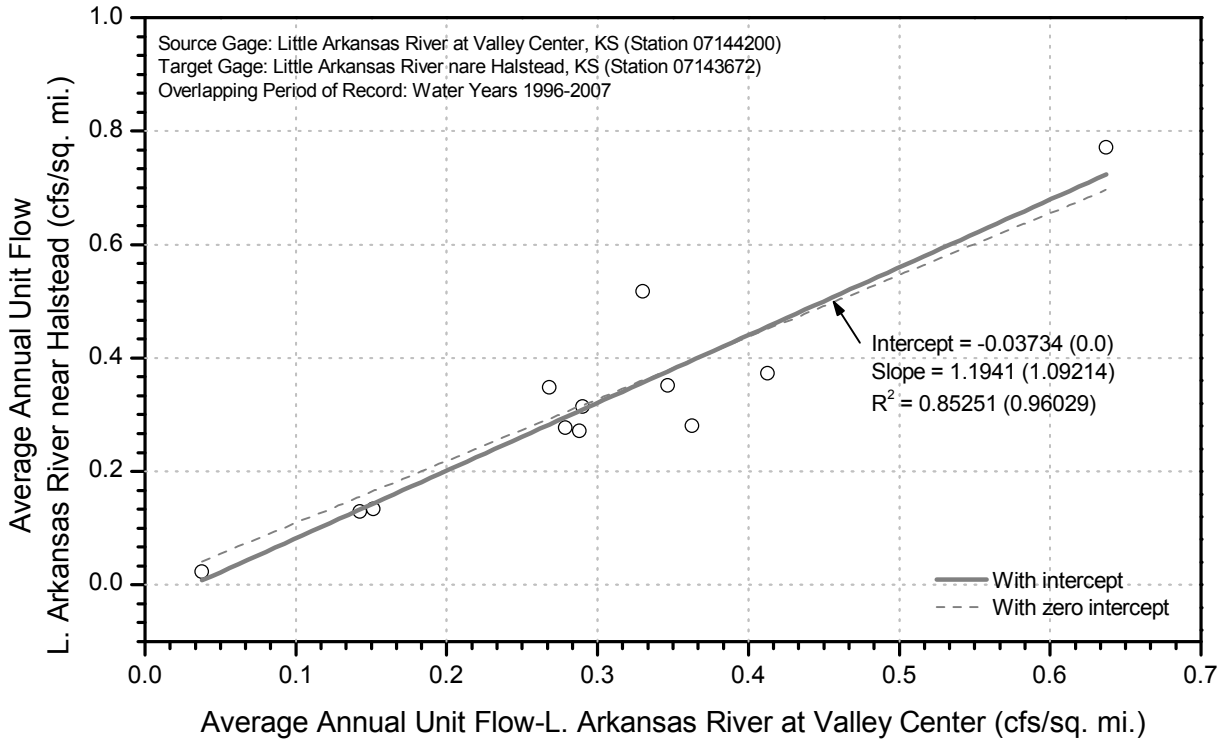
Figure 9: Little Arkansas River Discharge Comparison–Alta Mills vs. Valley Center



Little Arkansas River at Halstead

As originally conceived, the ILWSP included a proposed surface water intake and/or diversion wells on the Little Arkansas River near Halstead. There is a stream gage near this location (Little Arkansas River at Highway 50 near Halstead, Kansas [Station 07143672]); the record at this station begins in May 1995. For the balance of the model simulation period, the flow at this gage was estimated from the flow records at the downstream Valley Center gage. A scatter plot that compares the average annual flow at these two gages for the available 12-year overlapping period of record is shown in Figure 10. The best-fit line through these points has an approximate intercept of -0.03734, a slope of 1.1941, and an R^2 of 0.85251. An alternate regression line with a forced intercept of zero was also added to this graph. This line has a slope of 1.09214 and R^2 of 0.96029. The results of this alternate regression analysis were used to estimate the discharge at Halstead for the missing period, September 1922–April 1995.

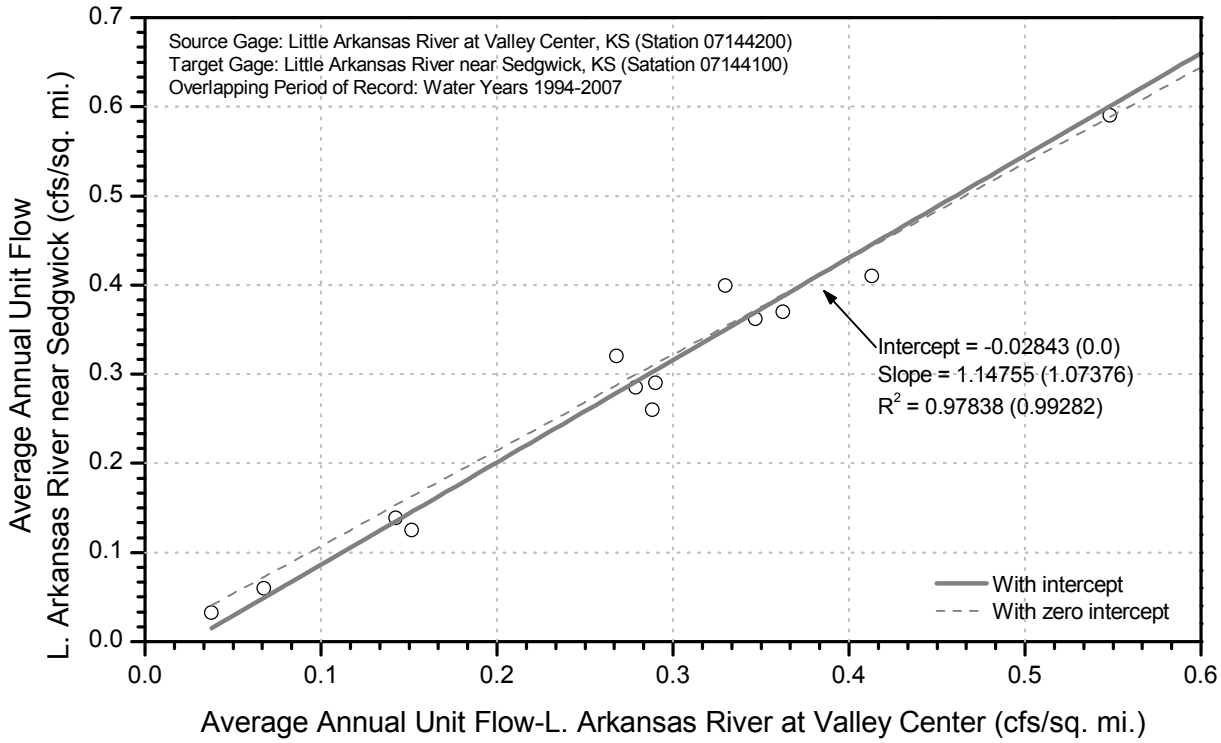
Figure 10: Little Arkansas River Discharge Comparison–Halstead vs. Valley Center



Little Arkansas River near Sedgwick

The USGS' Little Arkansas River near Sedgwick gage had been in operation since October 1993. Figure 11 shows that the average annual unit flow at the Sedgwick and Valley Center gages has a very nearly linear relationship. The best-fit line through these points has an intercept of -0.02843 and a slope of 1.14755 with an R^2 of 0.97838. An alternate best-fit line with a zero intercept has a slope of 1.07376 and an R^2 of 0.99282. The discharge at this stream node for the period prior to October 1993 was estimated from the data at the Valley Center gage using the results of this latter regression analysis.

Figure 11: Discharge Comparison–Little Arkansas River near Sedgwick vs. at Valley Center



Little Arkansas River at Valley Center

The Valley Center stream node on the Little Arkansas River is located at the USGS' stream gage of the same name (Station 07144200). The available data at this stream gage cover the entire model simulation period, so no streamflow estimates were necessary.

Little Arkansas River at Mouth

There are no stream gages on the Little Arkansas River below Valley Center; some of the proposed elements of the ILWS plan will impact the flow in the lowest reaches of this river. Therefore, it was necessary to develop flow estimates for the Little Arkansas River near its mouth in downtown Wichita. These flow estimates were developed from the data available at the Valley Center gage using a flow multiplier based on the ratio of the respective drainage areas. The drainage area of the Little Arkansas River at it mouth was estimated as 1,314 square miles, yielding a drainage area ratio of 1.049.

Arkansas River at Wichita

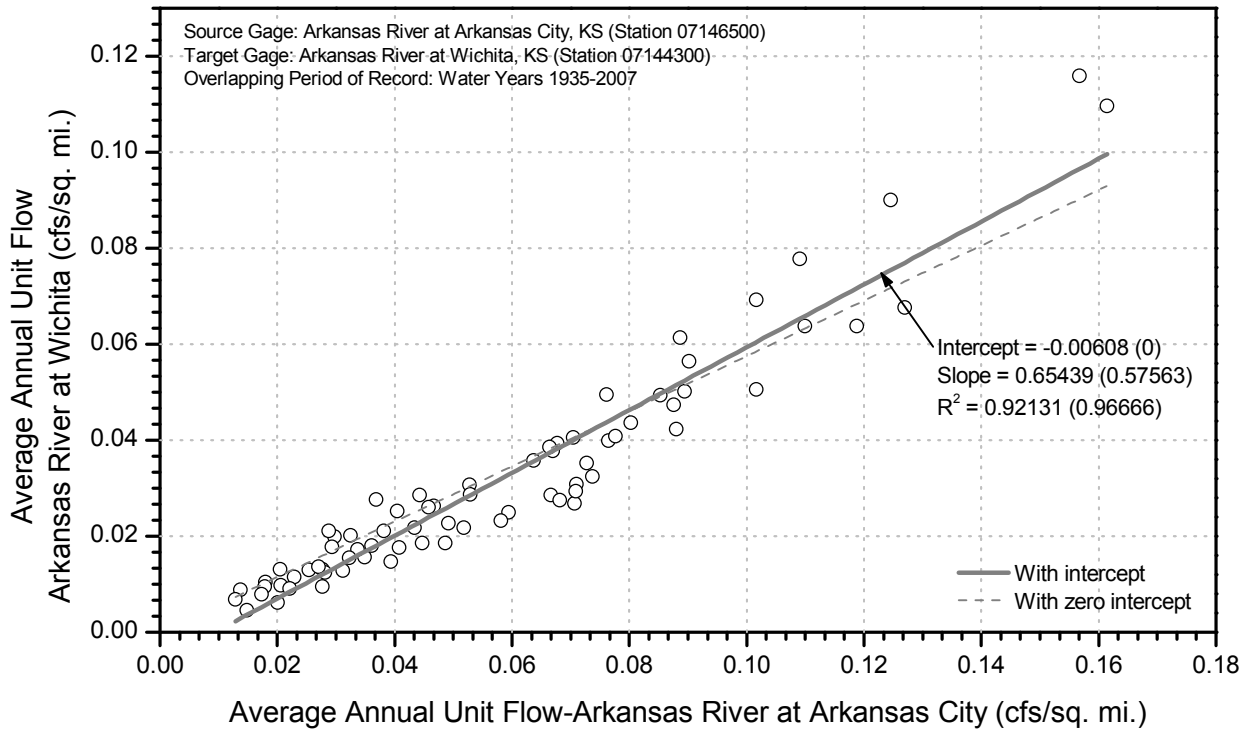
In Wichita, the discharge in the Arkansas River is recorded at a USGS stream gage located at the South Broadway Bridge (Station 07144300). This stream gage (Arkansas River at Wichita) has been in continuous operation since October 1934. Prior to this date, two possible methods were investigated to extend this record back to the start of the model simulation period. These methods are discussed below:

- Arkansas River near Wichita (Station 07143400): There is another stream gage located about six miles upstream of the target stream node that has flow records extending back beyond the start of the model simulation period. This gage (Arkansas River near Wichita) was discontinued shortly after the at-Wichita gage was placed in operation (March 1935). As there are only six months of overlapping data at the near-Wichita and at-Wichita gages, the results of any regression analysis would not be considered to have much validity. Although this gage is located only a short distance upstream, it is also above the confluence of the Little Arkansas River and has a significantly different (smaller) drainage area. Therefore, one method for estimating the flow at this target node would be to total the flow in the Arkansas River at the near-Wichita gage and the estimated flow in the Little Arkansas River at its mouth (Section 4.8).

- Arkansas River at Arkansas City (Station 07146500): The USGS stream gage on the Arkansas River at Arkansas City is one of the few gages with data for the earliest portion of the model simulation period. Figure 12 is a scatter plot that shows the relationship between the average annual unit flows at this gage and the target stream node. Two best-fit regression lines were plotted through these points. The first line has an intercept of -0.00608, an approximate slope of 0.65439, and an R^2 of 0.92131. The second line has a zero intercept, slope of 0.57563 and R^2 of 0.96666.

The flow record at the Wichita stream node was extended using the first method described above — sum of the discharge data for the near-Wichita gage and estimated flow in Little Arkansas River at its mouth.

Figure 12: Discharge Comparison–Arkansas River at Wichita vs. at Arkansas City



North Fork Ninnescah River at Cheney Reservoir

Cheney Reservoir is one of the City's principal water sources. This reservoir is located on the North Fork Ninnescah River above Cheney, Kansas. There is a stream gage located at Cheney Dam that was placed in operation at about the same time as the reservoir (October 1964); however, this gage (Station 07144795) records reservoir discharge only. For the operations model, estimates of reservoir inflow are required. These inflow data were estimated from the following sources:

- North Fork Ninnescah River near Cheney, Kansas (07144800): This source stream gage was located downstream of Cheney Dam. Its period of record starts in October 1950 and ends in September 1964. The inflow to Cheney Reservoir for this same period was estimated from this gage's data using a drainage area ratio (664 square miles/685 square miles = 0.969).

- North Fork Ninnescah River above Cheney Reservoir (Station 07144780): This source stream gage is located just a few miles upstream of the reservoir. This gage was placed in service after the reservoir became operational (July 1965) and is still active at present. The reservoir inflow estimates developed

from this source gage were developed by multiplying recorded flows by the ratio of contributing drainage areas of the dam and gage (664 square miles/550 square miles = 1.207).

- Little Arkansas River at Valley Center (Station 07144200): Prior to installation of the near-Cheney gage, there are no stream flow records for the North Fork Ninnescah River. For this period, Cheney Reservoir inflow was estimated using data for the Valley Center gage on the Little Arkansas River. Figure 13 is a scatter plot that compares the average annual unit discharge at this gage with those for the near-Cheney and above-Cheney-Reservoir gages. The regression analyses for these data were developed after excluding one outlying data point. This single outlier was shown to have a significant influence on the regression results. The best-fit line through the remaining data points has an intercept of 0.08256 and a slope of 0.62079. Using these regression results to estimate the missing flow data for this target gage results in an unrealistically high minimum reservoir inflow estimate; therefore an alternate regression line with a zero intercept was used to estimate Cheney Reservoir inflow for the period October 1922–September 1950 and October 1964–June 1965. This zero-intercept regression line has a slope of 0.82864 and an R^2 of 0.90329.

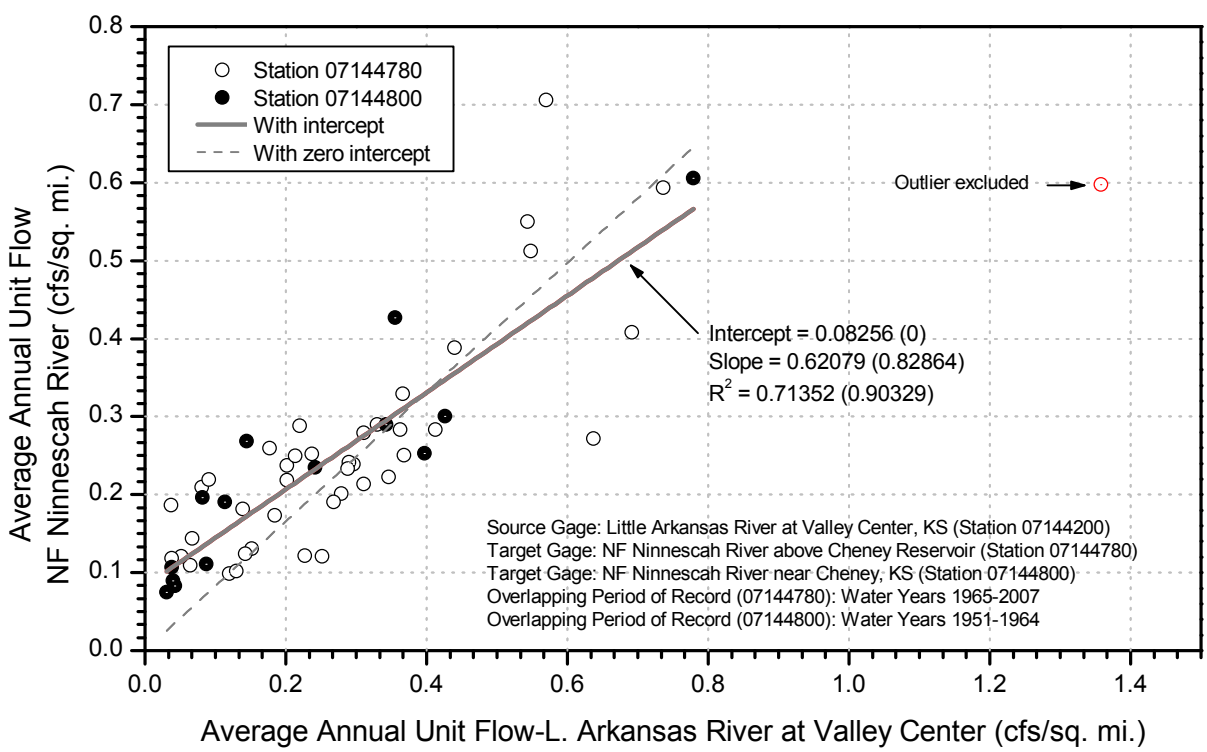


Figure 13: Discharge Comparison–Little Arkansas River vs. NF Ninnescah River

Ninnescah River near Peck

Below Cheney Reservoir on the main stem of the Ninnescah River is a USGS stream gage near Peck (Station 07145500). This gage has a period of record from April 1938 to the present. For the early portion of the model simulation period before this gage became active, these flows were estimated using data for the Arkansas City gage on the Arkansas River (Station 07146500). A scatter plot that compares the average annual unit flow at these source and target gages is included as Figure 14. From regression analyses, the best-fit line through these data points has an intercept of 0.05233, a slope of 4.10385, and an R^2 of 0.84037. The missing data at this stream node were estimated using the results of this regression analysis.

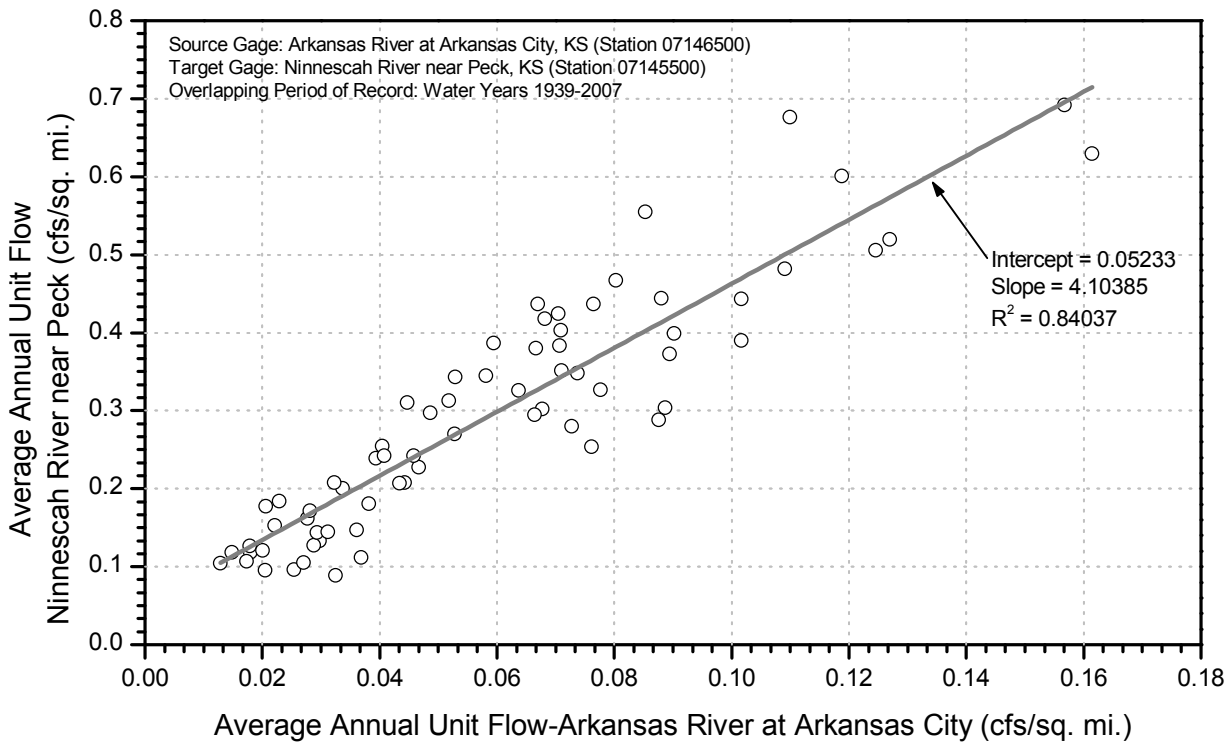


Figure 14: Discharge Comparison–Arkansas River vs. Ninnescah River

Arkansas River at Arkansas City

The last stream node used in the operations model is located on the Arkansas River near the Kansas-Oklahoma state line. This stream node is located at the USGS' Arkansas River at Arkansas City stream gage (Station 07146500). The available data at this stream gage cover the entire model simulation period so no streamflow estimates were necessary.

Unregulated stream node inflow

The streamflow data presented above includes estimates of the mean daily flow at each stream node for the entire model simulation period. The flow input data required for the operations model, however, are the unregulated inflow at each stream node. The unregulated inflow to a stream node is defined as the net runoff that accrues to the stream between that node and any upstream nodes. For example, the Arkansas River at Wichita stream node is located downstream of two other stream nodes: Arkansas River near Maize and Little Arkansas River at Mouth. Therefore, the unregulated inflow at the Wichita stream node is calculated as the estimated discharge at this node less the estimated discharge at the two upstream nodes. These unregulated inflow data can be negative at times when there are net depletions within a stream reach. These data can also be negative because of differences in the timing of storm hydrographs, which can cause the discharge at an upstream gage to be higher on a given day than the discharge at a downstream gage.

The streamflow estimates at each stream node were converted to unregulated inflow estimates by subtracting the flow from any upstream flow nodes. The upstream nodes at each stream node (if any) can be discovered by examination of Figure 1, but are also listed in Table 4 for convenience.

Table 4: Upstream Nodes at each Stream Node

Node No.	Node Name	Upstream Node(s)	
		Node No.	Node Name
10	Arkansas R. near Hutchinson	---	---
20	Arkansas R. near Maize	10	Arkansas R. near Hutchinson
30	L. Arkansas R. at Alta Mills	---	---
40	L. Arkansas R. at Halstead	30	L. Arkansas R. at Alta Mills
50	L. Arkansas R. near Sedgwick	40	L. Arkansas R. at Halstead
60	L. Arkansas R. at Valley Center	50	L. Arkansas R. near Sedgwick
70	L. Arkansas R. at Mouth	60	L. Arkansas R. at Valley Center
80	Arkansas R. at Wichita	50	L. Arkansas R. near Sedgwick
		70	L. Arkansas R. at Mouth
90	NF Ninnescah R. at Cheney Dam	---	---
100	Ninnescah R. near Peck	90	NF Ninnescah R. at Cheney Dam

110	Arkansas R. at Arkansas City	80	Arkansas R. at Wichita
		100	Ninnescah R. near Peck

Inflow Adjustments for Groundwater Interaction

Groundwater modeling has shown there is a strong hydraulic connection between the Arkansas and Little Arkansas rivers and the Equus Beds aquifer. The rates at which the aquifer gains or loses water to these streams is a function of aquifer water levels and storage. Table 5 lists the estimated rates of aquifer gain from and loss to local rivers as a function of aquifer water levels (Burns & McDonnell, 2008a).

Table 5: Equus Beds Aquifer Gain and Loss Rates

Aquifer Water Level (feet NGVD)[a]	Total Aquifer Gain Rate[b] (cfs)	Total Aquifer Loss Rate[b] (cfs)	Net Aquifer Loss Rate[c] (cfs)
1342	133[d]	23[d]	-110
1360	100	38	-62
1366	89	43	-46
1370	82	44	-38
1375	73	48	-25
1380	62	53	-9
1385	54	60	6
1389	48	68	20
1390	46	70	24
1395	38	82	44
1396	36	85	49
1402	29	99	70

a. Aquifer water level is the water elevation measured in Monitoring Well 886.

b. Estimates of gains and losses to area streams from MODFLOW groundwater model (Burns & McDonnell, 2008a).

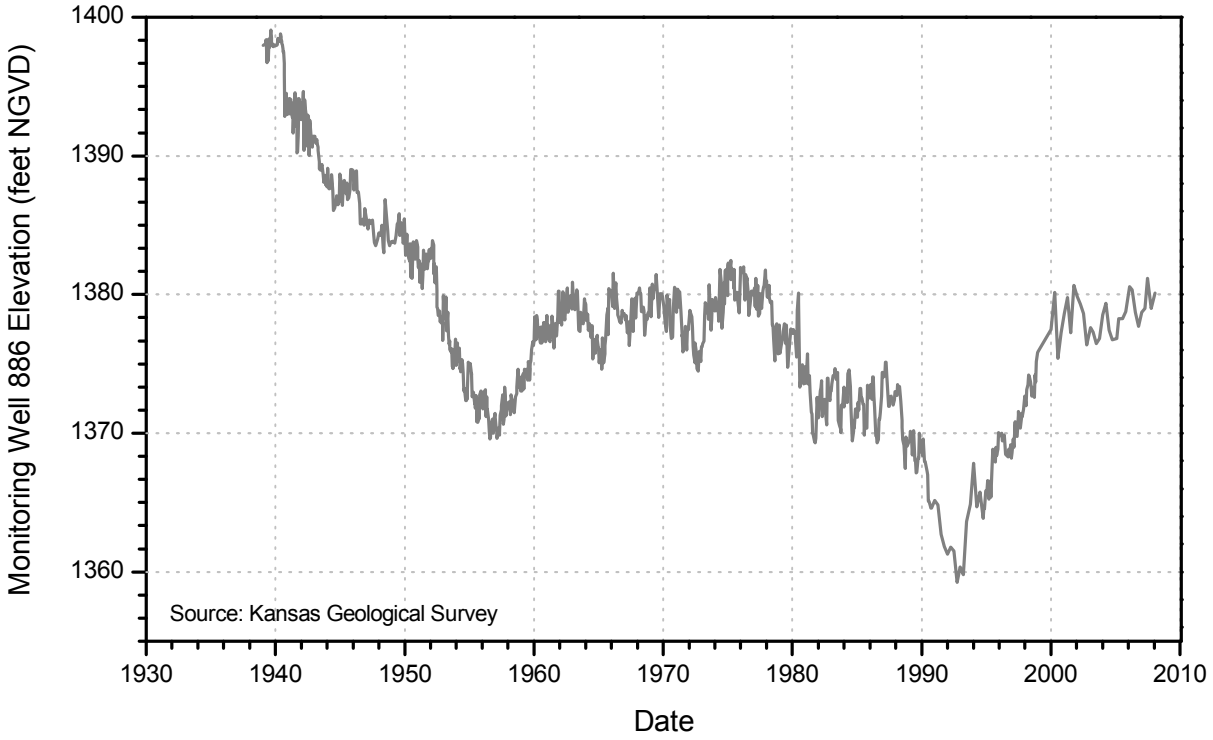
c. Negative values indicate a net aquifer gain.

d. Values extrapolated from remaining data.

In past analyses, it has been generally assumed that all Equus Beds aquifer gains come from Arkansas River depletions and all aquifer losses from discharge to the Little Arkansas River. The Little Arkansas River is down gradient of the aquifer so the assumption that all aquifer gains must come from the Arkansas River seems valid. However, review of measured flows in the Little Arkansas River seems at odds with the assumption that all aquifer discharge accrues to this river. The reasons for this conclusion are discussed further below.

The aquifer gain and loss rates listed in Table 5 are relative to aquifer water levels (piezometric water surface elevations) measured in Monitoring Well 886. A hydrograph of historical water levels in this monitoring well is plotted in Figure 14. These measured water levels have ranged from a peak elevation of 1399.09 feet NGVD in August 1939 to a low of 1359.24 feet NGVD in October 1992. From the data in Table 5, the corresponding aquifer discharge would have ranged from a minimum rate of about 37 cfs in 1992 to a maximum of 92 cfs in 1939. With an average water level of nearly 1382 feet, the historical aquifer discharge would have averaged about 56 cfs. If all of this aquifer discharge accrues to the Little Arkansas River then one would expect the baseflow in this stream to be comparable to these groundwater discharge values (that is, to average 56 cfs and never be less than 37 cfs). If fact the measured flow in this river has been less than 56 cfs at Valley Center about 48 percent of the time and less than 37 cfs about 30 percent of the time (Figure 4).

Figure 14: Water Levels in Equus Beds Aquifer



Various methods were tested to find a means to reconcile these estimated Equus Beds aquifer discharge rates with measured flows in the Arkansas and Little Arkansas River, but none of these methods were completely successful. The method that was adopted was to apportion the aquifer discharge between the Little Arkansas and Arkansas rivers in a manner that best balances flows in the Little Arkansas River. Preference was given to balancing flows in the Little Arkansas River because it is the primary new water supply source — both for direct use and aquifer recharge — to be developed under the ILWS plan. This analysis included the following steps:

- The historical water levels measured for Well 886 (Figure 14) were paired with the gain and loss rates listed in Table 5 to yield estimates of historical aquifer gain and loss rates for the entire model simulation period. The first available aquifer level reading (1397.98 feet NGVD) was collected on January 14, 1939. Prior to this date, the aquifer water level was assumed to be a constant 1398 feet NGVD. The recording interval for these data varied from approximately weekly to quarterly. Between sample dates, water levels were assumed to vary linearly with time. After water levels were estimated for each day, the corresponding aquifer gain and loss rates were estimated using these water levels and the data in Table 5.

- The apparent groundwater accretions to the Little Arkansas River were estimated for each day during the 85-year modeling period as the difference in the measured or estimated flows at Alta Mills and Valley Center.
- The apparent net groundwater accretions to the Arkansas River were estimated for each day as the flow at Wichita less the flows at Hutchinson and Valley Center.
- The datasets described above were filtered to eliminate those days when the flow at Valley Center was greater than or equal to its median value of 59 cfs. On the remaining days in these flow records, it was assumed that most of the flow in these streams came from baseflow and not surface runoff.

From the data subsets described above, the following statistics were developed:

- Average total loss from Equus Beds aquifer to rivers: 61.8 cfs
- Average total gain from rivers to Equus Beds aquifer: 60.0 cfs
- Average net loss from Equus Beds aquifer to rivers: 1.8 cfs
- Average flow in Little Arkansas River at Alta Mills: 15.5 cfs
- Average flow in Little Arkansas River at Valley Center: 33.1 cfs
- Average net flow accretion in Little Arkansas River between Alta Mills and Valley Center: 17.6 cfs
- Average flow in Arkansas River near Hutchinson: 197.1 cfs
- Average flow in Arkansas River at Wichita: 254.4 cfs
- Average net flow accretion to Arkansas River between Hutchinson and Wichita: 24.2 cfs

From these statistics, it was concluded that only 28.5 percent of total Equus Beds losses should be assumed to enter the Little Arkansas River (17.6 cfs / 61.8 cfs = 0.285). This percentage of total aquifer losses should approximately preserve the flow balance in the Little Arkansas River. Unfortunately, the same cannot be said for the Arkansas River. These statistics show that, on average, the Arkansas River gains 24.2 cfs through this reach. However, using the remaining gains and losses from the aquifer one would expect a net loss from the Arkansas River (0.715 * 61.8 cfs – 60.0 cfs = -15.8 cfs). From these data, there is no apparent way to balance the accretion rates to both the Arkansas and Little Arkansas rivers.

If Equus Beds discharge (loss) is distributed as indicated above, 28.5 percent will accrue to the Little Arkansas River and the remaining 71.5 percent to the Arkansas River. With 100 percent of the aquifer gains assumed to be from the Arkansas River, the resulting net aquifer loss rates are listed in Table 6.

Table 6: Allocation of Equus Beds Aquifer Loss Rates

Aquifer Water Level (feet NGVD)[a]	Net Aquifer Loss to (Gain from) Arkansas River[b] (cfs)	Net Aquifer Loss to Little Arkansas River[b] (cfs)
1342	-116.6	6.6
1360	-72.8	10.8
1366	-58.3	12.3
1370	-50.5	12.5
1375	-38.7	13.7
1380	-24.1	15.1
1385	-11.1	17.1
1389	0.6	19.4
1390	4.1	20.0
1395	20.6	23.4
1396	24.8	24.2
1402	41.8	28.2

a. Aquifer water level is the water elevation measured in Monitoring Well 886.

b. All aquifer gains and approximately 71.5 percent of aquifer losses accrue from/to Arkansas River. The remaining 28.5 percent of aquifer losses accrue to the Little Arkansas River.

For the project study period, the estimated historical discharge between the Equus Beds aquifer and the Arkansas and Little Arkansas rivers each day was estimated using the rates in Table 6 and the recorded water levels in Well 886 (Figure 14). These estimates were then used to adjust the unregulated inflow data at three stream nodes. The net losses from the Equus Beds aquifer to the Arkansas River were assumed to occur between the near-Hutchinson and near-Maize stream nodes. Therefore, the unregulated inflow at Maize was adjusted by adding estimated Arkansas River losses (aquifer gains) and subtracting corresponding river gains (aquifer discharge). In the Little Arkansas River, the estimated historical gains from the Equus Beds aquifer were split between two stream nodes. Forty percent of these gains were subtracted from the unregulated inflow at the Halstead stream node and the remaining 60 percent from the

inflow at Sedgwick. If an estimated negative flow adjustment on a particular day was greater than the original recorded or estimated streamflow at the same point, the adjusted inflow on that date was limited to a minimum of zero.

Flow Estimate Spreadsheet

The Microsoft Excel workbook file that accompanies this appendix contains all of the source and estimated flow data described herein. This worksheets included in this workbook are described below:

- Stream Gages — List of USGS stream gages utilized in this streamflow appendix
- Recorded Flows — Copy of USGS flow records for referenced gages
- Flow Estimates — Complete record of flow estimates at model stream nodes. Where applicable, there data are a composite of recorded and estimated flow data.
- Unregulated Inflow — Unregulated inflow estimates used in RESNET operations model
- Equus Beds GainLoss — Estimates of historical Equus Beds aquifer gain and loss rates
- Inflow Adjustments — Groundwater interaction adjustments made to Maize, Halstead and Sedgwick flow data.

References

Complete citations for the references cited in this document are listed below:

Burns & McDonnell. (2003). *Final Environmental Impact Statement for Integrated Local Water Supply Plan, Wichita, Kansas.* Prepared for City of Wichita, Department of Water and Sewer. Kansas City, MO: Published by author.

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Appendix B

Socioeconomic Impact Evaluation

Equus Beds Aquifer Recharge and Recovery Project: Regional Economic Impacts, Payment Capability, and Environmental Justice

Background

Over the last few decades the withdrawal of water from the Equus Beds aquifer for agricultural, municipal, industrial, and domestic uses has exceeded recharge. The water table has dropped significantly in many areas and water quality has also been adversely affected. Water demands in the Equus Beds area are projected to increase, so the current water system will need to be expanded and new water sources developed. As a result, the Equus Beds Aquifer Recharge and Recovery Project has been proposed to provide a reliable water supply to the Wichita water service area.

Two possible funding alternatives are possible for the recharge and recovery project. The first is for the water users to self-finance an expanded water supply and the second includes some level of Federal cost sharing for the project. This analysis is somewhat unique in that the only difference between the alternatives evaluated from an economic perspective is the source of funding. Essentially the same action will be taken regardless of Federal participation. This analysis evaluates the regional economic impacts that would be expected under each of the two scenarios, the affordability of each scenario for water users, and potential environmental justice issues that may result from a water supply project.

In general, water supply projects will generate positive regional economic impacts. One source of these positive impacts is from project funding obtained from outside the economic region defined for the project. Outside funding represents money injected into the region and represents a net increase in regional spending. Another potential positive impact could result from a reduction in the probability and duration of a municipal water shortage (improved reliability). The availability of water supplies for commercial users can influence the level of output, production costs, the location of activities, and the types of businesses locating in a region in the future.

The fact that essentially the only difference between the alternatives evaluated is the funding source, complicates the regional impact analysis. For example, it is clear that Federal funding sources represent an exogenous (outside region) change in spending, where funds flow into the region from an outside source and lead to increased economic activity. However, self-financing water supply improvements from water user payments represents a shift in spending by households from typical household spending patterns to

spending for municipal water supply projects. Since water supply project construction spending increases at the expense of residential household spending for other items under the self financing scenario, the overall regional impact of the project is the net difference between the impacts of the two different types of spending.

The regional economic impacts from construction and operation of facilities associated with each alternative stem from capital, labor, energy, and other expenditures within the region. These expenditures will generally lead to positive regional output and employment impacts. However, for the self financing scenario the net difference in regional impacts may actually be negative if the regional activity associated with water supply project expenditures is less than the activity associated with typical household expenditures. This analysis describes the potential regional economic impacts associated with a municipal water supply project and the methods used to estimate these impacts.

Affordability or financial feasibility refers to the ability of households, businesses, and other water users to pay the costs associated with the provision of a water supply. If water users have the financial resources to pay the allocated costs of a project, including construction and operation and maintenance costs, then the project would be considered financially feasible. These costs may be paid through monthly user fees, retirement of debt incurred to build the project, tax assessments, or through other funding methods. The source of funding is to some extent irrelevant. What is relevant is the amount that must be paid by water users and how that compares with their payment capability. If project costs are determined to be greater than the ability of water users to pay for a project, then imposing the cost of project repayment on water users will result in financial hardship unless some government cost sharing is made available to make the water supply project affordable.

Different financing alternatives will have varying effects on the affordability of a water supply project. Clearly, a greater Federal or state cost share will reduce the amount that must be paid by water users and will improve affordability from the perspective of the water users. In order to evaluate water supply affordability for the Equus Beds project, the impact of each scenario on water bills to water users is estimated and compared to water affordability thresholds. If the analysis indicates that a water supply project is affordable regardless of available cost sharing, then Federal participation would not be a financial constraint to expanding the water supply. This analysis describes different methods for determining affordability thresholds and evaluates the affordability of various water supply funding alternatives for the study area.

Environmental justice addresses potential concerns about disproportionately large negative project impacts that are imposed on low income or minority populations in a project area. For example, if project construction occurs primarily in low income areas and disrupts activities in these areas, then this could be a significant environmental justice issue. An analysis comparing the distribution of project impacts with the location of low income and minority populations is needed to address Environmental Justice issues. This analysis focuses on the impact of funding a water supply project on water rates and the

impact of these costs on low income households and analyzes the extent to which project impacts are disproportionate.

Methodologies

Regional Impact Analysis

A regional economic impact analysis measures changes in economic activity that occurs as a result of a project or some other action within a defined area. Economic activity can be measured in terms of income, value of output produced, or employment. Regional impacts represent flows of money (or employment) into and out of a region. Spending associated with an action may lead to substantial increases in income or employment within a specific region. However, these regional impacts do not necessarily translate into benefits to society at the national level. Economic benefits represent an improvement in efficiency or resource use that improves social welfare. Regional impacts are simply a measure of economic activity in a specified region of interest. It is also possible that an action may result in reduced regional output and income in a particular area, while generating positive benefits to the nation as a result of environmental enhancement or other improvements that are not translated into actual money flows. Therefore, estimates of project benefits and regional impacts are not directly comparable. A regional impact analysis can also be useful for environmental justice analysis because a regional analysis provides information on where the greatest economic impacts occur and the extent of those impacts.

When completing a regional economic impact analysis, there are three basic steps that need to be followed. First, the impact region of concern must be determined. Second, the types of activities that will be affected by the action under consideration must be identified and expenditures associated with each activity must be estimated. Third, the changes in expenditures that represent a change in final demand must be determined and the resulting spin-off effects estimated.

The study area considered in a regional economic impact analysis includes those areas that experience a direct monetary impact from construction or changes in operations. From an economic perspective these direct impacts may extend well outside the impact areas typically considered for other resources in order to account for flows of goods, services, and payments to major trade centers outside of direct impact areas. For this analysis the construction impact area is larger than the water user area and includes all of the water user counties. For purposes of consistency, the construction impact region was used to evaluate all categories of regional impacts. The counties included in the economic impact region are listed in table 1.

Table 1 – Counties included in the economic impact region

Impact Analysis Counties
Butler
Harvey
Kingman
Marion
McPherson
Reno
Rice
Sedgwick

The impacts associated which each of the alternatives are measured in terms of changes in industry output, value added, employee compensation, and employment. Industry output is a measure of the value of industry's total production. Industry output is directly comparable to Gross Regional Product. Value added represents payments made by industry to workers, interest payments, profits, and indirect business taxes. Employee compensation represents wages and benefits paid to employees. Employment is measured as full and part-time jobs combined.

The types of activities associated with construction of a water supply project include construction of intake facilities, wells, water lines, buildings, and instrumentation. Activities associated with operation and maintenance of these facilities include water treatment, facility repair, pumping, and storage. The costs for each of these activities are estimated by cost category. These categories include materials, equipment, fuel, and labor.

The regional impacts from construction and operation and maintenance expenditures were analyzed using the IMPLAN (IMpact analysis for PLANing) model. The IMPLAN model uses the Department of Commerce national input-output model to estimate flows of commodities used by industries and commodities produced by industries. Social accounts are included in the IMPLAN model data base for each region under consideration. Social accounts represent the flow of commodities to industry from producers and consumers, as well as consumption of the factors of production from outside the region. Social accounts are converted into input/output accounts and the multipliers for each industry within the region, which accounts for the multiple effects of changes in spending associated with land retirement. The IMPLAN model also accounts

for the percentage of expenditures in each category that would remain within the region and expenditures that would flow outside the region.

In order to estimate the regional economic impacts associated with an alternative, estimates of changes in expenditures for goods and services must be input into the IMPLAN model. Estimating the impacts of construction and operation, maintenance, and repair activities requires estimates of these expenditures by expenditure category.

Affordability Analysis

Several federal laws related to the protection of water resources and provision of clean water supplies require an evaluation of water supply affordability. Some of these laws include the Safe Drinking Water Act, the Clean Water Act, the Toxic Substances Control Act, the Asbestos Hazard Emergency Response Act, the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and the Resources Conservation and Liability Act (RCRA). The Environmental Protection agency (EPA) has included affordability criteria as part of their guidelines for evaluating compliance with federal laws, assessing financial responsibility, establishing penalties and fines, setting standards, and when allocating grants and credit assistance.

There is no universally accepted method of measuring payment capability or affordability for domestic water supplies. Government agencies, water resource consultants, and academic institutions have used a wide range of methods to evaluate how much water users can pay for domestic water supply improvements. The most common method of evaluating affordability is the cost of water as a percentage of median household income. Using this measure of affordability, total annual user charges are divided by median household income and compared to a predetermined threshold value of water utility affordability. There are variations to this basic formula, such as the use of average (mean) household income in the denominator or using cost of living indices to account for differences in household expenditures. Affordability criteria are often used in conjunction with other measures that consider general socio-economic conditions such as poverty rates or unemployment rates.

In 1980 the EPA Office of Drinking Water completed a Water Utility Financing Study that was initiated as a result of a 1977 Congressional requirement that EPA study the costs of complying with new drinking water regulations (EPA, 1980). The study evaluated the cost of water service to households and concluded that an annual user cost divided by household income of 1.5% to 2.5% was of questionable affordability and an annual user cost/income greater than 2.5% was not affordable (EPA, 1980). These rates correspond with rate increases of 100% to 200% being of questionable affordability and an increase of 200% or greater as being unaffordable. A subsequent EPA study of the affordability of the 1986 Safe Drinking Water Act estimated a threshold of 2.0% of median household income (EPA, 1993).

A 1990 EPA municipal ability-to-pay study indicated an average user charge per household greater than 1.0% of median household income for a water system should require additional financial resources to reduce the percentage to less than 1.0% (EPA, 1990). In addition, the study estimated that the short-run threshold for rate increases was 25% of the current rate, beyond which financial hardship would be created for water users.

The Environmental Protection Agency established affordability criteria for drinking water systems as a result of 1996 Amendments to the Safe Drinking Water Act. These Amendments allowed small public water supply systems to use less extensive water treatment technology if the most effective technology was not considered affordable. Therefore, EPA was required to define affordability in the context of household bills for sewer and drinking water service. As a result, EPA established a 4% of household income benchmark for affordability (2% for wastewater treatment and 2% for drinking water supplies). This was later amended to 4 ½% to allow 2 ½% for drinking water expenses.

It is important to understand that this benchmark is applied to whole systems, not to individual households. This measure of affordability was not intended to be applied to individual households. In other words, as a whole system 4% to 4 ½% of the system-wide household income could be used to pay for wastewater and drinking water service, but some households could pay more and some households may only be able to pay much less. The overall threshold does not recognize variations in income distribution. An analysis by The Congressional Budget Office indicated that about 7% of all households spent more than 4% of their household income and almost 2% of households spent 10% or more of their income on sewer and water services (CBO, 2002). This indicates that the 4% to 4 ½% of income thresholds for water and sewer bills do not preclude some households from the ability to spend more than 4% of their household on water and sewer bills.
It should be noted that the EPA affordability threshold is not a true measure of affordability, but is instead based on acceptability of fee increases by lending institutions and the cost of other utilities. It should also be recognized that simply using ratios of costs to income to determine affordability ignores other important factors related to paying for water system improvements.

The Department of Housing and Urban Development has set an affordability threshold of 1.3% of household income for water payments and 1.4% for sewer payments (EPA, 2006). A study by the National Consumer Law Center independently set affordability thresholds for water bills and sewer bills at 2.0% of average household income for each service (National Consumer Law Center, 1991). United States Department of Agriculture (USDA) Rural Development grant eligibility criterion uses a threshold debt service portion of annual user charge of greater than 0.5% of income when income is below 80% of the state median household income (EPA, 2006). The USDA Rural Development threshold for the debt service portion of annual user charge is greater than 1.0% of income when income is between 80% and 100% of the state median household income (EPA, 2006).

Payment capability/affordability based on a household budgeting approach

The affordability thresholds discussed above are based on a variety of factors including financing considerations, current rates, household income, and costs of alternate water supplies. The thresholds do not necessarily represent a maximum payment that can be made for water supplies. The actual ability of water users to pay for water supplies can be defined as the maximum amount households could pay for water given their income after accounting for housing expenses, transportation costs, food costs, insurance payments, other necessary expenses, and some level of discretionary spending. However, it would be very difficult to account for all possible household expenses to derive residual income that would potentially be available for making water payments.

A 1999 study assessing the financial and economic feasibility of rural water system improvements provided a framework for using a simple household budgeting methodology to estimate the ability to pay of water users for water supply improvements (Piper and Martin, 1999). This methodology accounts for necessary household expenses, differences in household income, and assumes that the highest observed water payments as a percentage of income made by households in a specific region represent an upper limit of ability to pay. The study identified a five step process that could be followed to estimate household payment capability.

Step 1 Gather water cost information for water users outside the area being evaluated.
Step 2 Collect household income, housing cost, tax payment, utility cost, insurance payment, and other necessary expense data for households outside the study area but in the same general region.
Step 3 Calculate residual household income (income less payments for housing, taxes, utilities other than water, etc.).
Step 4 Calculate the cost paid for water per $1,000 of residual income by water users outside the study area but in the same region (ability to pay factor).
Step 5 Apply the ability to pay factors to the residual income of households in the study area. The factors applied could be the highest factor observed from the data, the factor that separates the top 10% of factors from the other 90% of factors, median factor, or some other factor that represents maximum ability to pay.

The ability to pay factors represent the proportion of discretionary income that households served by various utilities must spend for domestic water supplies. Therefore, they are a measure of dollars spent on water service per dollar of discretionary household income. The ability to pay factors represent actual payments made by households for water. Therefore, the higher factors are likely to be the best estimate of maximum ability to pay.

The calculations used to estimate the ability to pay factors and total ability to pay for each household in the study area are shown below:

Residual Income	=	household – income	home - payment	non-water utilities	-	payments for necessities
Ability to Pay factor	=	average water bill paid	÷	residual income in 1,000's of dollars		
Ability To pay	=	ability to pay factor	x	residual income in study area in 1,000's of dollars		

This methodology provides an estimate of payment capability that accounts for variation in household income, household expenses, and costs of living that are not considered when using set percentages of household income. Accounting for the variation in the percentage of total income spent by different levels of income may better represent household ability to pay for water supplies. This approach is used in this analysis to estimate water supply affordability in the Equus Beds area. The EPA affordability criterion of 2 ½% of median household income is also applied as a basis for comparison.

Environmental Justice Analysis

Environmental justice refers to the pursuit of equal protection under environmental laws for a clean environment for all people regardless of socioeconomic status, race, or ethnicity. Any action that harms the environment and provides little no improvement in income or employment in a low income area but provides economic improvements to a wealthy region may violate the intent of environmental justice.

An evaluation of environmental justice impacts is mandated by Executive Order 12898 on Environmental Justice (February 11, 1994) for Federal actions that affect the environment. Environmental justice addresses the fair treatment of people of all races and incomes, where fair treatment implies that no group of people should bear a disproportionate share of negative impacts from an action. The impacts of an action can be considered disproportionately distributed if the percentage of total impacts imposed on a specific group is greater than the percentage of the total population represented by that group. A group can be defined by race, ethnicity, income, community, or some other grouping.

Evaluating potential environmental justice concerns requires an understanding of where the project impacts are likely to occur and where potentially affected groups are located. The analysis relies on demographic data from sources such as the U.S. Bureau of the Census, individual counties and municipalities, and local school districts to determine the location of different groups of people. Identifying the location of specific groups can be difficult when nonpermanent residents, such as migrant workers, are in the affected area. Demographic data are poor for many groups of people. Census data do not account for all nonpermanent residents because some cannot be contacted or some may not want to

be counted. In addition, the Census has a tendency to undercount the number of people in rural areas, due to difficulties encountered with contacting residents in sparsely population regions. However, Census data are typically the most complete and comparable demographic and economic data available for individuals and households.

The environmental justice evaluation in this analysis is based on the impact of funding a water supply project on water rates and the impact of these costs on low income households. The analysis is completed using U.S. Census data at the Zip Code level.

Regional Economic Impacts from Construction, Operation, and Maintenance Costs

In order to estimate the regional economic impacts that could occur as a result of construction and annual operation of an expanded Wichita water supply, the costs of building and operating the proposed system must be known. These expenditures will lead to a change in final demand for goods and services within the project area. The estimated change in final demand used in a regional impact analysis is equal to the change in local spending that is directly attributable to the project. Construction costs represent a one-time infusion of spending that would occur during the construction period. Updated construction cost estimates were obtained from R.W. Beck, Inc. (2008) and were broken down into materials, labor, and equipment related costs. The accuracy of the regional impact estimates is improved if costs are placed into specific categories.

Project expenditures that occur within the study region represent a change in final demand for those categories of goods and services. There are two basic questions that must be considered to determine the expenditures that actually represent a change in final demand and influence regional output. First, is the money used to purchase product related goods and services coming from inside or outside the study region? Money coming from outside the region that is spent on goods and services within the region will generate regional economic impacts while spending that originates from within the study region generally represents a redistribution of income and output rather than an increase in regional economic activity. For this analysis regional purchase coefficients (RPC's) are used to address the question of where the construction and operation related goods and services come from. RPC's are ratios provided within the IMPLAN model and represent the portion of regional demands purchased from local producers and trade flows in the model.

The second question is if the money used to purchase goods and services is determined to originate from inside the region, would those expenditures have otherwise flowed outside the region if the project under consideration was not built? If so, then the project may generate net positive regional impacts even if the source of funds is from within the region. This is a much more difficult question to answer because it requires very specific data on consumer spending patterns that generally does not exist. For the purposes of this analysis it is assumed that any water supply related costs that are avoided by households would be spent in the local region.

Labor costs were treated as household expenditures in this analysis, where the average percentage of household expenditures by category for a household in the study area was applied to labor costs. The assumption is that all labor costs are translated into household income. While some labor costs actually fit into benefit categories that cannot be translated directly into income, the majority of costs are income. Equipment costs were split up into fuel costs and non-fuel costs. Fuel costs are input into the regional model as direct fuel expenditures while non-fuel costs are placed into an appropriate equipment category for that specific construction activity. The estimated construction costs used to evaluate the one-time impacts from building water supply facilities are presented in table 2.

The source of information used to estimate the regional impacts associated with annual operation and maintenance costs was a 2000 Concept Design Study completed by Burns and McDonnell Consulting Engineers and the Final Environmental Impact Statement for Integrated Local Water Supply Plan – Wichita, Kansas completed by Burns and McDonnell (2003). Operation and maintenance costs were separated into material, labor, equipment, fuel, and power costs using previously estimated percentages of costs for a regional water supply in South Dakota, Iowa, and Minnesota (U.S. Bureau of Reclamation, 1993). The category percentages applied to operation and maintenance costs are shown below in table 3. Cost estimates for operation and maintenance by cost category are presented in table 4.

Table 2 – Construction costs by category used to estimate regional impacts

Construction Feature	Total Cost	Materials Cost	Labor Cost	Equipment Non-Fuel	Equipment Fuel
Recharge/Recovery Wells at Existing Sites					
Recharge/Recovery Well	$3,109,000	$1,119,882	$552,239	$949,796	$487,083
Control Building	$1,536,000	$926,417	$551,906	$32,827	$24,850
Piping and Valving	$995,000	$696,500	$248,750	$35,048	$14,702
Monitor Wells (1 shallow & 1 deep)	$124,000	$41,100	$19,991	$39,426	$23,482
SCADA	$311,000	$248,037	$62,963	$0	$0
Electrical and Instrumentation	$1,710,000	$1,561,864	$108,686	$19,409	$20,040
Site Work, Access and Fence	$622,000	$450,511	$83,839	$53,703	$33,947
Subtotal	**$8,407,000**	**$5,044,312**	**$1,628,374**	**$1,130,209**	**$604,105**
Recharge/Recovery Wells at New Sites					
Recharge Well	$1,473,000	$530,584	$261,643	$450,000	$230,773
Control Building	$727,000	$438,480	$261,221	$15,537	$11,762
Piping and Valving	$515,000	$360,500	$128,750	$18,140	$7,610
Monitor Wells (1 shallow & 1 deep)	$59,000	$19,556	$9,512	$18,759	$11,173
SCADA	$147,000	$117,239	$29,761	$0	$0
Electrical and Instrumentation	$810,000	$739,831	$51,483	$6,346	$12,340
Land	$91,000	$65,911	$12,266	$7,857	$4,966
Site Work, Access and Fence	$368,000	-	-	-	-
Subtotal	**$4,190,000**	**$2,272,100**	**$754,635**	**$516,640**	**$278,624**

Waterlines					
12-inch DIP	$489,000	$234,958	$157,282	$62,962	$33,797
16-inch DIP	$966,000	$506,481	$289,200	$109,570	$60,749
20-inch DIP	$491,000	$258,677	$147,981	$53,846	$30,495
24-inch DIP	$1,562,000	$908,549	$417,391	$150,220	$85,840
30-inch DIP	$1,023,000	$698,413	$194,800	$91,502	$38,286
36-inch DIP	$7,822,000	$5,252,988	$1,505,749	$750,579	$312,684
42-inch DIP	$2,139,000	$1,432,504	$416,315	$205,040	$85,141
48-inch DIP	$3,007,000	$1,987,709	$599,134	$297,117	$123,039
66-inch PCCP	$33,857,000	$25,393,341	$4,950,675	$2,480,456	$1,032,528
Subtotal	**$51,356,000**	**$36,673,620**	**$8,678,528**	**$4,201,293**	**$1,802,559**
Computer and Radio Systems					
Power Lines	$4,909,000	$3,681,750	$981,800	$75,764	$169,686
Transmission Lines	$6,620,000	$4,288,543	$1,544,428	$492,438	$294,590
Service Drop	$119,000	$106,856	$9,143	$1,502	$1,499
Subtotal	**$6,739,000**	**$4,395,399**	**$1,553,572**	**$493,940**	**$296,089**
Surface Water Treatment (Membrane - 30 MGD)	$59,600,000	$41,720,000	$11,920,000	$3,874,000	$2,086,000
Sedgewick Surface Water Intake (60 MGD)	$4,935,000	$3,454,500	$987,000	$320,775	$172,725
Substation	$4,908,000	$3,435,600	$981,600	$319,020	$171,780
Standpipe	$505,000	$353,500	$101,000	$32,825	$17,675
Raw project cost	**$145,549,000**	**$101,287,000**	**$27,656,000**	**$10,992,000**	**$5,614,000**
Contingency @ 30%	**$43,664,700**	**$30,386,100**	**$8,296,900**	**$3,297,700**	**$1,684,000**
Administrative, legal, planning costs	**$47,303,400**	**$21,002,700**	**$26,300,700**	**-**	**-**
TOTAL PROJECT COSTS	**$236,517,100**	**$152,675,800**	**$62,253,600**	**$14,289,700**	**$7,298,000**

Table 3 – Percentages applied to O&M cost categories

Activity	Material Costs	Labor	Power	Equipment	Fuel
Treatment	17.5%	32.5%	38.0%	9.0%	3.0%
Wells	26.0%	36.0%	-	35.0%	3.0%
Water lines	63.0%	26.0%	-	11.0%	-

Table 4 – Operation and maintenance costs by category used to estimate regional impacts

Construction Feature	Total Cost	Materials cost	Labor cost	Equipment		Power
				Non-fuel	Fuel	
Capture flow from Little Arkansas River						
Surface water intake	$147,200	$38,400	$53,150	$51,250	$4,400	-
Recharge water treatment	$2,300,000	$404,800	$747,500	$209,300	$69,000	$869,400
Equus beds aquifer recharge						
Recharge (vertical wells)	$290,950	$75,900	$105,000	$101,300	$8,750	-
Recharge (recovery wells)	$539,350	$140,750	$194,650	$187,750	$16,200	-
Surface water recharge	$263,350	$68,700	$95,050	$91,700	$7,900	-
Waterlines	$17,250	$10,850	$4,500	$1,900	-	-
Powerlines	$11,500	$7,250	$3,000	$1,250	-	-
SCADA	$79,350	$49,950	$20,700	$8,700	-	-
Expansion of local well field						
Horizontal collector wells	$46,000	$12,000	$16,600	$16,000	$1,400	-
Vertical wells	$14,950	$3,900	$5,400	$5,200	$450	-
Waterlines and powerlines	$2,300	$1,450	$600	$250	-	-

Development of Bentley field Vertical wells	$26,000	$6,800	$9,400	$9,050	$750	-
Raw water delivery and treatment improvements Pipeline improvements	$6,900	$1,800	$2,500	$2,400	$200	-
Treatment plant (phase I)	$747,500	$130,800	$244,800	$67,300	$22,400	$282,200
Treatment plant (phase II)	$1,322,500	$231,450	$433,100	$119,000	$39,700	$499,250
Total O&M Costs	**$5,815,100**	**$1,184,800**	**$1,935,950**	**$872,350**	**$171,150**	**$1,650,850**

In order to accurately estimate the regional impacts associated with building and operating water supply facilities, it is important to know if the funds are from local sources. If the project is funded entirely by water users, then water supply related expenditures are made in place of expenditures for other items. A change in the distribution of final demands will result in a change in regional output and income if the demand sectors have different rates of leakage. Leakages occur as a result spending on goods and service that are not produced within the regional economy and do not generate additional local spending. If demand shifts from a good or service sector which has a high level of leakage to a sector with few leakages, there will be a positive effect on overall regional output and income.

The impacts from construction spending and annual operating expenditures are estimated assuming a range of local spending. Impacts at the low end of the range are based on the assumption that the project is paid entirely by local sources. The high range of impacts is based on the assumption that the project is paid entirely by outside sources, such as the Federal Government. Regional impacts are also estimated for intermediate scenarios, where 30%, 50%, and 70% cost sharing is assumed.

Construction of a municipal water supply project would generally be expected to generate positive regional economic impacts because of relatively high costs. However, as noted previously, the net effect of a municipal water supply construction project depends on the proportion of local spending with and without the water supply project and the amount of cost sharing. The estimated regional economic impacts associated with different construction cost categories are shown in table 5. These one-time construction impacts would be realized only if the project was funded entirely from outside sources. It is also important to note that these impacts will occur in total over the period of time that project construction takes place. For example, if the construction period is five years the total impacts over five years would equal the total shown in table 5 assuming 100% funding from outside of region sources.

Table 5– Regional economic impacts associated with construction spending assuming all project costs are paid by sources outside the region

Construction Expenditure Category	***Cost of* feature** (millions)	**Impact Category**			
		Value Added (millions)	Employee Compensation (millions)	Employment (total)	Output (millions)
Recharge/recovery wells	$4.582	$1.796	$0.861	27.5	$5.963

Control Building	$2.263	$1.744	$1.045	32.1	$3.585
Piping and Valving	$1.510	$0.621	$0.316	8.8	$2.126
Monitor Wells	$0.183	$0.050	$0.023	0.8	$0.218
SCADA	$0.458	$0.107	$0.064	1.6	$0.556
Electrical and Instruments	$2.520	$0.409	$0.266	6.7	$2.895
Site work, Access, Fence	$0.990	$0.256	$0.123	3.9	$1.169
Land	$0.091	$0.047	$0.011	0.6	$0.115
Waterlines	$51.356	$7.664	$3.753	112.2	$21.004
Computer, Radio Systems	$4.909	$0.897	$0.456	13.2	$5.671
Powerlines	$6.739	$1.472	$0.750	22.0	$7.975
Surface Water Treatment	$59.600	$26.987	$15.171	462.8	$80.550
Water Intake	$4.935	$1.484	$0.734	21.4	$6.172
Substation	$4.908	$3.713	$2.287	71.9	$7.624
Standpipe	$0.505	$0.123	$0.063	1.8	$0.604
Administrative, planning, legal, management costs	$47.303	$22.004	$12.512	338.7	$62.961
Contingency	$43.665	$20.812	$11.531	337.8	$62.756
Total	**$236.52**	**$90.186**	**$49.966**	**1,463.8**	**$271.944**

The regional impacts shown in table 5 represent the high end of the range of possible impacts. The low end of the impact range would assume that all project funding comes from local water users, through increased water bills or some other user based funding mechanism, and that the funds would otherwise be spent on typical household items for households making $35,000 to $50,000 annually. The proportion of income spent on various types of goods and services and the RPC's were obtained from the IMPLAN model database. Table 6 shows the impacts from water supply project expenditures (the same total impacts shown in table 5) and regional impacts if the same level of expenditures were spent in the same proportion as representative households in the region.

Table 6– Regional economic impacts associated with water supply project expenditures and equivalent household spending

	Impact Category			
Construction Expenditure Scenario	Value Added (millions)	Employee Compensation (millions)	Employment (total)	Output (millions)
Regional impacts from household expenditures equal to project cost	$165.8	$83.2	2,365	$382.4
Project expenditure impacts	$90.2	$50.0	1,464	$271.9

The results in table 6 clearly show that there are considerably greater leakages associated with water supply project spending than for representative household spending. This should not be surprising considering household items would be more likely to be produced, or a greater proportion of their total value produced, in the local region. The

data provided in table 6 is used to interpolate a range of impacts for various cost sharing scenarios. The regional impacts from project expenditures were constant for all scenarios, but the regional impacts lost as a result of reduced local spending was reduced by the percentage of project cost sharing. The results are shown in table 7.

Table 7- Regional economic Impacts of No Action and the Water Supply Alternative, assuming various levels of Federal cost sharing

	Impact Category			
Construction Expenditure Scenario	Value Added (millions)	Employee Compensation (millions)	Employment (total)	Output (millions)
No Action (equivalent to no cost share)	-$75.6	-$33.2	-901	-$110.5
Project 30% cost shared	-$25.9	-$8.2	-192	+$4.2
Project 50% cost shared	+$7.3	+$8.4	+281	+$80.7
Project 70% cost shared	+$40.5	+$25.0	+754	+$157.2
Project 100% cost shared	+$90.2	+$50.0	+1,464	+$271.9

The construction impact analysis indicates that a minimum 50% cost share from outside of region sources would be required in order for a water supply project in the Wichita area to generate net positive regional impacts. A water supply project funded entirely by water users would result in a loss in the value of regional out of slightly over $110 million and 900 jobs lost.

The same type of analysis was completed for O&M related expenditures. The estimated annual O&M related impacts are presented in table 8 along with the impacts associated with equivalent household income impacts.

Table 8 – Annual regional impacts from O&M expenditures and impacts from equivalent household spending

	Annual regional impacts from O&M expenditures			
Component	Value Added	Employee compensation	Employment	Output
Intake and recharge O&M	$134,600	$67,200	1.9	$524,400
Water treatment O&M	$1,832,400	$673,100	16.1	$5,173,200
Well O&M	$227,900	$109,600	3.4	$1,083,400
Powerlines, waterlines, SCADA	$38,400	$19,200	0.5	$149,800
O&M	**$2,233,300**	**$869,100**	**21.9**	**$6,930,800**
Total impact				
	$4,462,700	$2,012,300	75.3	$11,025,400
Equivalent household income impacts				

The impacts associated with O&M expenditures are also presented for different cost sharing scenarios. However, it is very unlikely that annual O&M would be cost shared on a permanent basis. Therefore, the scenario with O&M paid by water users is most likely to actually occur with or without Federal participation over the long run. The regional impacts associated with each financing scenario are shown in table 9.

Table 9 – Annual regional impacts from O&M expenditures resulting from various cost sharing scenarios

	Impact Category			
Construction Expenditure Scenario	Value Added (1,000's)	Employee Compensation (1,000's)	Employment (total)	Output (1,000's)
Impacts if O&M 100% cost shared	$2,233.3	$869.1	21.9	$6,930.8
Impacts if O&M 50% cost shared	-$1,114.7	-$571.6	-26.7	-$2,047.3
Impacts if O&M paid by water users	-$2,229.4	-$1,143.1	-53.4	-$4,084.6

Affordability Analysis - What can water users afford to pay towards municipal water supplies?

As discussed in the Methodologies section, EPA and various rural development agencies have used water payments and household income estimates as a basis for evaluating the potential of water users to pay for water system improvements. Financial investment firms evaluate the revenues and expenses of public and private water utilities seeking funds for improvements as a measure of investment risk. The primary consideration in evaluating the financial viability of water supply improvements is the cost of the improvement relative to available income. Many of these analyses do not account for the effect of varying household expenses on ability to pay for increased water rates.

The proportion of income that households can pay towards water bills will vary considerably from region to region. In regions with low housing costs, the percentage may be much greater than in areas with high housing costs. Households in areas that have very poor water supplies may be willing to give up some goods and services and use those payments toward higher water costs. The household budgeting approach discussed in the Methodologies section is used to evaluate water supply affordability.

Ability to pay can be defined as the maximum amount households can pay for water given their income and other household expenses. This does not consider consumer preferences in determining the allocation of income to goods and services. Housing costs, local tax payments, utility costs other than water, average health insurance payments, and other payments for necessities are subtracted from household income to derive discretionary income.

Payment Capability of Water Users in the Equus Beds Study Region

Estimates of water costs and use in the Equus Beds study area and outside the study area were developed using data obtained from the report Kansas Municipal Water Use 2006 (Kansas Water Office 2008). The report provided detailed water use and water rate data for municipalities and rural water suppliers throughout Kansas. Housing cost data were obtained from the U.S. Bureau of the Census 2000 data. This was the most recent data available at the municipal level.

Housing costs were estimated for each municipality using data for percentage of households owning a home with a mortgage, home owners without a mortgage, percentage of renters, and average costs for each category of home occupancy. A weighted average housing cost for all types of housing was then derived. Average health care costs for Kansas were estimated to be $4,089 annually (U.S. Department of Health and Human Services 2008). Representative costs for food ($5,366), transportation ($8,166), and insurance ($3,630) were obtained for the Midwest region from the 2000 Consumer Expenditure Survey (U.S. Bureau of Labor Statistics 2008). Median household income data were obtained from the 2000 Census (2008) for each of the municipalities included in the Kansas Water Office water use report.

Representative household expenditures were subtracted from median household income to estimate residual income for each municipality. Water cost was then divided by residual income to estimate payment capability factors. These factors were estimated for all Kansas municipalities and rural water suppliers included in the water use report, for water suppliers in Kansas but outside the study area region, and suppliers within the study region. Payment capability factors for all three groups are presented in table 10 for comparison. However, only the factors estimated for the Kansas suppliers excluding the study area are used to evaluate payment capability.

Table 10 – Payment capability factors

Measure	Complete Kansas data	Kansas, excluding study area	Study area only
Mean	.05118	.05983	.04032
Median	.04015	.04212	.03079
Top 10%	.13088	.13596	.05604
Top 25%	.05530	.07062	.04367

The mean payment capability factor for all of Kansas is about 5.1% of residual income. The top 10% factor of 13.1% of residual income is equivalent to 2.95% of median family income. Looking at the Kansas data excluding the Equus Beds project area municipalities, the top 10% factor is about 13.6% of residual income which translates to 2.59% of median household income. The top 10% payment factor excluding the Equus Beds area is slightly higher than but very similar to the EPA threshold of 2.5% of median household income.

The capability to pay for the Equus Beds study area is estimated by applying the top 10% factor estimated using the data excluding the study area of .13596 to the residual household income for Wichita. The residual annual household income for Wichita is estimated to be $7,275. Applying the top 10% factor to residual income results in a payment capability of $990 per connection per year. The median household income for Wichita was $39,939 in 2000. The estimated payment capability for Wichita is 2.48% of median household income. Coincidentally, this is essentially the same payment capability that would be calculated using the EPA threshold of 2.5% ($1,000 per household annually).

The Final Environmental Impact Statement for Integrated Local Water Supply Plan – Wichita, Kansas completed by Burns and McDonnell (2003) provided estimates of the number of water supply customers in 2000 and projections of the number of customers in 2050. These are used to estimate total payment capability over a 50 year project period to evaluate project affordability. There were an estimated 110,000 residential customers and 12,000 commercial customers for 2000. Projected service in the future was estimated to be 164,200 residential customers and 15,000 commercial customers by 2050. For the purposes of estimating the average cost per customer of the water supply project, residential and commercial customers were combined and the payment capability factors was applied to the total number of customers for these two sectors.

The construction cost for the proposed project is estimated to be about $236.52 million. The annual equivalent construction cost using the current water project planning rate of 4.875% over a 50 year period is about $12.71 million. The annual O&M costs for the project were estimated to be $5.82 million annually. Therefore, assuming all project costs (construction and O&M) were paid by project users, the annual project costs over the 50 year planning period would be $18.53 million. Using the base number of users the cost per customer would be $151.90 annually. Using the projected 2050 number of customers the cost per customer would be $103.50 annually. The average cost per customer over the entire 50 year period is $124.50 per customer, which is used to evaluate project affordability.

It is assumed that the current average amount paid for water would still need to be paid to cover current operating and replacement expenses. The average cost per customer for Wichita is estimated using the Kansas Municipal Water Use 2006 (Kansas Water Office, 2008) data. The current average water payment for Wichita is estimated to be about $342 per year. Therefore, total water supply costs with a water supply project are estimated to be about $467 annually. The estimated cost per household is much less than the estimated maximum payment capability of $990 for Wichita. This indicates that construction, operation, and maintenance costs can be paid by water users and meets affordability criterion.

Environmental Justice Analysis

The primary potential environmental justice issue associated with the water supply project is the effect of water payments on low income or minority households. In order

to complete this analysis, income, race, and ethnic origin data were collected from the U.S. Bureau of the Census by Zip Code within the City of Wichita. The data are shown in table 11.

Table 11 – Selected zip code data for household income, race, and ethnicity in Wichita

Zip Code	Median HH Income	Black	American Indian	Hispanic
67037	$60,066	0.75%	0.53%	2.33%
67038	*$36,719	0.44%	*6.65%	1.92%
67050	$51,328	0.17%	0.28%	2.00%
67060	$48,463	0.45%	0.90%	2.49%
67101	$52,000	0.82%	0.66%	2.33%
67108	$46,464	0.70%	0.30%	0.30%
67202	*$17,384	*19.62%	0.85%	6.50%
67203	*$34,345	5.60%	*1.34%	*16.84%
67204	$41,181	3.13%	*1.26%	*21.93%
67205	$75,070	0.43%	*1.28%	3.01%
67206	$64,258	4.14%	0.55%	1.17%
67207	$43,251	*11.02%	0.89%	5.28%
67208	*$34,291	*29.80%	1.01%	3.77%
67209	$56,033	1.83%	0.79%	4.54%
67210	*$36,657	*10.86%	*1.47%	*18.46%
67211	*$29,794	7.96%	*1.52%	*12.51%
67212	$52,022	2.38%	0.88%	5.04%
67213	*$28,541	6.20%	*2.29%	*12.15%
67214	*$21,119	*54.98%	*1.32%	*17.85%
67215	$59,028	1.02%	1.07%	2.92%
67216	*$36,691	7.93%	*1.53%	8.02%
67217	*$39,874	4.72%	*1.45%	6.71%
67218	*$32,153	*10.25%	0.99%	*11.28%
67219	*$34,594	*30.43%	*1.38%	*9.29%
67220	$50,972	*25.92%	0.76%	3.52%
67226	$67,206	6.35%	0.11%	3.51%
67230	$93,593	2.76%	*1.61%	1.82%
67235	$80,472	1.58%	0%	4.90%
Area Average	**$43,459**	**10.12%**	**1.16%**	**8.78%**
All of Kansas	**$40,624**	**5.60%**	**0.92%**	**6.93%**

* Median household income for zip code less than for entire area or percentage of minority population for area code greater than for entire area.

Zip codes that have a median household income less than the median for the entire study area plus at least one additional category of minority population greater than the study area average include the following Zip Codes: 67038, 67202, 67203, 67208, 67210, 67211, 67213, 67214, 67216, 67217, 67218, 67219, and 67220. These zip codes have the

potential to have environmental justice issues. Of particular concern are the area codes 67210, 67214, and 67219.

In order to evaluate potential environmental justice concerns in the Zip Codes identified as having the potential for problems, the average water cost per customer with and without the project were compared to median household in these zip codes. The resulting percentages can then be compared to thresholds established by other agencies and the threshold estimated as part of the payment capability analysis. The results of the water cost divided by household income calculations are shown in table 12. The threshold used for affordability is 2.5% of household income.

Table 12 – Water cost per consumer as a percentage of household income

Zip Code	Percentage of Household Income @ $342 per customer (current cost)	Percentage of Household Income @ $467 per customer (cost with project)
67038	0.93%	1.27%
67202	1.97%	2.69%
67203	1.00%	1.36%
67204	0.83%	1.13%
67205	0.46%	0.62%
67207	0.79%	1.08%
67208	1.00%	1.36%
67210	0.93%	1.27%
67211	1.15%	1.57%
67213	1.20%	1.64%
67214	1.62%	2.21%
67216	0.93%	1.27%
67217	0.86%	1.17%
67218	1.06%	1.45%
67219	0.99%	1.35%
67220	0.67%	0.92%
67230	0.37%	0.50%

The resulting calculations presented in table 12 indicate that under current conditions all of the Zip Codes of concern are within all threshold levels. However, with the additional cost of the Equus Beds project, Zip Code 67202 would not meet the 2.5% threshold criteria and 67214 would be fairly close to the threshold as well. However, an outside cost share of 26% or more would result in all Zip Codes being within the U.S. EPA threshold. Therefore, a 26% outside cost share would mitigate the potential environmental justice problems associated with the impact of increased water rates on low income households.

Other Possible Regional Impact Issues Associated with Municipal and Industrial Water Supplies

Municipal and industrial (M&I) water supplies can create regional economic impacts in several ways. As discussed in detail in the regional impact section above, expenditures for construction and continued operation, maintenance, and repair of M&I facilities can generate regional impacts. Changes in M&I water rates can have a significant impact on the composition of goods and services purchased by households and businesses, resulting in regional impacts. In addition, improvement in the availability of reliable and good quality water service associated with expanded water supplies may have an important impact on the number and types of businesses locating in a region. Expanding water supplies may lead to increased commercial activity and positive regional impacts due to increased certainty of available water in the future. However, in most cases the increase in commercial activity attributable to expanded water supplies is very difficult to estimate. The regional impacts associated with increased commercial activity are not estimated in this analysis.

Summary

The regional impact analysis of the Equus Beds Project indicates the without outside cost sharing, which is essentially the No Action Alternative, the project would actually result in negative regional economic impacts due to the change in household expenditures from typical household spending to spending for water construction and annual operation related costs. If outside cost sharing is equal to at least 50% of total project construction costs, then construction related regional impacts would be positive. Assuming operation, maintenance and repair costs will always be paid entirely by water users, regional impacts related to annual operation costs will be negative.

The payment capability analysis indicates that the water users are capable of payment project costs. However, the environmental justice analysis, which is basically an extension of the payment capability analysis, indicates that there could be environmental justice issues in one Zip Code area if there is no outside cost sharing. If there is outside construction cost sharing, the environmental justice concerns would be mitigated.

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Appendix C

EPA Environmental Justice Evaluation

MEMORANDUM

Subject: EJ Screen/Assessment Support for Wichita Equus Beds Groundwater Recharge Project Environmental Impact Statement

From: Debbie Bishop
Region 7 EJ Program

Thru: Althea Moses
Region 7 EJ Program Coordinator

To: Joe Cothern
Region 7 NEPA Coordinator

The Region 7 National Environmental Policy Act (NEPA) Program requested assistance from the Environmental Justice (EJ) Program to provide supporting documentation to the U.S. Bureau of Reclamation in the preparation of an Environmental Impact Statement (EIS) for the Wichita Equus Beds Groundwater Recharge Project. The EJ Program initiated the EJ screening process which includes information gathering, GIS analysis, and site-visit documentation. The information provided in the memo provides supporting documentation that details the EJ screening process and conclusions and/or recommendations.

Our Authority

EPA's authority to address EJ allegations falls under Presidential Executive Order 12898, which states that "To the greatest extent practicable and permitted by law, and consistent with the principles set forth in the report to the National Performance Review, each Federal Agency shall make achieving Environmental Justice part of its mission by identifying and addressing as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low income populations…"

Introduction

It is the goal of the Environmental Protection Agency (EPA) Region 7 EJ Program that principles of fair treatment and meaningful involvement are not only understood but acted upon. The purpose of this report is to provide information with regards to the environmental, social and economic characteristics of a community in an

effort to ensure fair treatment and meaningful involvement of all people. Potential EJ areas of concern are determined on a census block group level based on three criteria: 1) facility concentration and compliance history; 2) 25% or greater minority population; and/or 3) 25% or greater low-income population. Areas are then assessed as to whether populations may be disproportionately impacted by negative and/or adverse effects.

The identification of potential EJ areas and concerns from this information is only the beginning step in a process to respond to and address potential EJ concerns. The information from this assessment is meant to assist staff and appropriate stakeholders to take caution and necessary measures to ensure fair treatment and meaningful involvement of populations that may be disproportionately impacted by a site or project. Please contact the EJ Program to discuss other opportunities or activities that may be conducted with the community to further enhance communications and ensure environmental justice.

Known Facility Data Summary

Zip codes 67135, 67056, 67147, and 67204 were identified as areas included within the recharge site areas. In order to determine the potential for disproportionate impacts within an area the EJ Program considers: facility density, number of facilities that have never been inspected, number of facilities with informal or formal enforcement actions and number of facilities that have been listed with two or more quarters of noncompliance. The information was obtained using EPA's Online Tracking Information System (OTIS) which provides enforcement and compliance information on all permitted facilities.

Zip Code	Total # of permitted facilities	# of facilities that have never been inspected	# of facilities with informal enforcement actions*	# of facilities with formal enforcement actions*	# of facilities with 2 or more quarters in non-compliance**
67135 (Sedgwick, KS)	23	13 (57%)	0	1	2
67056 (Halstead, KS)	31	15 (48%)	0	0	0
67147 (Valley Center, KS)	51	27 (53%)	2	1	1
67204 (NW Wichita, KS)	65	42 (65%)	4	2	1

Source: EPA OTIS database

Observation: According to the OTIS database, at least 50% of the permitted facilities within the zip codes of concern (67135, 67056, 67147, 67204) have never been inspected. The maps however, indicate only one facility located within a one-mile radius of the Halstead recharge site and no facilities within a one-mile radius of the Sedgwick recharge site.

Demographic Summary

The EJ Program looks at the demographics of the areas in relation to the surrounding potentially impacted sites. For this assessment, the EJ Program looked at demographics within one-mile, three-mile, five-mile and ten-mile radii to ensure that potentially impacted populations would be known. The information was obtained by using the U.S. Census Bureau data from 1990 and 2000. The NEPA Program and the Bureau of Reclamation were interested in learning about any historical demographic trends that may have occurred since the 1990 census data collection.

Sedgwick Recharge Site	Total # people	Population Density (persons per square mile)	Percent Minority	Percent Low-Income
One-mile	109	35	6%	5%
Three-mile	940	33	6%	5%
Five-mile	3,468	44	6%	5%
Ten-mile	21,824	70	6%	4%

Source: US Census Bureau / EPA Region GIS Sitemapper application

Halstead Recharge Site	Total # people	Population Density (persons per square mile)	Percent Minority	Percent Low-Income
One-mile	94	30	5%	5%
Three-mile	1,271	45	4%	5%
Five-mile	2,808	36	5%	6%
Ten-mile	8,808	28	8%	5%

Source: US Census Bureau / EPA Region GIS Sitemapper application

Observations:

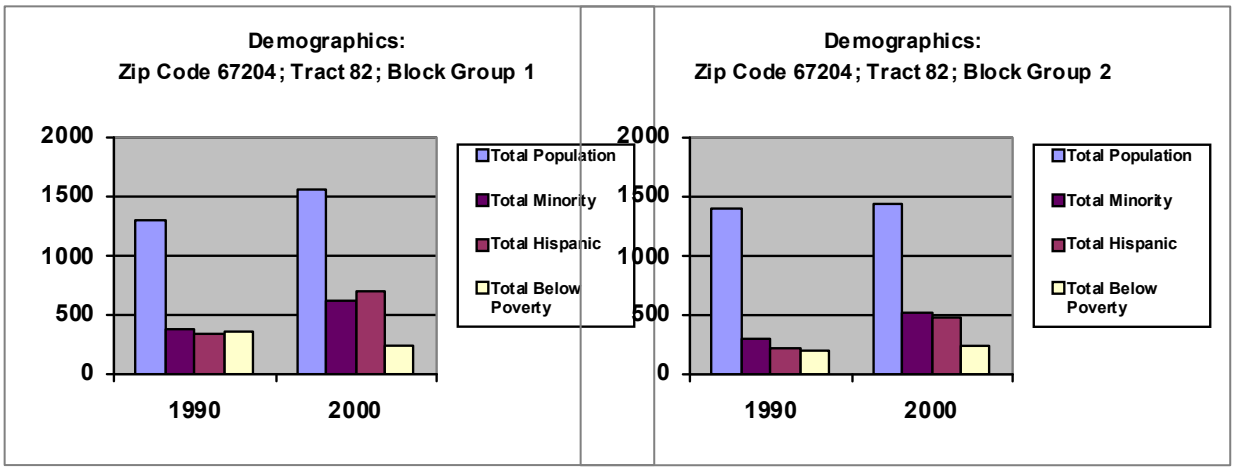
- According to the census data, there is low population density, low percent minority and low percent low-income populations within ten miles of the recharge sites. The project does not meet the region's indicator threshold for potential EJ concerns. There are however a few households and agricultural fields located within proximity of the treatment plant and recharge sites.

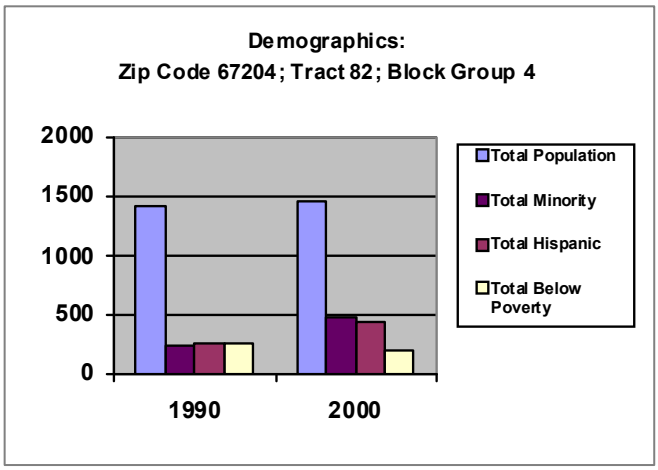
- During the site-visit with project leaders, the EJ Program asked questions with regards to any impacts such as noise, truck traffic, water depletion and whether or not the surrounding communities were informed. Project leaders noted that the surrounding immediate communities were informed about the project and had

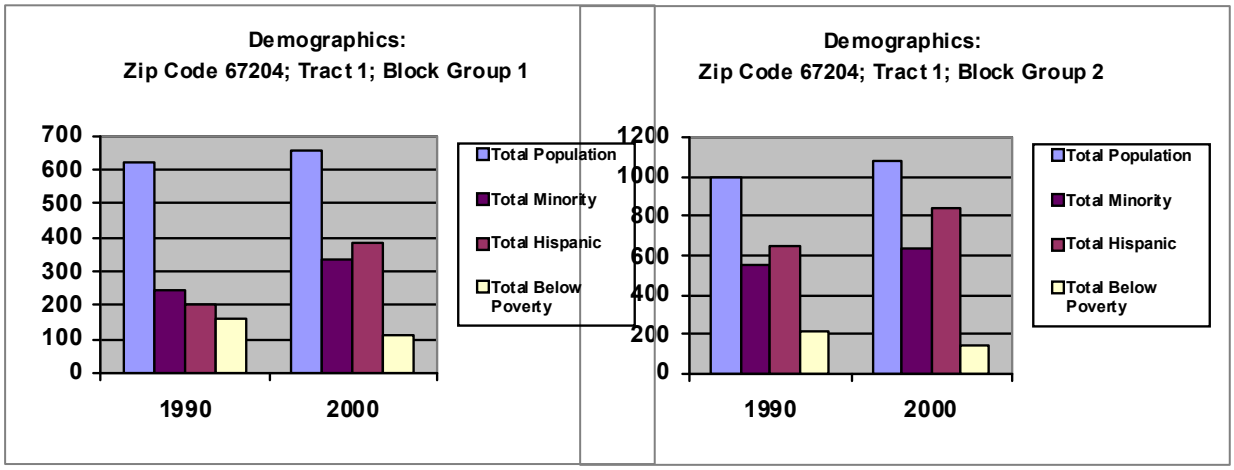
participated in public meetings. It was also noted that some surrounding farmers were worried about water resource use because most the agricultural fields were irrigated areas using surface and/or groundwater resources. Project leaders said they were committed to continue the dialogue with interested stakeholders and educate them on any impacts the project may have.

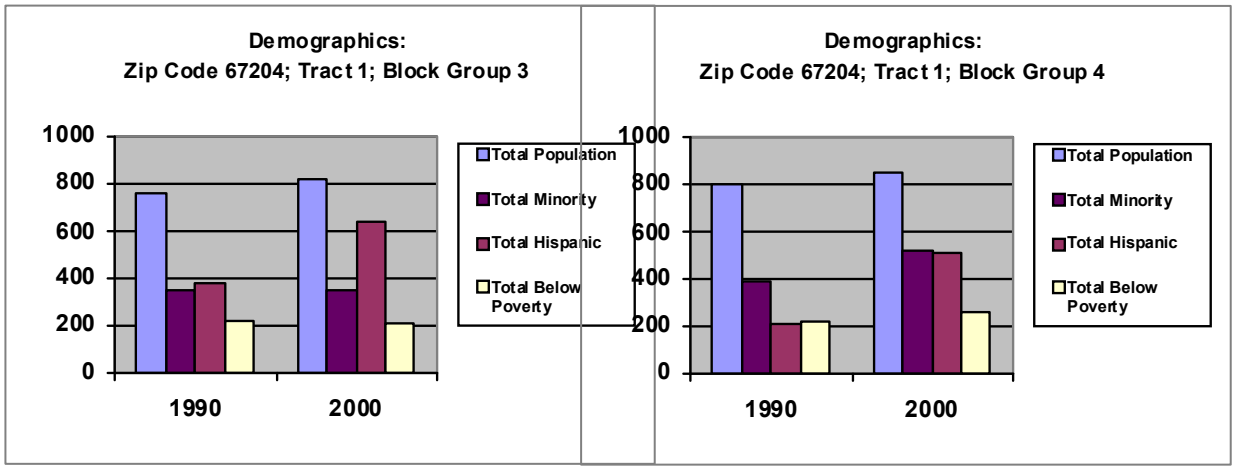
- Refer to maps for visual representation of data.

The EJ Program also looked at demographics in the NW section of Wichita, an area that was indicated to have been an area of significant growth in the past ten years. This area's growth was a concern with regards to the project and any impacts to surrounding populations that may be experienced.









Source: US Census Bureau / EPA Region GIS Sitemapper application

Observations:

- There is a large Hispanic population along the Little Arkansas River in NW Wichita about 13.25 miles from the Sedgwick recharge site. (3,995 total Hispanics in the seven block groups closest to site, according to the 2000 Census) The EJ Program concentrated on zip code 67204 in NW Wichita, the closest residential population to the recharge site areas. The charts above depict demographic data for zip code 67204 for 1990 and 2000 at the census block group level, which provides the greatest detail for analysis.

- The average population growth from 1990 to 2000 for each of the seven block groups within zip code 67204 was less than 10%. The Hispanic population grew by an average of 91% in each block group and more than doubled in three of the seven block groups. Based on population growth trends from 1990 to 2000, there has most likely been very significant growth of the Hispanic community in NW Wichita from 2000 to 2008.

- If the project is going to draw significant amounts of water from the Little Arkansas River, it has the potential to affect all communities downstream of the site. After the site-visit conducted on August 18, 2008, project leaders from the city of Wichita stated that surface water from the Little Arkansas River would only be diverted when the river is above base stream flow. In which case, the Equus Beds Groundwater Recharge Project should have no detrimental impact on communities downstream that may access the river.

- Refer to map for visual representation of data.

Conclusions & Recommendations

Based on the EJ Screening analysis performed and the site-visit to the project area, it is the opinion of the EJ Program that the project will not have any disproportionate negative environmental burden on nearby communities.

As discussed in previous sections, the project leaders have made the necessary efforts to invite public participation and communicate with the public with regards to their planned activities. Residents nearest the recharge areas have the potential to be impacted by increased truck noise and/or traffic near the treatment plants. Any expected increases are probably minimal, based on the seasonality of the project.

The nearest densely populated area in NW Wichita has seen significant population growth with increased Hispanic residents. The main water resource for this project, the Little Arkansas River is not expected to be impacted, therefore not impacting any populations that may use it for recreational and/or subsistence fishing purposes.

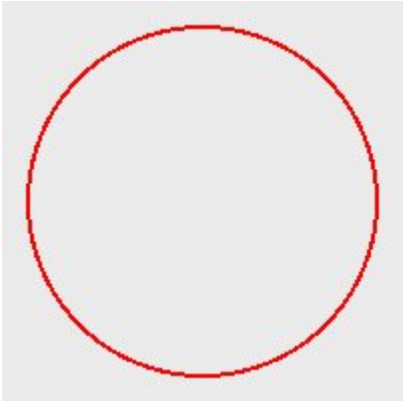
Project leaders should continue commitment to communicate the activities of the project with interested stakeholders and invite public participation and/or comment as a part of transparency and openness. A list of community resources is attached to assist the project leaders in enhancing outreach and/communication efforts.

Attachments:
1. Maps 1-9
2. Demographic Comparison Table for NW Wichita zip code 67204
3. Demographic Summary Reports surrounding recharge areas (Sedgwick & Halstead)
4. Site-Visit Summary Report
5. Community Resources

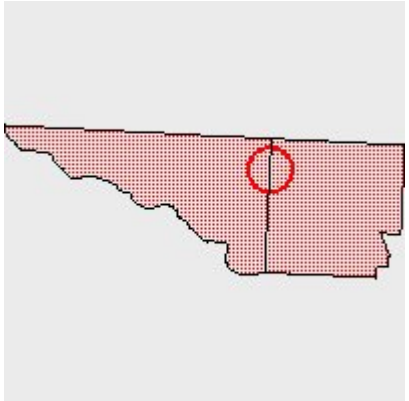
2000 Census Demographic Summary within 1 mile(s) of:
Geographic Point 37.8919562 -97.4817094
Sedgwick Recharge site; 1-mile radius

Report Created: Mon Oct 06 13:38:59 CDT 2008

The Radius for this Report



Intersects 2 Census Block Group(s)



DEMOGRAPHIC TOTALS
Demographic information recalculated to reflect the proportion of each block group that falls all or partway within the radius or polygon.

TOTAL RADIUS AREA = 3.14 sq. miles
TOTAL AREA OF DEMOGRAPHIC REPORTING UNITS = 3.13 sq. miles

TOTAL POPULATION = 109
POPULATION DENSITY = 35 persons per sq. mile (rounded)

TOTAL MINORITY = 6
PERCENT MINORITY = 6% (rounded)

One Race Persons = 107
White Persons = 104
Black Persons = 0
American Indian Persons = 1
Asian Persons = 0
Pacific Islander Persons = 0
Other Persons = 2
Multi-Race Persons = 2

Hispanic Persons = 3
White Hispanic Persons = 1

POVERTY STATUS INFORMATION

Total Households = 1
Total Persons of Poverty Status = 6
Percent Poverty Status = 5% (rounded)

TOTALS FOR SITES IN THE CURRENT RADIUS OF 1 MILE(S)

AFS - Major = 0

AFS - Minor = 0

RCRA TSD = 0

RCRA LQG = 0

Superfund NPL = 0

Superfund = 0

TRIS = 0

NPDES - Major = 0

NPDES - Minor = 0

PWS Wells = 0

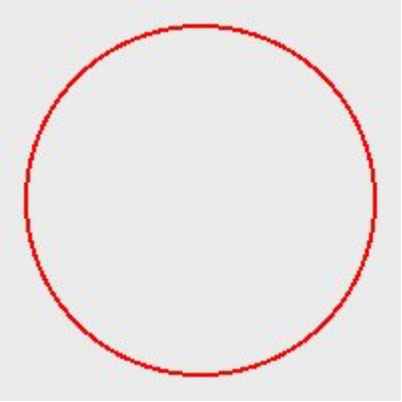
PWS Intakes = 0

TOTAL NUMBER OF SITES = 0

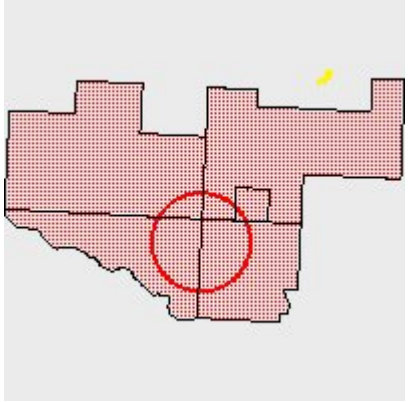
2000 Census Demographic Summary within 3 mile(s) of:
Geographic Point 37.8919562 -97.4817094
Sedgwick Recharge site; 3-mile radius

Report Created: Mon Oct 06 13:40:29 CDT 2008

The Radius for this Report



Intersects 5 Census Block Group(s)



DEMOGRAPHIC TOTALS
Demographic information recalculated to reflect the proportion of each block group that falls all or partway within the radius or polygon.

TOTAL RADIUS AREA = 28.27 sq. miles
TOTAL AREA OF DEMOGRAPHIC REPORTING UNITS = 28.16 sq. miles

TOTAL POPULATION = 940
POPULATION DENSITY = 33 persons per sq. mile (rounded)

TOTAL MINORITY = 54
PERCENT MINORITY = 6% (rounded)

One Race Persons = 924
White Persons = 895
Black Persons = 3
American Indian Persons = 11
Asian Persons = 1
Pacific Islander Persons = 0
Other Persons = 14
Multi-Race Persons = 15
Hispanic Persons = 27
White Hispanic Persons = 10

POVERTY STATUS INFORMATION

Total Households = 7
Total Persons of Poverty Status = 47
Percent Poverty Status = 5% (rounded)

TOTALS FOR SITES IN THE CURRENT RADIUS OF 3 MILE(S)

AFS - Major = 0

AFS - Minor = 0

RCRA TSD = 0

RCRA LQG = 0

Superfund NPL = 0

Superfund = 0

TRIS = 0

NPDES - Major = 0

NPDES - Minor = 0

PWS Wells = 0

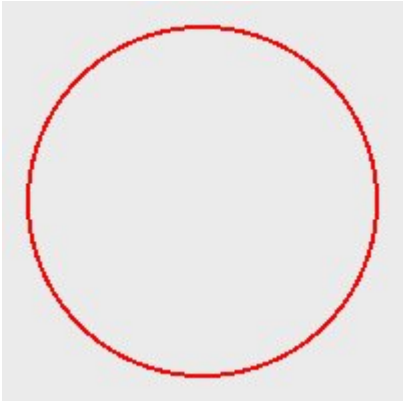
PWS Intakes = 0

TOTAL NUMBER OF SITES = 0

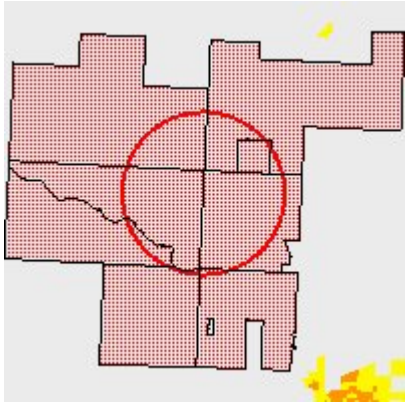
2000 Census Demographic Summary within 5 mile(s) of:
Geographic Point 37.8919562 -97.4817094
Sedgwick Recharge site; 5-mile radius

Report Created: Mon Oct 06 13:41:25 CDT 2008

The Radius for this Report



Intersects 8 Census Block Group(s)



DEMOGRAPHIC TOTALS
Demographic information recalculated to reflect the proportion of each block group that falls all or partway within the radius or polygon.

TOTAL RADIUS AREA = 78.54 sq. miles
TOTAL AREA OF DEMOGRAPHIC REPORTING UNITS = 78.25 sq. miles

TOTAL POPULATION = 3468
POPULATION DENSITY = 44 persons per sq. mile (rounded)

TOTAL MINORITY = 198
PERCENT MINORITY = 6% (rounded)

One Race Persons = 3415
White Persons = 3310
Black Persons = 8
American Indian Persons = 47
Asian Persons = 6
Pacific Islander Persons = 1
Other Persons = 43
Multi-Race Persons = 53
Hispanic Persons = 97
White Hispanic Persons = 40

POVERTY STATUS INFORMATION

Total Households = 49
Total Persons of Poverty Status = 159
Percent Poverty Status = 5% (rounded)

TOTALS FOR SITES IN THE CURRENT RADIUS OF 5 MILE(S)

AFS - Major = 1

AFS - Minor = 6

RCRA TSD = 0

RCRA LQG = 0

Superfund NPL = 0

Superfund = 0

TRIS = 1

NPDES - Major = 0

NPDES - Minor = 1

PWS Wells = 1

PWS Intakes = 0

TOTAL NUMBER OF SITES = 10

1 AFS - Major Site(s)

KS0057905
TEXACO TRADING & TRANSPORTATION INC
S1-T26S-R1W
WICHITA, KS 000000000

6 AFS - Minor Site(s)

KS0059611
MASSMAN CONSTRUCTION COMPANY
NO STREET ADDRESS
PORTABLE, KS 000000000

KS0989730
SKYLINE HOMES
920 W. SECOND
HALSTEAD, KS 67056

KS0057936
EQUILON PIPELINE COMPANY L.L.C.
1901 W. 77TH N.
VALLEY CENTER, KS 67147

KS0055782
DELANGE SEED HOUSE INCORPORATED J A
610 N. WASHINGTON
SEDGWICK, KS 67135

KS0055756
ANDALE FARMERS COOPERATIVE
EAST 4TH STREET AT NORTH JACKSON AVENUE
SEDGWICK, KS 67135

KS0059679
MASSMAN CONSTRUCTION COMPANY
NO STREET ADDRESS
PORTABLE, KS 000000000

1 TRIS Site(s)

67056SKYLN920WE
SKYLINE HOMES
920 W. SECOND
HALSTEAD, KS 67056

1 NPDES - Minor Site(s)

KS0081108
SEDGWICK CITY OF WWTP

SEDGWICK COUNTY,

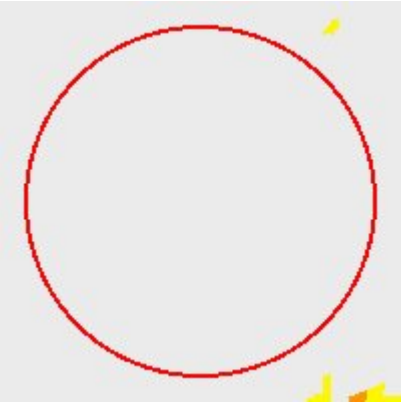
1 PWS Wells Site(s)

1537
KS2007904
67135 WL

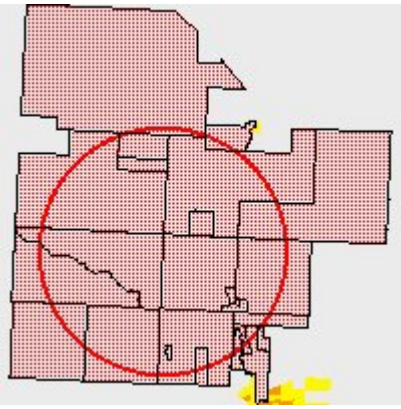
2000 Census Demographic Summary within 10 mile(s) of:
Geographic Point 37.8919562 -97.4817094
Sedgwick Recharge site; 10-mile radius

Report Created: Mon Oct 06 13:42:19 CDT 2008

The Radius for this Report



Intersects 25 Census Block Group(s)



DEMOGRAPHIC TOTALS
Demographic information recalculated to reflect the proportion of each block group that falls all or partway within the radius or polygon.

TOTAL RADIUS AREA = 314.16 sq. miles
TOTAL AREA OF DEMOGRAPHIC REPORTING UNITS = 313.71 sq. miles

TOTAL POPULATION = 21824
POPULATION DENSITY = 70 persons per sq. mile (rounded)

TOTAL MINORITY = 1232
PERCENT MINORITY = 6% (rounded)

One Race Persons = 21484
White Persons = 20864

Black Persons = 113
American Indian Persons = 183
Asian Persons = 89
Pacific Islander Persons = 4
Other Persons = 232
Multi-Race Persons = 339
Hispanic Persons = 558
White Hispanic Persons = 272

POVERTY STATUS INFORMATION

Total Households = 270
Total Persons of Poverty Status = 795
Percent Poverty Status = 4% (rounded)

TOTALS FOR SITES IN THE CURRENT RADIUS OF 10 MILE(S)

AFS - Major = 4

AFS - Minor = 27

RCRA TSD = 0

RCRA LQG = 3

Superfund NPL = 0

Superfund = 0

TRIS = 8

NPDES - Major = 0

NPDES - Minor = 0

PWS Wells = 12

PWS Intakes = 0

TOTAL NUMBER OF SITES = 54

4 AFS - Major Site(s)

KS0057995
COLEMAN COMPANY INCORPORATED BEACON FACILITY
5605 NORTH 119TH STREET WEST
MAIZE, KS 67101

KS0057905
TEXACO TRADING & TRANSPORTATION INC
S1-T26S-R1W
WICHITA, KS 000000000

KS0057699
WESTERN RESOURCES GORDON EVANS
6001 NORTH 151ST ST. WEST
COLWICH, KS 67201

KS0057958
JAYHAWK MERGED W 1730120
6358 NORTH MERIDIAN
VALLEY CENTER, KS 67204

27 AFS - Minor Site(s)

KS0055778
FARMERS COOPERATIVE GRAIN & MERC COMPANY
106 EAST NORTH STREET
HALSTEAD, KS 670560000

KS0059611
MASSMAN CONSTRUCTION COMPANY
NO STREET ADDRESS
PORTABLE, KS 000000000

KS0990549
ALL PETS CREMATORY
5500 NORTH WEST STREET
WICHITA, KS 67204

KS0057972
CENTER TERMINAL COMPANY WICHITA
7452 NORTH MERIDIAN STREET
VALLEY CENTER, KS 67147

KS0989730
SKYLINE HOMES
920 W. SECOND
HALSTEAD, KS 67056

KS0057809
HIGH PLAINS CORPORATION
523 EAST UNION AVENUE
COLWICH, KS 67030

KS0057936
EQUILON PIPELINE COMPANY L.L.C.
1901 W. 77TH N.
VALLEY CENTER, KS 67147

KS0990566
EPCO CARBON DIOXIDE PRODUCTS INCORPORATED
521 EAST UNION AVENUE
COLWICH, KS 00000

KS0055762
FARMERS COOP ELEVATOR CO
302 W 1ST
HALSTEAD, KS 67056

KS0057934
DOLESE BROS CO
5620 N 119TH W
MAIZE, KS 000000000

KS0057748
BERT & WETTA SALES INCORPORATED
5551 NORTH 119TH STREET WEST
MAIZE, KS 67101

KS0055782
DELANGE SEED HOUSE INCORPORATED J A
610 N. WASHINGTON
SEDGWICK, KS 67135

KS0780962
BARTON SOLVENTS INCORPORATED WICHITA BRANCH
201 S. CEDAR
VALLEY CENTER, KS 67147

KS0057980
LONE STAR INDUSTRIES INCORPORATED
330 E. KECHI RD
KECHI, KS 67067

KS0057983
ONEOK FIELD SERVICES COMPANY
15701 WEST 61ST STREET NORTH
COLWICH, KS 00000

KS0057788
ANDALE FARMERS COOPERATIVE
143 NORTH COLORADO STREET
COLWICH, KS 67030

KS1005947
A & C ENTERPRISES
225 W. 1ST
HALSTEAD, KS 67056

KS0057880
DELANGE SEED
206 E. ALBERT
MAIZE, KS 67101

KS0055756
ANDALE FARMERS COOPERATIVE
EAST 4TH STREET AT NORTH JACKSON AVENUE
SEDGWICK, KS 67135

KS0057935
JAYHAWK PIPELINE L.L.C.
6559 N. MERIDIAN
VALLLEY CENTER, KS 000000000

KS0965730
LEGG COMPANY INCORPORATED
325 E. 10TH STREET
HALSTEAD, KS 67056

KS0059679
MASSMAN CONSTRUCTION COMPANY
NO STREET ADDRESS
PORTABLE, KS 000000000

KS0055791
IDAHO TIMBER CORPORATION
515 INDUSTRIAL PARK
HALSTEAD, KS 67056

KS0055777
FARMERS COOPERATIVE GRAIN & MERCANTILE COMPANY
222 EAST FIRST
HALSTEAD, KS 670560000

KS1005946
WOOTEN ENTERPRISES
321 E. 1ST
HALSTEAD, KS 67056

KS1005171
HAYES COMPANY INC.
7700 HAYES DRIVE
VALLEY CENTER, KS 67147

KS0057868
ANDALE FARMERS COOPERATIVE COMPANY
101 SOUTH ASH
VALLEY CENTER, KS 67147

3 RCRA LQG Site(s)

KSD096537857
BARTON SOLVENTS INCORPORATED WICHITA BRANCH
201 S. CEDAR
VALLEY CENTER, KS 67147

KSD980971428
RITCHIE PAVING
2424 NORTH SHORE BOULEVARD
WICHITA, KS 67205

KSD984990903
NATIONAL PLASTICS COLOR INCORPORATED
2600 W. 77TH ST. N.
VALLEY CENTER, KS 671470127

8 TRIS Site(s)

67030GRDNV6001N
WESTERN RESOURCES GORDON EVANS
6001 NORTH 151ST ST. WEST
COLWICH, KS 67030

67205CRLSN4601N
CARLSON PRODUCTS
4601 NORTH TYLER ROAD
WICHITA, KS 67101

67147NTNLP2600W
NATIONAL PLASTICS COLOR INCORPORATED
2600 W. 77TH ST. N.
VALLEY CENTER, KS 67147

67101CLMNT5605N
COLEMAN COMPANY INCORPORATED BEACON FACILITY
5605 NORTH 119TH STREET WEST
MAIZE, KS 67101

67147HYSCN7700H
HAYES COMPANY INC.
7700 HAYES DRIVE
VALLEY CENTER, KS 671470430

67030HGHPL412NF
HIGH PLAINS CORPORATION
523 EAST UNION AVENUE
COLWICH, KS 67030

67147BRTNS201SC
BARTON SOLVENTS INCORPORATED WICHITA BRANCH
201 S. CEDAR
VALLEY CENTER, KS 67147

67056SKYLN920WE
SKYLINE HOMES
920 W. SECOND
HALSTEAD, KS 67056

12 PWS Wells Site(s)

60
KS2017333
67030 WL

18070
KS2007905
671140426 WL

74
KS2017330
67211 WL

350
KS2117308
67001 WL

1873
KS2007901
67056 WL

900
KS2117303
67101 WL

4883
KS2017318
67147 WL

870
KS2117304
67101 WL

1537
KS2007904
67135 WL

900
KS2117303
67101 WL

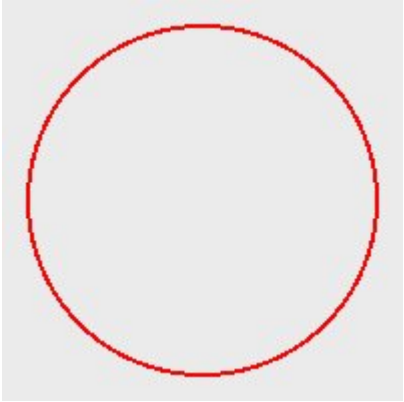
5814
KS2017303
672192499 WL

329249
KS2017308
672021679 WL

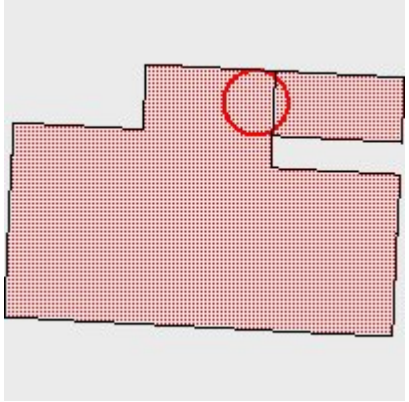
2000 Census Demographic Summary within 1 mile(s) of:
Geographic Point 38.014178 -97.5655979
Halstead Recharge site, 1-mile radius

Report Created: Mon Oct 06 13:33:05 CDT 2008

The Radius for this Report



Intersects 2 Census Block Group(s)



DEMOGRAPHIC TOTALS
Demographic information recalculated to reflect the proportion of each block group that falls all or partway within the radius or polygon.

TOTAL RADIUS AREA = 3.14 sq. miles
TOTAL AREA OF DEMOGRAPHIC REPORTING UNITS = 3.13 sq. miles

TOTAL POPULATION = 94
POPULATION DENSITY = 30 persons per sq. mile (rounded)

TOTAL MINORITY = 4
PERCENT MINORITY = 5% (rounded)

One Race Persons = 93
White Persons = 91
Black Persons = 0
American Indian Persons = 1
Asian Persons = 0
Pacific Islander Persons = 0
Other Persons = 1
Multi-Race Persons = 1
Hispanic Persons = 2
White Hispanic Persons = 1

POVERTY STATUS INFORMATION

Total Households = 2
Total Persons of Poverty Status = 5
Percent Poverty Status = 5% (rounded)

TOTALS FOR SITES IN THE CURRENT RADIUS OF 1 MILE(S)

AFS - Major = 1

AFS - Minor = 0

RCRA TSD = 0

RCRA LQG = 0

Superfund NPL = 0

Superfund = 0

TRIS = 0

NPDES - Major = 0

NPDES - Minor = 0

PWS Wells = 0

PWS Intakes = 0

TOTAL NUMBER OF SITES = 1

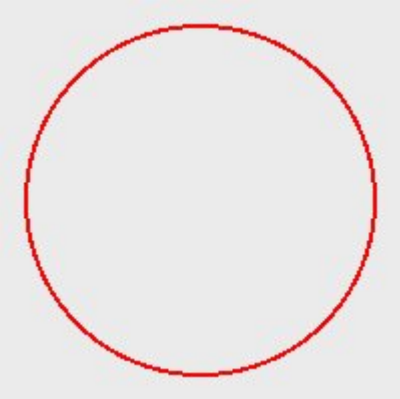
1 AFS - Major Site(s)

KS0055755
KINDER MORGAN OPERATING LP
HALSTEAD PUMP STA.
HALSTEAD, KS 67056

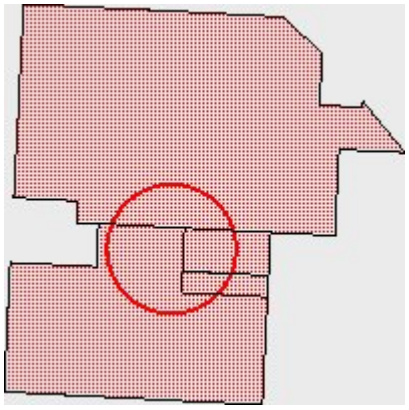
2000 Census Demographic Summary within 3 mile(s) of:
Geographic Point 38.014178 -97.5655979
Halstead Recharge site, 3-mile radius

Report Created: Mon Oct 06 13:34:21 CDT 2008

The Radius for this Report



Intersects 4 Census Block Group(s)



DEMOGRAPHIC TOTALS
Demographic information recalculated to reflect the proportion of each block group that falls all or partway within the radius or polygon.

TOTAL RADIUS AREA = 28.27 sq. miles
TOTAL AREA OF DEMOGRAPHIC REPORTING UNITS = 28.16 sq. miles

TOTAL POPULATION = 1271
POPULATION DENSITY = 45 persons per sq. mile (rounded)

TOTAL MINORITY = 55
PERCENT MINORITY = 4% (rounded)

One Race Persons = 1253
White Persons = 1231
Black Persons = 3
American Indian Persons = 6
Asian Persons = 5
Pacific Islander Persons = 0
Other Persons = 9
Multi-Race Persons = 18
Hispanic Persons = 27
White Hispanic Persons = 15

POVERTY STATUS INFORMATION

Total Households = 32
Total Persons of Poverty Status = 67
Percent Poverty Status = 5% (rounded)

TOTALS FOR SITES IN THE CURRENT RADIUS OF 3 MILE(S)

AFS - Major = 1

AFS - Minor = 1

RCRA TSD = 0

RCRA LQG = 0

Superfund NPL = 0

Superfund = 0

TRIS = 0

NPDES - Major = 0

NPDES - Minor = 0

PWS Wells = 0

PWS Intakes = 0

TOTAL NUMBER OF SITES = 2

1 AFS - Major Site(s)

KS0055755
KINDER MORGAN OPERATING LP
HALSTEAD PUMP STA.
HALSTEAD, KS 67056

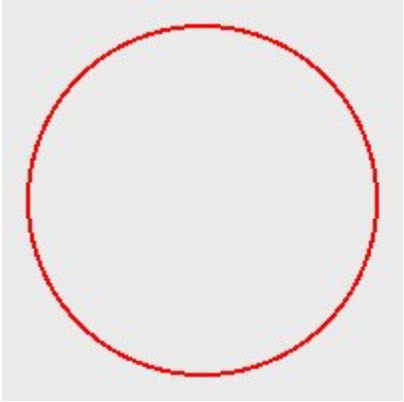
1 AFS - Minor Site(s)

KS0055791
IDAHO TIMBER CORPORATION
515 INDUSTRIAL PARK
HALSTEAD, KS 67056

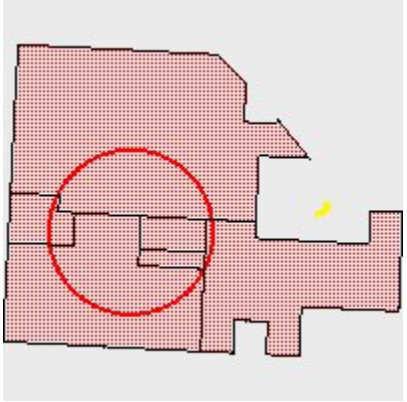
2000 Census Demographic Summary within 5 mile(s) of:
Geographic Point 38.014178 -97.5655979
Halstead Recharge site; 5-mile radius

Report Created: Mon Oct 06 13:35:18 CDT 2008

The Radius for this Report



Intersects 6 Census Block Group(s)



DEMGRAPHIC TOTALS
Demographic information recalculated to reflect the proportion of each block group that falls all or partway within the radius or polygon.

TOTAL RADIUS AREA = 78.54 sq. miles
TOTAL AREA OF DEMOGRAPHIC REPORTING UNITS = 78.23 sq. miles

TOTAL POPULATION = 2808
POPULATION DENSITY = 36 persons per sq. mile (rounded)

TOTAL MINORITY = 132
PERCENT MINORITY = 5% (rounded)

One Race Persons = 2766
White Persons = 2711
Black Persons = 9
American Indian Persons = 12
Asian Persons = 9
Pacific Islander Persons = 0
Other Persons = 25
Multi-Race Persons = 42
Hispanic Persons = 66
White Hispanic Persons = 34

POVERTY STATUS INFORMATION

Total Households = 63
Total Persons of Poverty Status = 157
Percent Poverty Status = 6% (rounded)

TOTALS FOR SITES IN THE CURRENT RADIUS OF 5 MILE(S)

AFS - Major = 1

AFS - Minor = 9

RCRA TSD = 0

RCRA LQG = 0

Superfund NPL = 0

Superfund = 0

TRIS = 0

NPDES - Major = 0

NPDES - Minor = 0

PWS Wells = 2

PWS Intakes = 0

TOTAL NUMBER OF SITES = 12

1 AFS - Major Site(s)

KS0055755
KINDER MORGAN OPERATING LP
HALSTEAD PUMP STA.
HALSTEAD, KS 67056

9 AFS - Minor Site(s)

KS0055778
FARMERS COOPERATIVE GRAIN & MERC COMPANY
106 EAST NORTH STREET
HALSTEAD, KS 670560000

KS0055762
FARMERS COOP ELEVATOR CO
302 W 1ST
HALSTEAD, KS 67056

KS0055784
TEXACO TRADING & TRANSPORTATION INCORPORATED
S34-T23S-R3W
BURRTON, KS 000000000

KS1005947
A & C ENTERPRISES
225 W. 1ST
HALSTEAD, KS 67056

KS0965730
LEGG COMPANY INCORPORATED
325 E. 10TH STREET
HALSTEAD, KS 67056

KS0055791
IDAHO TIMBER CORPORATION
515 INDUSTRIAL PARK
HALSTEAD, KS 67056

KS0055777
FARMERS COOPERATIVE GRAIN & MERCANTILE COMPANY
222 EAST FIRST
HALSTEAD, KS 670560000

KS1005946
WOOTEN ENTERPRISES
321 E. 1ST
HALSTEAD, KS 67056

KS0055769
PEOPLES NATURAL GAS
S21-T23S-R3W
BURRTON, KS 67020

2 PWS Wells Site(s)

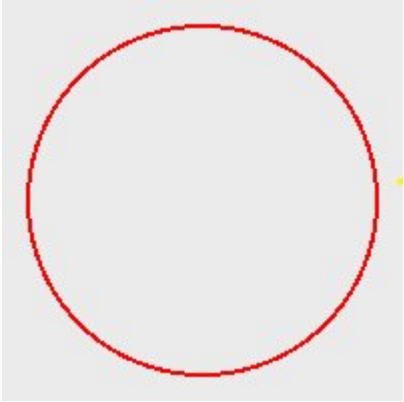
1873
KS2007901
67056 WL

329249
KS2017308
672021679 WL

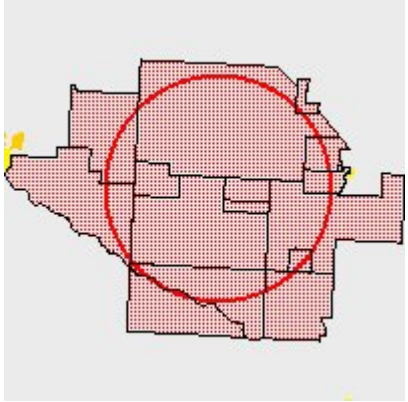
2000 Census Demographic Summary within 10 mile(s) of:
Geographic Point 38.014178 -97.5655979
Halstead Recharge site; 10-mile radius

Report Created: Mon Oct 06 13:36:16 CDT 2008

The Radius for this Report



Intersects 15 Census Block Group(s)



DEMGRAPHIC TOTALS
Demographic information recalculated to reflect the proportion of each block group that falls all or partway within the radius or polygon.

TOTAL RADIUS AREA = 314.16 sq. miles
TOTAL AREA OF DEMOGRAPHIC REPORTING UNITS = 312.85 sq. miles

TOTAL POPULATION = 8808
POPULATION DENSITY = 28 persons per sq. mile (rounded)

TOTAL MINORITY = 662
PERCENT MINORITY = 8% (rounded)

One Race Persons = 8653
White Persons = 8303
Black Persons = 58
American Indian Persons = 52
Asian Persons = 24
Pacific Islander Persons = 0
Other Persons = 217
Multi-Race Persons = 155
Hispanic Persons = 421
White Hispanic Persons = 157

POVERTY STATUS INFORMATION

Total Households = 135
Total Persons of Poverty Status = 453
Percent Poverty Status = 5% (rounded)

TOTALS FOR SITES IN THE CURRENT RADIUS OF 10 MILE(S)

AFS - Major = 2

AFS - Minor = 13

RCRA TSD = 0

RCRA LQG = 0

Superfund NPL = 0

Superfund = 0

TRIS = 1

NPDES - Major = 0

NPDES - Minor = 0

PWS Wells = 6

PWS Intakes = 0

TOTAL NUMBER OF SITES = 22

2 AFS - Major Site(s)

KS0055749
SOUTHERN STAR CENTRAL GAS PIPELINE INCORPORATED
7616 WEST DUTCH AVENUE
HESSTON, KS 67062

KS0055755
KINDER MORGAN OPERATING LP
HALSTEAD PUMP STA.
HALSTEAD, KS 67056

13 AFS - Minor Site(s)

KS0055778
FARMERS COOPERATIVE GRAIN & MERC COMPANY
106 EAST NORTH STREET
HALSTEAD, KS 670560000

KS0989730
SKYLINE HOMES
920 W. SECOND
HALSTEAD, KS 67056

KS0055762
FARMERS COOP ELEVATOR CO
302 W 1ST
HALSTEAD, KS 67056

KS0055758
YODER ELEVATOR INC (BURRTON BRANCH)
WEST EDGE OF TOWN
BURRTON, KS 000000000

KS0055784
TEXACO TRADING & TRANSPORTATION INCORPORATED
S34-T23S-R3W
BURRTON, KS 000000000

KS1005947
A & C ENTERPRISES
225 W. 1ST
HALSTEAD, KS 67056

KS0055768
PATTERSON-FARMERS CO-OP ELEVATOR CO.
RURAL
PATTERSON, KS 000000000

KS0965730
LEGG COMPANY INCORPORATED
325 E. 10TH STREET
HALSTEAD, KS 67056

KS0055791
IDAHO TIMBER CORPORATION
515 INDUSTRIAL PARK
HALSTEAD, KS 67056

KS0055777
FARMERS COOPERATIVE GRAIN & MERCANTILE COMPANY
222 EAST FIRST
HALSTEAD, KS 670560000

KS1005946
WOOTEN ENTERPRISES
321 E. 1ST
HALSTEAD, KS 67056

KS0975067
GOERING ENTERPRISES INCORPORATED
5304 W 1ST STREET
NEWTON, KS 671148621

KS0055769
PEOPLES NATURAL GAS
S21-T23S-R3W
BURRTON, KS 67020

1 TRIS Site(s)

67056SKYLN920WE
SKYLINE HOMES
920 W. SECOND
HALSTEAD, KS 67056

6 PWS Wells Site(s)

18070
KS2007905
671140426 WL

1873
KS2007901
67056 WL

932
KS2007903
670200200 WL

932
KS2007903
670200200 WL

3509
KS2007902
67062 WL

329249
KS2017308
672021679 WL

Equus Beds Aquifer Recharge Project Site Visit
SUMMARY REPORT

Location: Equus Beds Well Field, Southern Harvey County, near U.S. Hwy 50, West of Newton, KS

Date: Monday, August 18, 2008

Staff: Debbie Bishop, ECO/EJ, x7529; Joe Cothern, ENSV/NEPA, x7148; Ron Hammerschmidt, ENSV Director, x7566; Krista Kasper, ECO/EJ, x7212; Althea Moses, ECO/EJ, x7649; Amber Tucker, ENSV/NEPA, x7565

SUMMARY:

On Monday, August 18, 2008, staff and interns from EPA Region 7's EJ and NEPA teams met with Richard Robinson, city of Wichita, and Charles F. Webster, Bureau of Reclamation. Mr. Robinson provided us with a tour of the Equus Beds Aquifer Recharge Project Site, including the Phase 1 water treatment facility, a recharge basin, and a municipal well. The purpose of this visit was to get visual confirmation of the project site, as well as to learn more about the aquifer recharge process in order to determine if the project could have any negative effects on the EJ communities in Northwest Wichita. The information gathered will be included in the EJ screen report for the project, which was conducted on a request by the NEPA program in support of the Bureau of Reclamation's Environmental Impact Statement.

Richard Robinson explains the aquifer recharge process

Water quality testing equipment

Tank used to remove solids from the water

Leftover mud that was extracted from the river water- local farmers use it as topsoil

Injection Well

Recharge Basin

Appendix D

Kansas State Historical Society Consultation Letter

(51)

KANSAS

KSR&C No. 08-03-206

Kansas State Historical Society
Jennie Chinn, *Executive Director*

KATHLEEN SEBELIUS, GOVERNOR

March 20, 2008

Charles F. Webster
Environmental Protection Specialist
Oklahoma-Texas Area Office
Bureau of Reclamation
5924 NW 2nd St., Ste 200
Oklahoma City, OK 73127-6514

Dear Mr. Webster:

In accordance with 36 CFR 800, the Kansas State Historic Preservation Office has reviewed your agency's notice that the Environmental Impact Statement Scoping Document for the Equus Beds Aquifer Recharge and Recovery Project is available for inspection. According to our records, an earlier version of this project was reviewed and cleared in 2003. We assume that any additional ground disturbing activities beyond those already cleared will be submitted for review.

This information is provided at your request to assist you in identifying historic properties, as specified in 36 CFR 800 for Section 106 consultation procedures. If you have questions or need additional information regarding these comments, please contact Tim Weston at (785) 272-8681 (ext. 214).

Sincerely,

Jennie Chinn
State Historic Preservation Officer

for

Patrick Zollner
Deputy State Historic Preservation Officer

6425 SW Sixth Avenue • Topeka, KS 66615-1099
Phone 785-272-8681 Ext. 205 • Fax 785-272-8682 • Email jchinn@kshs.org • TTY 785-272-8683
www.kshs.org

Appendix E

TX-CB

APR 1 4 2009

Mr. Michael J. LeValley
Field Supervisor
U.S. Fish and Wildlife Service
Kansas Ecological Field Office
2609 Anderson Avenue
Manhattan, Kansas 66502

Subject: Informal Consultation Determination Letter for the Equus Beds Aquifer Storage and Recovery Project

Dear Mr. LeValley:

The City of Wichita (City) has requested funds from the U.S. Bureau of Reclamation (Reclamation) to implement an aquifer storage and recovery project (ASR Project) that stores flood flows withdrawn from the Little Arkansas River into the Equus Beds Aquifer. This would constitute a federal action and warrants consultation under Section 7 of the Endangered Species Act with the U.S. Fish and Wildlife Service.

Three Federally-listed species were determined to be potentially impacted by the project. These include the Arkansas River shiner (*Notropis girardi*), interior least tern (*Sterna antillarum*), and whooping crane (*Grus americana*).

Please find the attached *Biological Assessment of Federally Listed Species, Equus Beds Aquifer Storage and Recovery Project* for your review. It includes: 1) a description of the proposed project and affected area; 2) the status and life-history requirements of potentially impacted species; and 3) a description of direct, indirect, and cumulative impacts of the proposed project on those species.

Reclamation has determined that the construction and operation of the City's ASR Project would **not likely adversely affect any of the three species.** No direct impacts would occur because construction activities would be temporary and localized. Indirect and cumulative impacts that result from project operations would be **insignificant and discountable** because changes in the frequency of low, medium, and high flows in the Little Arkansas, Arkansas, North Fork Ninnescah, and Ninnescah rivers would have only minimal impacts on life-history characteristics of the three Federally-listed species.

Reclamation therefore requests your written concurrence with this determination. If you have any questions or need additional information, please call Ms. Ashley Ladd at (405) 470-4828. Thank you for your timely assistance in this matter.

Sincerely,

MARK A. TREVIÑO

Mark Treviño
Area Manager

Enclosure

cc: Mr. Eric R. Johnson, Ecologist
Kansas Department of Wildlife and Parks
Pratt Operations Office
512 SE 25th Ave.
Pratt, KS 67124
(w/enclosure)

bc: OK-Ladd, OK-Webster, OK-Claggett
(w/o enclosure to each)

GP-4200 (Davis), GP-4200 (LaFontaine)
(w/ enclosure to each)

WBR:CBalcombe:jms:04 13 09
Filename: Equus Beds ASR Project Consultation Letter